The Geodesist's Handbook 2024

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International Association of Geodesy

A constituent Association of the International Union of Geodesy and Geophysics (IUGG).

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Foreword by the IAG Secretary General

The Geodesist's Handbook is published by the International Association of Geodesy (IAG) periodically after each IUGG/IAG General Assembly. The objective is to present the current IAG structure and its specifications, and to introduce the terms of reference and the officers of the Association's components for the upcoming legislative period to the broad geodetic community. The scientific program and planned activities are described in detail.

The first part of the Handbook 2024 presents the historical developments and current regulations of the IAG (Statutes, Bylaws as reviewed during the IUGG/IAG General Assembly 2023). The second part summarises the outcome of the IAG General Assembly held in conjunction with the 28th IUGG General Assembly in Berlin,Germany, in July 2023. An overview of the most important IAG results from 2019 to 2023 is given in the presidential address. The citations of the scientists decorated with the highest IAG awards (Levallois Medal, Guy Bomford Prize, and Young Authors Award) are published. Reports of the Secretary General, the IAG Council and Executive Committee meetings, and the IUGG and IAG resolutions conclude this section.

The third, fourth and fifth parts of the Handbook contain the detailed structures and programs of all IAG components, along with their sub-components (Sub-Commissions, Study Groups and Working Groups), for the period 2023-2027. The planned scientific work of the whole IAG for the coming years is described. Commissions, Inter-commission Committees, the QuGe Project, Communication and Outreach Branch are presented in Part 3. The Global Geodetic Observing System with its internal structure is presented in Part 4. The Services are described in Part 5.

The sixth part completes the Handbook with some general information useful for the geodetic community. The IAG Internet representation and the publication series are highlighted, and the IAG national delegates and representatives to services and international scientific bodies are listed.

We thank the contributors to the Geodesist's Handbook 2024. These are in particular all the IAG officers listed in the structures, but also the uncounted secretaries and technicians in the institutions affiliated with IAG or one of its components and sub-components. The engaged and authentic cooperation in geodesy is one of the most effective means for the great success of our science. We hope that this collaboration will be continued and even extended in the current period 2023-2027.

Daniela Thaller
IAG Secretary General 2023-2027

List of previous Geodesist's Handbooks

- 1980: Bulletin Géodesique, Vol. 54, No. 3,
  http://link.springer.com/journal/190/54/3/page/1
- 1984: Bulletin Géodesique, Vol. 58, No. 3,
  http://link.springer.com/journal/190/58/3/page/1
- 1988: Bulletin Géodesique, Vol. 62, No. 3,
  http://link.springer.com/journal/190/62/3/page/1
- 1992: Bulletin Géodesique, Vol. 66, No. 2,
  http://link.springer.com/journal/190/66/2/page/1
- 1996: Journal of Geodesy, Vol. 70, No. 12,
  http://link.springer.com/journal/190/70/12/page/1
- 2000: Journal of Geodesy, Vol. 74, No. 1,
  http://link.springer.com/journal/190/74/1/page/1
- 2004: Journal of Geodesy, Vol. 77, No. 10-11,
  http://link.springer.com/journal/190/77/10/page/1
- 2008: Journal of Geodesy, Vol. 82, No. 11,
  http://link.springer.com/journal/190/82/11/page/1 (open access)
- 2012: Journal of Geodesy, Vol. 86, No. 10,
  http://link.springer.com/journal/190/86/10/page/1 (open access)
- 2016: Journal of Geodesy, Vol. 90, No. 10,
  https://link.springer.com/journal/190/90/10/page/1 (open access)
- 2020: Journal of Geodesy, Vol. 94, No. 11,
  https://link.springer.com/journal/190/94/11/page/1 (open access)

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Part I

The International Association of Geodesy (IAG)

Historical Overview of the IAG

The history of the International Association of Geodesy goes back to April 1862 when the Central European Arc Measurement ("Mitteleuropäische Gradmessung") was initiated at a "preliminary consultation" of representatives of the states of Prussia, Austria and Saxony in Berlin. At the end of the year, 16 countries had joined the project. The first General Conference was held in Berlin, October 1864, with delegates from 14 countries. In 1867 it was expanded to the European Arc Measurement and in 1886 to the International Geodetic Association ("Internationale Erdmessung", "Association Géodésique Internationale"). At the Constitutive Assembly of the International Research Council (IRC) in Brussels, July 1919, the "Section Geodesy" was one of the constituents of the International Union of Geodesy and Geophysics (IUGG) and held its Constitutive Assembly during the first IUGG General Assembly in Rome, April-May 1922. The name was changed to "Association of Geodesy" in Stockholm, August 1930, and to the present name in July 1946. The following summarises the historic development.

General Conferences / General Assemblies of the IAG and its predecessors

No	*Venue*	*Year*
I. General Conferences		
Mitteleuropäische Gradmessung - Central European Arc Measurement (1862-1867)		
1	Berlin, Prussia	1864
2	Berlin, Prussia	1867
Europäische Gradmessung - European Arc Measurement (1867-1886)		
3	Vienna, Austria-Hungary	1871
4	Dresden, German Empire	1874
5	Stuttgart, German Empire	1877
6	Munich, German Empire	1880
7	Rome, Italy	1883
8	Berlin, German Empire	1886
Internationale Erdmessung -Association Géodésique Internationale - Int. Geodetic Association (1886-1922)		
9	Paris, France	1889
10	Brussels, Belgium	1892
11	Berlin, German Empire	1895
12	Stuttgart, German Empire	1898
13	Paris, France	1900
14	Copenhagen, Denmark	1903

Continuation of Table		
No	*Venue*	*Year*
15	Budapest, Austria-Hungary	1906
16	Cambridge, United Kingdom	1909
17	Hamburg, German Empire	1912
II. General Assemblies of the Section and Association of Geodesy at the General Assemblies of the IUGG		
IUGG Section of Geodesy (1919-1930)		
18	Rome, Italy (Constitutive Assembly)	1922
19	Madrid, Spain	1924
20	Prague, Czechoslovakia	1927
21	Stockholm, Sweden	1930

No	*Venue*	*Year*	*Participants*	
			IUGG	*IAG*
IUGG Association of Geodesy (1930-1946)				
22	Lisbon, Portugal	1933	200	90
23	Edinburgh, UK	1936	344	91
24	Washington, USA	1939	805	86
IUGG International Association of Geodesy (1946-...)				
25	Oslo, Norway	1948	368	
26	Brussels, Belgium	1951	918	134
27	Rome, Italy	1954	923	235
28	Toronto, Canada	1957	1165	218
29	Helsinki, Finland	1960	1375	345
30	Berkeley, USA	1963	1938	329
31	Zurich/Lucerne, Switzerland	1967	2200	357
32	Moscow, USSR	1971	2577	449
33	Grenoble, France	1975	2564	398
34	Canberra, Australia	1979	1944	278
35	Hamburg, F.R. Germany	1983	3204	472
36	Vancouver, Canada	1987	3939	420
37	Vienna, Austria	1991	4331	594
38	Boulder, USA	1995	4481	567
39	Birmingham, UK	1999	4052	478
40	Sapporo, Japan	2003	4151	407
41	Perugia, Italy	2007	4351	433
42	Melbourne, Australia	2011	3392	370
43	Prague, Czech Republic	2015	4231	534
44	Montreal, Canada	2019	3715	465
45	Berlin, Germany	2023	4572	566

Scientific Assemblies of the IAG

No	*Venue*	*Date*	*Number of Attendees*
1	Tokyo, Japan	May 7-15,1982	200
2	Edinburgh, UK	August 3-12,1989	355
3	Beijing, China	August 8-13,1993	340
4	Rio de Janeiro, Brazil	September 3-9,1997	250
5	Budapest, Hungary	September 2-7, 2001	461
6	Cairns, Australia	August 22-26, 2005 (joint with IAPSO and IABO)	IAG: 145 (in all: 724)
7	Buenos Aires, Argentina	August 31- Sept. 4, 2009	363
8	Potsdam, Germany	September 1-6, 2013	538
9	Kobe, Japan	July 30 – August 4, 2017 (joint with IASPEI)	IAG: 361 (in all: 1107)
10	Beijing, China	June 28 – July 3, 2021	1516

Presidents of the IAG and predecessors

The President's Position has had different names as follows:

- 1864 - 1886 President of the Permanent Commission
- 1887 - 1917 President of the Association
- 1917 - 1922 President of the Reduced Association
- 1922 - 1933 President of the Section
- 1933 - 1946 President of the Association
- 1946 - . . . President of the IAG

No	*Period*	*Name*	*Residence*
Mitteleuropäische Gradmessung (1862-1867) *Europ. Gradmessung (European Arc Measurement) (1867-1886)*			
1	1864 – 1868	Peter Andreas Hansen	Gotha, Thuringia
2	1869 – 1874	August von Fligely	Vienna, Austria-Hungary
3	1874 - 1886	Carlos Ibañez de Ibero	Madrid, Spain
Internat. Erdmessung - Association Géodésique Internationale (International Geodetic Association) (1886-1917)			
3	1887 – 1891	Carlos Ibañez de Ibero	Madrid, Spain
4	1892 – 1902	Hervé A. E. A. Faye	Paris, France
5	1903 – 1917	Léon J. A. Bassot	Paris, France
Reduced Geodetic Association among Neutral States (1917-1922)			
6	1917 – 1922	Raul Gautier	Geneva, Switzerland
IUGG Section of Geodesy (1919-1930)			
7	1922 – 1933	William Bowie	Washington, USA
IUGG Association of Geodesy (1930-1946)			
8	1933 – 1946	Felix A. Vening-Meinesz	Amersfoort, Netherlands
International Association of Geodesy (IAG) of the IUGG (1946-. . .)			
9	1946 – 1951	Walter D. Lambert	Washington, USA
10	1951 – 1954	Carl F. Bäschlin	Zurich, Switzerland
11	1954 – 1957	James de Graaf Hunter	London, United Kingdom
12	1957 – 1960	Gino Cassinis	Milan, Italy
13	1960 – 1963	Charles A. Whitten	Washington, USA
14	1963 – 1967	Guy Bomford	London, United Kingdom
15	1967 – 1971	Antonio Marussi	Trieste, Italy
16	1971 – 1975	Youri D. Boulanger	Moscow, USSR
17	1975 – 1979	Tauno J. Kukkamäki	Helsinki, Finland
18	1979 – 1983	Helmut Moritz	Graz, Austria
19	1983 – 1987	Peter V. Angus-Leppan	Kensington, Australia
20	1987 – 1991	Ivan I. Mueller	Columbus, USA
21	1991 – 1995	Wolfgang Torge	Hannover, Germany
22	1995 – 1999	Klaus-Peter Schwarz	Calgary, Canada
23	1999 – 2003	Fernandó Sansó	Milan, Italy

Continuation of Table			
No	*Period*	*Name*	*Residence*
24	2003 – 2007	Gerhard Beutler	Bern, Switzerland
25	2007 – 2011	Michael G. Sideris	Calgary, Canada
26	2011 – 2015	Chris Rizos	Sydney, Australia
27	2015 – 2019	Harald Schuh	Potsdam, Germany
28	2019 – 2023	Zuheir Altamimi	Paris, France
29	2023 – 2027	Richard Gross	Pasadena, USA

Secretaries of the IAG and predecessors

The Secretary's Position has had different names as follows:

- 1886 - 1921 Permanent Secretary
- 1922 - . . . Secretary General

No	*Period*	*Name*	*Residence*
Internationale Erdmessung - Association Géodésique Internationale (International Geodetic Association) (1886-1917)			
1	1886 – 1900	Adolf Hirsch	Neuchatel, Switzerland
2	1900 – 1921	H. G. van de Sande-Bakhuysen	Leiden, Netherlands
IUGG Section of Geodesy (1919-1930) and IUGG Association of Geodesy (1930-1946)			
3	1922 – 1946	Georges Perrier	Paris, France
International Association of Geodesy of the IUGG (1946-. . .)			
4	1946 – 1960	Pierre Tardi	Paris, France
5	1960 – 1975	Jean-Jacques Levallois	Paris, France
6	1975 – 1991	Michel Louis	Paris, France
7	1991 – 1995	Claude Boucher	Paris, France
8	1995 – 2007	Secretary General	Copenhagen, Denmark
9	2007 – 2019	Hermann Drewes	Munich, Germany
10	2019 – 2023	Markku Poutanen	Masala, Finland
11	2023 – 2027	Daniela Thaller	Frankfurt am Main, Germany

IAG Central Bureau (since 2007: IAG Office)

No	*Period*	*Host Institute*	*Director*	*Residence*
1	1864 – 1885	Royal Prussian Geodetic Institute	Johann Jacob Baeyer	Potsdam, Prussia
2	1886 – 1917		Friedrich Robert Helmert	Potsdam, Germany
3	1917 – 1922		J. H. Louis Krüger (p.p.)	Potsdam, Germany
4	1922 – 1946	Institut Géographique National (IGN)	Georges Perrier	Paris, France
5	1946 – 1960		Pierre Tardi	Paris, France
6	1960 – 1975		Jean-Jacques Levallois	Paris, France
7	1975 – 1991		Michel Louis	Paris, France
8	1991 – 1995		Claude Boucher	Paris, France
9	1995 – 2007	Niels Bohr Institute, Department of Geophysics, University of Copenhagen	Carl Christian Tscherning	Copenhagen, Denmark
10	2007 – 2019	Deutsches Geodätisches Forschungsinstitut	Hermann Drewes	Munich, Germany
11	2019 – 2023	Finnish Geospatial Research Institute (FGI)	Markku Poutanen	Masala, Finland
12	2023 – 2027	Bundesamt für Kartographie und Geodäsie (BKG)	Daniela Thaller	Frankfurt am Main, Germany

Editors in Chief of Official Journals of the IAG and predecessors

No	*Period*	*Editor in Chief*	*Residence*
Bulletin Géodésique			
I.1	1922 – 1945	Georges Perrier	Paris, France
I.2	1946 – 1951	Pierre Tardi	Paris, France
I.3	1952 – 1964	Jean-Jacques Levallois	Paris, France
I.4	1965 – 1975	Michel Louis	Paris, France
I.5	1975 – 1986	Ivan I. Mueller	Columbus, USA
I.6	1987 – 1995	Carl Christian Tscherning	Copenhagen, Denmark
Manuscripta Geodaetica			
II.1	1976 – 1980	Ivan I. Mueller	Columbus, USA
II.2	1980 – 1982	Peter Meissl	Graz, Austria
II.3	1982 – 1988	Erwin Groten	Darmstadt, F.R. Germany
II.4	1989 – 1991	Clyde C. Goad Erik W. Grafarend	Columbus, USA Stuttgart, Germany
II.5	1991 – 1995	Petr Vaníček	New Brunswick, Canada
Journal of Geodesy			
III.1	1995 – 2003	Peter J. G. Teunissen	Delft, Netherlands
III.2	2003 – 2007	William E. Featherstone	Perth, Australia
III.3	2007 – 2015	Roland Klees	Delft, Netherlands
III.4	2015 – 2023	Jürgen Kusche	Bonn, Germany
III.5	2023 – 2027	Peiliang Xu	Kyoto, Japan

Editors of the IAG Symposia Series

No	*Period*	*Editor*	*Residence*	*Assistant Editor*	*Residence*
1	1991 – 1995	Wolfgang Torge	Hannover, Germany		
2	1995 – 1999	Klaus-Peter Schwarz	Calgary, Canada		
3	1999 – 2003	Fernandó Sansó	Milan, Italy		
4	2003 – 2007	Gerhard Beutler	Bern, Switzerland		
5	2007 – 2011	Michael G. Sideris	Calgary, Canada		
6	2011 – 2015	Chris Rizos	Sydney, Australia	Pascal Willis	Paris, France
7	2015 – 2027	Jeff Freymueller	Fairbanks, USA	Laura Sánchez	Munich, Germany

Editors of the Geodesist's Handbook

Year	*Editor*	*Residence*
1980	Ivan I. Mueller	Columbus, USA
1984	Carl Christian Tscherning	Copenhagen, Denmark
1988	Carl Christian Tscherning	Copenhagen, Denmark
1992	Carl Christian Tscherning	Copenhagen, Denmark
1996	Pascal Willis	Paris, France
2000	Ole B. Andersen	Copenhagen, Denmark
2004	Ole B. Andersen	Copenhagen, Denmark
2008	H. Drewes, H. Hornik/ J. Ádám, Sz. Rózsa	Munich, Germany/ Budapest, Hungary
2012	H. Drewes, H. Hornik/ J. Ádám, Sz. Rózsa	Munich, Germany/ Budapest, Hungary
2016	H. Drewes, F. Kuglitsch/ J. Ádám, Sz. Rózsa	Munich & Potsdam, Germany/ Budapest, Hungary
2020	M. Poutanen/ Sz. Rózsa	Masala, Finland/ Budapest, Hungary
2024	D. Thaller, C. Dimopoulou	Frankfurt am Main, Germany

Awardees of the IAG Levallois Medal

No	*Year*	*Name of Awardee*	*Residence*
1	1979	Charles Whitten	Washington, USA
2	1983	Rudolf Sigl	Munich, F.R.Germany
3	1987	Arne Bjerhammar	Stockholm, Sweden
4	1991	Paul Melchior	Brussels, Belgium
5	1995	Willem Baarda	Delft, Netherlands
6	1999	Torben Krarup	Copenhagen, Denmark
7	2003	George Veis	Athens, Greece
8	2007	Carl C. Tscherning	Copenhagen, Denmark
9	2011	Ruth E. Neilan	Pasadena, USA
10	2015	Reiner Rummel	Munich, Germany
11	2019	Christoph Reigber	Potsdam, Germany
12	2023	Georges Balmino	Toulouse, France
13	2023	Hermann Drewes	Munich, Germany

Awardees of the IAG Guy Bomford Prize

No	*Year*	*Name of Awardee*	*Residence*
1	1975	Erik Grafarend	Munich, F.R.Germany
2	1979	Fernandó Sansó	Milan, Italy
3	1983	John Wahr	Boulder, USA
4	1987	Peter J. Teunissen	Delft, Netherlands
5	1991	Shuhei Okubo	Tokyo, Japan
6	1995	Thomas Herring	Cambridge, USA
7	1999	Véronique Dehant	Brussels, Belgium
8	2003	Ramon Hanssen	Delft, Netherlands
9	2007	Masato Furuya	Tokyo, Japan
10	2011	Johannes Böhm	Vienna, Austria
11	2015	Yoshiyuki Tanaka	Tokyo, Japan
12	2019	Michal Šprlák	Newcastle, Australia
13	2023	Amir Khodabandeh	Melbourne, Australia

Winners of the IAG Young Authors Award

Year	*Author's Name*	*Country*	*Title of the Publication*
1993	Hussein A. Abd-Elmotaal	Egypt	Vening-Meinesz Moho depths: traditional, exact and approximated. *Manuscripta Geodaetica*, 18: 171-181.
1994	Jean-Pierre Barriot	France	Line of sight operators in planetary geodesy. *Manuscr. Geod.*, 19: 269-283.
1995	Srinivas V. Bettadpur	India	Hotine's geopotential formulation revisited. *Bull. Géod.*, 69: 135-142.
1996	Giovanna Sona	Italy	Numerical problems in the computation of ellipsoidal harmonics. *J. of Geodesy,* 70: 117-126.
1998	Cheinway Hwang	Taiwan	Inverse Vening-Meinesz formula and deflection-geoid formula: applications to the predictions of gravity and geoid over the South China Sea. *J. of Geodesy*, 72: 304-312.
1999	Peiliang Xu	China	Biases and accuracy of, and an alternative to, discrete nonlinear filters. *J. of Geodesy*, 73: 35-46.
2000	Christopher Kotsakis	Canada	The multiresolution character of collocation. *J. of Geodesy*, 74: 275-290.
2000	Rüdiger Lehmann	Germany	Altimetry-gravimetry problems w. free vertical datum. *J. of Geodesy*, 74:327-334.
2001	Susan Skone	Canada	The impact of magnetic storms on GPS receiver performance. *J. of Geodesy*, 75: 457-468.
2003	Michael Kern	Germany	A study on the combination of satellite, airborne and terrestrial gravity data. *J. of Geodesy*, 77: 217-225.
2004	Shfaqat Abbas Khan	Pakistan	Shallow water loading tides in Japan from superconducting gravity (with J.L. Hoyer). *J. of Geodesy*, 78: 245-250.
2005	Roland Pail	Austria	A parametric study on the impact of satellite attitude errors on GOCE gravity field recovery. *J. of Geodesy*, 79: 231-241.
2006	Steffen Schön	Germany	Uncertainty in GPS networks due to remaining systematic errors: the internal approach (with H. Kutterer). *J. of Geodesy*, 80: 150-162.
2008	Franziska Wild-Pfeiffer	Germany	A comparison of different mass elements for use in gravity gradiometry. *J. of Geodesy*, 82: 637-653.

Continuation of Table			
Year	*Author's Name*	*Country*	*Title of the Publication*
2010	Elizabeth Petri	UK	A first look at the effects of ionospheric signal bending on a globally processed GPS network. *J. of Geodesy*, 84: 491-499.
2011	Thomas Artz	Germany	Assessment of periodic sub-diurnal Earth rotation variations at tidal frequencies through VLBI normal equations. *J. of Geodesy*, 85: 565-584.
2012	Manuela Seitz	Germany	The 2008 DGFI realization of the ITRS: DTRF2008. *J. of Geodesy*, 86: 1097-1123.
2013	Krzysztof Sośnica	Switzerland	Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results. *J. of Geodesy*, 87: 751-769.
2014	Alvaro Santamaría Gómez	France	Long-term vertical land motion from double-differenced tide gauge and satellite altimetry data. *J. of Geodesy*, 88: 207-222.
2015	Xingxing Li	Germany	Accuracy and reliability of multi-GNSS real-time precise positioning: GPS, GLONASS, BeiDou, and Galileo. *J. of Geodesy*, 89: 607-635.
2016	Olga Didova	Netherlands	An approach for estimating time-variable rates from geodetic time series. *J. of Geodesy*, 90: 1207–1221.
2017	Minghui Xu	China	The impacts of source structure on geodetic parameters demonstrated by the radio source 3C371. *J. of Geodesy*, 91: 767-781.
2018	Athina Peidou	Canada	On the feasibility of using satellite gravity observations for detecting large-scale solid mass transfer events. *J. of Geodesy*, 92: 517–528.
2019	Susanne Glaser	Germany	On the impact of local ties on the datum realization of global terrestrial reference frames. *J. of Geodesy*, 93: 655–667.
2020	Khosro Ghobadi-Far	USA	GRACE gravitational measurements of tsunamis after the 2004, 2010, and 2011 great earthquakes. *J. of Geodesy*, 94: 65.
2021	Radosław Zajdel	Poland	Sub-daily polar motion from GPS, GLONASS, and Galileo. *J. of Geodesy*, 95: 3.
2022	Matthias Willen	Germany	Feasibility of a global inversion for spatially resolved glacial isostatic adjustment and ice sheet mass changes proven in simulation experiments. *J. of Geodesy*, 96: 75.

History of the IAG Services

*: historical Services; 1 . . . 12: presently active Services			
No	*Acronym*	*Name of the IAG Service*	*Formation*
*	**ILS**	International Latitude Service (1962 renamed International Polar Motion Service, IPMS)	1899
*	**BIH**	Bureau International de l'Heure (1987 integrated into IERS)	1912
1	**PSMSL**	Permanent Service for Mean Sea Level	1933
2	**BGI**	Bureau Gravimetrique International	1951
*	**ICET**	International Centre for Earth Tides (2015 integrated into IGETS)	1956
*	**IPMS**	International Polar Motion Service (Successor of ILS, 1987 integrated into IERS)	1962
3	**IERS**	International Earth Rotation and Reference Systems Service	1987
4	**ISG**	International Service for the Geoid	1991
5	**IGS**	International GNSS Service	1994
6	**ILRS**	International Laser Ranging Service	1998
7	**IDEMS**	International Digital Elevation Models Service	1999
8	**IVS**	International VLBI Service for Geodesy and Astrometry	1999
9	**IDS**	International DORIS Service	2003
10	**ICGEM**	International Centre for Global Earth Models	2003
11	**IGFS**	International Gravity Field Service	2004
12	**IGETS**	International Geodynamics and Earth Tide Service	2015

Fellows of the IAG

1991:

O. Adebekun (Nigeria)
D.-E. Ajakaiye (USA)
V. Ashkenazi (UK)
W. Augath (Germany)
T.F. Baker (UK)
G. Balmino (France)
L.W. Baran (Poland)
G. Birardi (Italy)
A. Bjerhammar (Sweden)
D. Blitzkow (Brazil)
Y. Bock (USA)
G. Boedecker (Germany)
J.D. Bossler (USA)
C. Boucher (France)
P. Brosche (Germany)
F.K. Brunner (Austria)
M. Burša (Czech Republik)
J. Campbell (Germany)
G. Carrera (Canada)
M. Charfi (Tunisia)
J. Y. Chen (China)
B. H. Chovitz (USA)
O. Coker (Nigeria)
O. L. Colombo (USA)
A. Comolet-Tirman (France)
A.H. Cook (UK)
P.A. Cross (UK)
K. I. Daugherty (USA)
P. de Jonge (USA)
A. Dermanis (Greece)
J.O. Dickey (USA)
A.H. Dodson (UK)
B.C. Douglas (USA)
A. Drozyner (Poland)
H. Dufour (France)
D. Eckhardt (USA)
O. Fadahunsi (Nigeria)
F. Fajemirokun (Nigeria)
M. Feissel-Vernier (France)
I. Fejes (Hungary)
I.K. Fischer (USA)
R. Forsberg (Denmark)
P. Forsyth (Canada)
D. Fritsch (Germany)
J. Gaignebet (France)
E.M. Gaposchkin (USA)
C. Gemael (Brazil)
C.C. Goad (USA)
E.W. Grafarend (Germany)
E. Groten (Germany)
E. Gubler (Switzerland)
B. Guinot (France)
B. Heck (Germany)
G. Hein (Germany)
H. Henneberg (Venezuela)
S. Henriksen (USA)
P. Holota (Czech Republic)
L. Hora (Czech Republic)
H.T. Hsu (China)
J.R. Huddle (USA)
C. Jekeli (USA)
G. Jentzsch (Germany)
I. Joó (Hungary)
C.S. Joshi (India)
H.-G. Kahle (Switzerland)
H.P. Kahmen (Austria)
J. Kakkuri (Finland)
K. Kasahara (Japan)
E. Kausel (Chile)
H. Kautzleben (Germany)
A.H.W. Kearsley (Australia)
R.W. King (USA)
A. Kiviniemi (Finland)
R. Klees (Netherlands)
K.R. Koch (Germany)
B. Kolaczek (Poland)
K. Konan (Ivory Coast)
J. Kovalevsky (France)
Y. Kozai (Japan)
J. Krynski (Poland)
M. Kumar (USA)
J.T. Kuo (USA)

G. Lachapelle (Canada)
M.P.M. Lefebvre (France)
D. Lelgemann (Germany)
G.W. Lennon (Australia)
G. Lensen (New Zealand)
J.-J. Levallois (France)
E. Livieratos (Greece)
M. Louis (France)
G.R. Mader (USA)
J. Makris (Germany)
A. Mancini (USA)
I. Marson (Italy)
M. McNutt (USA)
D.D. McCarthy (USA)
W.G. Melbourne (USA)
P. Melchior (Belgium)
C. Morelli (Italy)
H. Moritz (Austria)
I.I. Mueller (USA)
I. Nakagawa (Japan)
A. Nobili (Italy)
J.D. Obel (Kenya)
M.Odlanicki-Poczobut (Poland)
B.P. Pertsev (Russia)
K. Poder (Denmark)
C. Poitevin (Belgium)
M.T. Prilepin (Russia)
J. Rais (Indonesia)
R.H. Rapp (USA)
C. Reigber (Germany)
A.R. Robbins (UK)
R.S. Rostom (Kenya)
R. Rummel (Germany)
F. Sacerdote (Italy)
F. Sansó (Italy)
N.K. Saxena (USA)
B. Schaffrin (USA)
G. Schmitt (Germany)
B.E. Schutz (USA)
K.-P. Schwarz (Canada)
G. Seeber (Germany)
M.J. Sevilla (Spain)
P.J. Shelus (USA)
M.G. Sideris (Canada)
L.E. Sjöberg (Sweden)
R.A. Snay (USA)
H. Sünkel (Austria)
T. Tanaka (Japan)
P.J.G. Teunissen (Netherlands)
W. Torge (Germany)
C.C. Tscherning (Denmark)
P. Vaníček (Canada)
C. Veillet (France)
P. Vyskočil (Czech Republic)
J. Wahr (USA)
D.E. Wells (Canada)
W.M. Welsch (Germany)
L.A. White (Australia)
P. Wilson (Germany)
P.L. Woodworth (UK)
A. Waalewijn (Netherlands)
Y.Y. Yatskiv (Ukraine)
K. Yokoyama (Japan)
D.B. Zilkoski (USA)
J.D. Zund (USA)

1995:

J. Ádám (Hungary)
R. Barzaghi (Italy)
M. Becker (Germany)
G. Beutler (Switzerland)
W. Bosch (Germany)
B.F. Chao (USA)
H. Denker (Germany)
J. Dow (Germany)
G.K. Elgered (Sweden)
B. Engen (Norway)
A. Geiger (Switzerland)
T. Kato (Japan)
A. Kleusberg (Germany)
J. Kouba (Canada)
H. Landau (Germany)
R.B. Langley (Canada)
K. Linkwitz (Germany)
S. Molodensky (Russia)

R. Neilan (USA)
C. Noll (USA)
S. Okubo (Japan)
P. Pâquet (Belgium)
J.C. Ries (USA)
J.M. Rüeger (Australia)
E.J.O. Schrama (Netherlands)
C.-K. Shum (USA)
T.A.Th. Spoelstra (Netherlands)
S. Takemoto (Japan)
C. Thomas (France)
J.A. Weightman (UK)
P. Willis (France)
C. Wilson (USA)
T. Yunck (USA)

1999:

N. Andersen (Denmark)
D. Arabelos (Greece)
M.G. Arur (India)
L. Ballani (Germany)
G.B. Benciolini (Italy)
M.G. Bevis (USA)
G. Blewitt (UK)
J.M. Bosworth (USA)
A. Cazenave (France)
T.A. Clark (USA)
J. Degnan (USA)
V. Dehant (Belgium)
H. Drewes (Germany)
B. Ducarme (Belgium)
W. Featherstone (Australia)
W. Freeden (Germany)
T. Herring (USA)
K.-H. Ilk (Germany)
J. Johansson (Sweden)
P. de Jonge (Netherlands)
P. Knudsen (Denmark)
Z.-X. Li (China)
J. Manning (Australia)
N. Pavlis (USA)
C. Rizos (Australia)
C. Rocken (USA)
I.N.Tziavos (Greece)
M. Vermeer M. (Finland)
M. Wei (Canada)
D. Wolf (Germany)
S. Zerbini (Italy)

2003:

E.F. Arias (Argentina)
J.-P. Barriot (France)
P.A. Berry (UK)
C.A. Brunini (Argentina)
C. Bruyninx (Belgium)
D. Gambis (France)
G. Gendt (Germany)
R.S. Gross (USA)
W. Gurtner (Switzerland)
S. Han (Australia)
R. Hanssen (Netherlands)
B.G. Harsson (Norway)
C. Hwang (China-Taipei)
W. Keller (Germany)
S.C. Kenyon (USA)
R. Kursinski (USA)
H. Kutterer (Germany)
R. Lehman (Germany)
A. Marchenko (Ukraine)
R. Scharroo (Netherlands)
W. Schlüter (Germany)
T. Schöne (Germany)
S. Skone (Canada)
N. Sneeuw (Canada)
M. Stewart (Australia)
G. Strykowski (Denmark)
C. Tiberius (Netherlands)
H. van der Marel (Netherlands)

N. Vandenberg (USA)
P. Visser (Netherlands)
L. Vitushkin (France)
J. Vondrak (Czech Republic)
R. Weber (Austria)
Y. Yuanxi (China)

2007:

Z. Altamimi (France)
R. Biancale (France)
M. Craymer (Canada)
D. Crossley (USA)
R. Dietrich (Germany)
X. Ding (Hong Kong)
L.P.S. Fortes (Brazil)
Y. Gao (Hong Kong)
D. Grejner-Brzezinska (USA)
K. Heki (Japan)
L. Hothem (USA)
J. Huang (China)
J. Ihde (Germany)
M. Kuhn (Australia)
J. Kusche (Netherlands)
U. Marti (Switzerland)
C. Merry (South Africa)
A.W. Moore (USA)
C. Noll (USA)
P. Novák (Czech Republic)
M.C. Pacino (Argentina)
M.R. Pearlman (USA)
H.-P. Plag (USA)
M. Poutanen (Finland)
B. Richter (Germany)
M. Rothacher (Germany)
Sz. Rózsa (Hungary)
M. Scheinert (Germany)
H. Schuh (Austria)
H.-P. Sun (China)
J.A. Torres (Portugal)
Gy. Tóth (Hungary)
P. Tregoning (Australia)
M. Verroneau (Canada)
J. Wang (Australia)
R. Wonnacott (South Africa)
P. Xu (Japan)
J. Yu (China)
S.Y. Zhu (Germany)

2011:

H. Abd-Elmotaal (Egypt)
L. Alfonsi (Italy)
D. Behrend (USA)
S. Bettadpur (USA)
S. Bisnath (Canada)
A. Brzezinski (Poland)
T. van Dam (Luxembourg)
J. Davis (USA)
Y. Fang (Australia)
J. Freymueller (USA)
Y. Fukuda (Japan)
Th. Hobiger (Japan)
H. Hornik (Germany)
S. Jin (South Korea)
M.O. Karslioglu (Turkey)
Ch. Kotsakis (Greece)
S. Lambert (France)
F. Lemoine (USA)
C. Ma (USA)
Z. Malkin (Russia)
S. Matsuzaka (Japan)
Gy. Mentes (Hungary)
A. Michlenz (Germany)
M. Omura (Japan)
R. Pail (Germany)
J. Ray (USA)
A. Reiterer (Germany)
G. Retscher (Austria)

L.J. Rickards (UK)
D. Roman (USA)
L. Sanchez (Germany)
M. Santos (Canada)
M. Schmidt (Germany)
F. Seitz (Germany)
L. Soudarin (France)
G. Tavernier (France)
S. Verhagen (Netherlands)
Y.M. Wang (USA)
J. Wickert (Germany)
H. Wilmes (Germany)

2015:

D. Angermann (Germany)
D. Avalos (Mexico)
F. Barthelmes (Germany)
O. Baur (Austria)
J. Boehm (Austria)
J. Bogusz (Poland)
S. Bonvalot (France)
C. Braitenberg (Italy)
J. Chen (USA)
R. Cunderlik (Slovakia)
X. Deng (Australia)
J. Dawson (Australia)
A. Eicker (Germany)
J. Ferrandiz (Spain)
Ch. Gerlach (Germany)
M. Hashimoto (Japan)
A. Jäggi (Switzerland)
G. Johnston (Australia)
A. Kealy (Australia)
Sh. Abbas Khan (Denmark)
M. King (Australia)
W. Kosek (Poland)
K. Mikula (Slovakia)
H. Ozener (Turkey)
S. Pagiatakis (Canada)
V. Palinkas (Czech Republic)
M. Reguzzoni (Italy)
S. Rosat (France)
M. Thomas (Germany)
M. Weigelt (Germany)
B. Wouters (UK/USA)
Li Zhenhong (UK)

2019:

J. Agren (Sweden)
M. Alizadeh (Iran)
S. Bergstrand (Sweden)
G. Bianco (Italy)
S. Claessens (Australia)
X. Collilieux (France)
L. Combrinck (South Africa)
M. Crespi (Italy)
J. Dousa (Czech Republic)
A. El-Mowafy (Australia)
Ch. Eschmann (Germany)
F. Flechtner (Germany)
J. Flury (Germany)
J. Geng (China)
V. Gikas (Greece)
R. Heinkelmann (Germany)
Ch. Hirt (Germany)
M. Hoque (Germany)
M. Horwath (Germany)
C. Huang (China)
U. Hugentobler (Germany)
M. Kalantari (Australia)
A. Kenyeres (Hungary)
A. Khodabandeh (Australia)
F. Kuglitsch (Germany)
J. LaBrecque (USA)
B. Luzum (USA)
D. MacMillan (USA)

W. Martinez (USA)
J. Müller Germany)
F. Nievinski (Brazil)
A. Nothnagel (Germany)
R. Pacione (Italy)
J.-A. Paffenholz (Germany)
E. Pavlis (USA)
U. Schreiber (Germany)
M. Seitz (Germany)
J. Skaloud (Switzerland)
K. Sosnica (Poland)
R. Stanaway (Australia)
D. Thaller (Germany)
L.-C. Tsai (China-Taipei)
D. Tsoulis (Greece)
G. Vergos (Greece)
P. Wielgosz (Poland)
H. Wziontek (Germany)
K. Zhang (Australia)
X. Zhang (China)

2023:

G. Appleby (UK)
K. Balidakis (Germany)
E. Brockmann (Switzerland)
S. Costa (Brazil)
Y. Dang (China)
G. do Nascimento Guimarães (Brazil)
W. Fei (China)
R. Hippenstiel (USA)
X. Li (USA)
M. Lidberg (Sweden)
U. Meyer (Switzerland)
B. Miyahara (Japan)
E. Montgomery-Brown (USA)
T. Nishimura (Japan)
J-M. Nocquet (France)
T. Otsubo (Japan)
P. Rebischung (France)
L. Ruotsalainen (Finland)
A. Santamaría-Gómez (France)
Z-K. Shen (USA)
W. Shen (China)
R. Steffen (Sweden)
D. van Westrum (USA)

Past Presidents and Secretaries General of the IAG (2019 - 2023)

This Chapter continues the series of articles "Past Presidents and Secretaries Generals (previously called Officers) of the IAG", belonging to the "History of the IAG". In the Geodesist's Handbook 2020 *Hermann Drewes* summarises the CVs of the Presidents and Secretaries General for the period 2007-2019. Similarly, in the Geodesist's Handbook 2008 *Carl Christian Tscherning* summarises for the period 1991-2007. He refers there to a similar article of his (pre-)predecessor Secretary General, *Michel Louis*, in 1992, and further back to an article written by the past Secretary General *J.-J. Levallois* in 1980.

Zuheir Altamimi - President 2019-2023

Zuheir Altamimi was born on January 15, 1958, in Al-Karak, a small city in Jordan known for its Crusader castle, the Kerak Castle. He received his Dipl.-Ing. /Master's degree in 1982 from the engineering school of Institut Géographique National (IGN-France) - "Ecole Nationale des Sciences Géographiques (ENSG)". He received his PhD degree in 1990 from Paris Observatory. After his Habilitation (2nd doctorate) in 2006 in space geodesy from the Paris University VI, he became Research Director at IGN-France, and now also at Institut de Physique du Globe de Paris (IPGP). He is the head of research activities on terrestrial reference systems and the International Terrestrial Reference Frame (ITRF), and the primary scientist of the International Terrestrial Reference System Center of the International Earth Rotation and Reference Systems (IERS).

His research focuses on space geodesy, theory and realization of terrestrial reference systems. Since more than three decades, he is the head of the research activities related to the development, maintenance, improvement and realization of the ITRF, the indispensable reference for solid earth science applications and satellite navigation. He has been a leader in adopting rigorous mathematical methods to combine diverse multi-center and multi-technique geodetic solutions. His papers on this topic are among the most cited articles in space geodesy, according to Google Scholar (April 2024): a total of about 13000 citations, with an H-Index 50.

Zuheir Altamimi's major contribution to global geodesy is the development in 1995 of the CATREF software (Combination and Analysis of Terrestrial Reference Frames) for the purpose of not only ITRF analysis and computation, but also for analysis

of time series of station positions, velocities and Earth Orientation Parameters, using full variance covariance information. CATREF has evolved since then to include many other features and in particular the modelling of periodic signals that we see in the time series of station positions. CATREF software is shared with many others, through training courses for international participants at geodetic institutes and universities around the world.

Zuheir Altamimi, together with other international colleagues, is deeply involved since 2013 in the United Nations initiative on Global Geospatial Information Management (UN-GGIM), where geodesy, and in particular the development of the Global Geodetic Reference Frame (GGRF) is one of the key areas of work of the Committee of Experts of UN-GGIM. The intensive activities of the GGRF Working Group, now elevated to a "Subcommittee on Geodesy", led to the adoption in 2015 by the UN General Assembly of a resolution on the "global geodetic reference frame for sustainable development".

Zuheir Altamimi has received the following honors and awards:

- Prix de Cartographie, French Academy of Sciences (1996);
- Chevalier dans l'Ordre des Palmes Académiques (2006);
- Prix Antoine d'Abbadie, French Academy of Sciences (2011);
- Vening Meinesz Medal of the European Geosciences Union (2013);
- Officier dans l'Ordre des Palmes Académiques (2014);
- Commandeur dans l'Ordre des Palmes Académiques (2018);
- Fellow of the International Association of Geodesy (2007);
- Fellow of the International Union of Geodesy and Geophysics (2023).

Zuheir Altamimi's involvement with the IAG started in 2003, as President of IAG Sub-commission 1.3 (Regional Reference Frames), followed by President of Commission 1 (Reference Frames) for the period 2007-2011. He became President of the IAG at the IUGG General Assembly in Montreal, 2019, after serving four years as Vice President.

Markku Poutanen - Secretary General 2019-2023

Markku Poutanen was born on November 20, 1955, in Parikkala, Finland. He earned his MSc in astronomy in 1981, and a PhD in geodesy in 2000 from the University of Helsinki. He studied and worked at the Astronomical Observatory of the University of Helsinki until 1985, focusing on research topics such as asteroid photometry (partly at the Lowell Observatory, Arizona, USA) and stellar spectroscopy. In 1985, he joined the Finnish Geodetic Institute (The Finnish Geospatial Research Institute, FGI, since 2015) as a researcher, where his work included satellite geodesy, positioning, reference frames, and geodetic metrology. In 2001, he was appointed Director of the Department of Geodesy and Geodynamics, concurrently holding the title of professor. He remained in this position until 2019 when he was elected Secretary General of the IAG. He retired in 2023. He is an Associate Professor (Docent) at both the University of Helsinki and Aalto University.

He has held several international positions and memberships, including:

- Chair of the IAG Sub-commission 3.2 "Crustal deformations" (2003-2015);
- Member of the UN-GGIM Subcommittee of Geodesy (SCoG) (2017-2022);
- Chair of the Working Group "Geodetic reference frame in Europe" (GRF: Europe) of the United Nations Committee of Experts on Global Geospatial Information Management in Europe (UN-GGIM: Europe) (2016-2019);
- Member of the Geodesy Advisory Board of the Bavarian Academy of Sciences, BAdW (2016-);
- President of the Geodesy Division, European Geosciences Union (EGU) (2009-2013);
- President of the Nordic Geodetic Commission (2018-2022);
- President of EUREF (IAG Reference Frame Sub-Commission 1.3a for Europe) (2015-2019);
- Secretary General of the IAG (2019-2023).

Markku Poutanen has received the following Awards and Honours:

- Asteroid 3760 Poutanen is named after Markku Poutanen (1984);
- Fellow of the International Association of Geodesy, IAG (2007);
- Golden Badge of Merit of the National Land Survey of Finland (2009);
- Member of Finnish Academy of Science and Letters (2009);
- Correspondent member of the German Geodetic Commission (2010);
- Knight of the White Rose of Finland (2012);
- Member of the Leibniz Society of Sciences (2020);
- State Official Service Medal (2022);
- Fellow of the International Union of Geodesy and Geophysics (IUGG) (2023).

IAG Statutes and Bylaws adopted by the IAG Council at the XXVIII IUGG General Assembly in Berlin, Germany, July 2023

IAG Statutes

1. **Definition of Terms**
   (a) Geodesy is the discipline that deals with the measurement and representation (geometry, physics, and temporal variations) of the Earth and other celestial bodies.
   (b) IUGG is an acronym for the International Union of Geodesy and Geophysics.
   (c) IAG or Association is an acronym for the International Association of Geodesy.
   (d) Adhering Body and Council have the same meaning as in the Statutes of the IUGG.
   (e) IAG General Assembly refers to an assembly for scientific and/or administrative purposes of:
      i. scientists from geodesy and other Earth science disciplines;
      ii. the Council Delegates (or Alternative Delegates) appointed by the Adhering Bodies; and
      iii. Individual members as defined by Statute 6(b).
   (f) IAG Scientific Assembly means an assembly for primarily scientific purposes and therefore it does not normally require the presence of the delegates appointed by the Adhering Bodies.
   (g) Council Delegate means the person appointed by the Adhering Body to be a member of the Council for one period (see 1(h)). Adhering Bodies may appoint an Alternative Delegate to an IAG Council meeting if the Council Delegate cannot attend the meeting.
   (h) Period means the interval of time between the closures of two successive IAG General Assemblies.
2. **International Association of Geodesy**
   (a) The International Association of Geodesy (IAG):
      i. is a constituent Association of the IUGG; and
      ii. is subject to the Statutes and Bylaws of the IUGG.
   (b) In the event of the dissolution of the IAG, its assets shall be ceded to the IUGG.
3. **Mission**
   The Mission of the Association is the advancement of geodesy. The IAG implements its mission by furthering geodetic theory through research and teaching, by collecting, analyzing, modelling and interpreting observational data, by stimulating technological development, by promoting refined observations, observing systems and satellite missions, and by providing a consistent representation of the figure, rotation, and gravity field of the Earth and other celestial bodies of the solar system.

4. **Objectives**
   The IAG shall pursue the following objectives to achieve its mission:
   (a) Study, at the highest possible level of accuracy, all geodetic problems related to Earth observation and global change, including:
      i. Definition, establishment, and maintenance of global and regional reference systems for interdisciplinary use.
      ii. Rotation of the Earth and other celestial bodies of the solar system.
      iii. Positioning and deformation.
      iv. Gravity field.
      v. Ocean, ice and sea level.
      vi. Atmosphere and hydrosphere.
      vii. Time and frequency transfer.
   (b) Support the maintenance of geodetic reference systems and frames for continuous, long-term observations and archival of results.
   (c) Provide observational and processed data, standards, methodologies, and models in a form that ensures the broadest possible range of research and application.
   (d) Stimulate development and take advantage of emerging space and other technologies to increase the resolution and accuracy of geodetic data and products in order to advance geodetic and interdisciplinary research.
   (e) Initiate, coordinate, and promote international cooperation and knowledge exchange through symposia, workshops, summer schools, training courses, publications, and other means of communication.
   (f) Foster the development of geodetic activities and infrastructure in all regions of the world, taking into consideration the specific situation of developing countries.
   (g) Collaborate with the international science and engineering community in supporting the application of geodetic theory and techniques and the interpretation of results.
   (h) Cooperate with national and international agencies in establishing research goals, missions, and projects.
5. **Structure and Administration**
   (a) The Association's structure shall comprise a small number of components: Commissions, Inter-commission Committees (ICCs), Services, the Global Geodetic Observing System (GGOS), and the Communication and Outreach Branch (COB).
   (b) Subcomponents, such as IAG Projects, Sub-commissions, Commission Projects, and Study and Working Groups, may be established as provided for in the Bylaws.
   (c) The administration of the IAG is carried out by the IAG General Assembly, the IAG Council, the IAG Bureau and the IAG Executive Committee. The COB is the office responsible for the promotional activities of the IAG and for communication with its members.
6. **Membership**
   The membership of the IAG shall comprise:
   (a) Adhering Bodies; and

(b) Individual members in accordance with the Bylaws.

7. **IAG Council**
   (a) The IAG Council is responsible for governance, strategic policy and direction.
   (b) The membership of the IAG Council consists of Delegates appointed by the Adhering Bodies.
   (c) Each Adhering Body may appoint one Delegate subject to the conditions in (d) and (e) below.
   (d) A Delegate may only represent one Adhering Body.
   (e) The IAG President, Vice President and Secretary General may not serve as Delegates.
8. **IAG Bureau**
   (a) The Bureau of the Association consists of the IAG President, the Vice President and the Secretary General.
   (b) The duties of the IAG Bureau shall be to administer the affairs of the Association in accordance with these Statutes and Bylaws and with the decisions of the IAG Council and the IAG Executive Committee.
9. **IAG President**
   (a) The IAG President shall be elected by the IAG Council.
   (b) The IAG President shall provide general leadership for the Association.
   (c) The IAG President presides over the meetings of the IAG General Assembly, the IAG Scientific Assembly, the IAG Council, the IAG Executive Committee, and the IAG Bureau. In the IAG Council meetings the President has no vote, except in the case of a tie as provided in 14(g).
   (d) The IAG President, on completion of their term of office of one period, shall serve for the next period in the position of Immediate Past President.
10. **IAG Vice President**
    (a) The IAG Vice President shall be elected by the IAG Council.
    (b) The IAG Vice President shall perform such tasks as may be assigned by the IAG President, the IAG Executive Committee or the IAG Council.
    (c) The IAG Vice President assumes the functions, duties and powers of the President when the latter is absent or otherwise unable to assume office.
11. **IAG Secretary General**
    (a) The IAG Secretary General shall be elected by the IAG Council.
    (b) The IAG Secretary General shall serve as secretary of the IAG General Assembly, the IAG Scientific Assembly, the IAG Council, the IAG Executive Committee, and the IAG Bureau and arrange for meetings of these bodies in accordance with the Bylaws.
    (c) The IAG Secretary General, on completion of their term of office, shall serve for the next period in the position of Immediate Past Secretary General.
12. **IAG Executive Committee**
    (a) The IAG Executive Committee shall consist of the following voting members: each member of the IAG Bureau, the immediate Past President, the immediate Past Secretary General, the Presidents of the Commissions, the Presidents of the Inter-commission Committees, the President of GGOS, the President of the COB, three representatives of the Services, and two Members-at-Large.

(b) The Chairs of the IAG Projects and the Assistant Secretaries shall attend any meeting of the IAG Executive Committee, with voice but without vote. The Past Presidents and past Secretaries General may attend any meeting of the IAG Executive Committee, with voice but without vote (except for the immediate Past President and the immediate Past Secretary General, who do have a vote in accordance with Statute 12(a) for one 4-year period).

(c) The election of IAG Executive Committee members shall be in accordance with the Bylaws.

(d) The responsibilities of the IAG Executive Committee shall be to further the objectives of the Association through effective coordination and through the formulation of general policies.

(e) Decisions of the Executive Committee shall be taken by a simple majority. If a tie should occur in an Executive Committee vote, the IAG President shall cast the decisive vote.

13. **Council Meetings**

(a) The IAG Council shall meet at the time of an IAG General Assembly.

(b) The IAG Council may hold extraordinary meetings, either in person or electronically, at times other than an IAG General Assembly. Such meetings must be proposed by the IAG Executive Committee.

(c) The members of the IAG Executive Committee may attend meetings of the IAG Council, with voice but without vote, except for those who are also Delegates.

14. **Voting in the Council**

Voting in the IAG Council shall follow the following rules:

(a) An Adhering Body which is not represented at an IAG Council meeting may vote electronically or by correspondence on any specific question, provided that the matter has been clearly defined on the final agenda distributed in advance, and that the discussion thereon has not produced any significant new considerations or change in its substance, and that the said vote has been received by the IAG President prior to the voting. In such a case the vote will be cast in accordance with 14(d)).

(b) Quorum in IAG Council meetings is achieved when the number of Council Delegates (or Alternative Delegates) in attendance is at least one third of the delegates from countries eligible to vote.

(c) On questions not involving matters of finance, each delegate from an Adhering Body, with its IUGG subscriptions paid up to the end of the calendar year preceding the voting, shall have one vote.

(d) On questions involving finance, each delegate from an Adhering Body, which has paid its IUGG subscriptions up to the end of the calendar year preceding the voting, shall have the right to vote. The number of votes allotted to each delegate of an Adhering Body shall then be in accordance with its category of membership, as defined by the IUGG.

(e) Prior to any vote in an IAG Council meeting, the IAG President shall decide whether or not the matter under consideration is financial in character and whether the procedure of voting by correspondence applies.

(f) The IAG Council may also deliberate and decide matters at other times by electronic voting, email ballot and/or correspondence, provided that the issues have been communicated to IAG Council members at least one month in advance of the voting date.

(g) Decisions of the IAG Council shall be taken by a simple majority, except as otherwise specified in these Statutes. If a tie should occur in an IAG Council vote, the IAG President shall cast the decisive vote. This procedure also applies if the vote is taken electronically. Simple and two-thirds majorities are determined by the proportion of affirmative votes to the sum of all votes (affirmative, negative and abstention). Blank and invalid ballots and votes not cast by delegates present are counted as abstentions.

(h) Elections for all members of the IAG Executive Committee shall be by electronic voting. For each post, the winner must receive an outright majority (number of votes being greater than the total combined votes of the other candidates). If there are three or more candidates for a position and no candidate has an outright majority after the first voting round, then the top two ranked candidates will be retained and a second round of votes conducted to elect the winner. Ties will be broken by a coin toss, drawing of lots, or equivalent random selection.

(i) Except as otherwise provided in the Statutes or Bylaws, meetings of the IAG Council, as well as those of other IAG administrative bodies, shall be conducted according to the edition of Robert's Rules of Order currently recommended by the IUGG.

15. **Decisions of the Council**

(a) Decisions of the IAG Council shall be reported to the individual membership in a meeting at the IAG General Assembly.

(b) If the majority of those present at this meeting disagrees with the decisions of the IAG Council, the IAG Council shall reconsider the question, and make a decision, which shall be final.

16. **Changes to Statutes and Bylaws**

Changes in the Statutes and Bylaws shall be made as follows:

(a) If deemed necessary, the Association may review the Statutes and Bylaws in each period, to ensure an up-to-date structure of its scientific and administrative organization. A Review Committee, known as the Cassinis Committee, will be appointed by the IAG Executive Committee to achieve this goal. Proposals for a substantive change of any article of these Statutes and Bylaws must reach the Secretary General at least two months before the announced date of the IAG Council meeting at which it is to be considered. The Secretary General shall notify all Adhering Bodies of any proposed changes at least one month before the announced date of the IAG Council meeting.

(b) The Statutes may not be modified except by a two-thirds majority of votes cast at an IAG Council meeting, and changes shall come into force at the close of that meeting.

(c) The IAG Council shall have the power to adopt Bylaws within the framework of the Statutes.

(d) The Bylaws may be modified by a simple majority of votes cast at an IAG Council meeting, and changes shall come into force at the close of the meeting.

IAG Bylaws

1. **Definition of Terms**
   (a) *Commissions* represent major fields of activity in accordance with the IAG Statutes.
   (b) *Inter-commission Committees* (ICCs) shall be responsible for well-defined, important and permanent tasks involving all Commissions.
   (c) *Services* collect and analyze observations to generate products relevant to geodesy and other sciences and applications.
   (d) The *Global Geodetic Observing System* (GGOS) works with the other IAG components in advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time.
   (e) *IAG Projects* are flagship long-term projects of broad scope and of significant interest for the entire field of geodesy.
   (f) The *Communication and Outreach Branch* (COB) provides the Association with communication, educational/public information and outreach links to the membership, to other scientific Associations and to the world as a whole.
   (g) *Association subcomponent* or *subcomponents* are long-term or short-term structures created by the IAG or one or more of its components.
   (h) *Long-term subcomponents* comprise IAG Projects (broad in scope and of high interest for the entire field of geodesy), Sub-commissions and Commission Projects which are expected to operate for several periods.
   (i) *Short-term subcomponents* refer to Study Groups and Working Groups which are established for a maximum term of one period.
   (j) *Steering Committee* means a group of elected or appointed IAG officers who oversee the work of Commissions (see Bylaw 5), Inter-commission Committees (see Bylaw 12), IAG Projects (see Bylaw 17), and the Communication and Outreach Branch (see Bylaw 16).
   (k) *Period* means the interval of time between the closures of two successive IAG General Assemblies.
2. **Responsibilities of Association Components**
   (a) The scientific work of the IAG is performed by Commissions, Inter-commission Committees, IAG Projects, Services and GGOS.
   (b) The responsibilities of the IAG Components are determined by the IAG Council on the recommendation of the IAG Executive Committee.
   (c) Components are expected to interact with each other where their activities are inter-related.
   (d) Each Component may set up subcomponents and is responsible for the activities of those subcomponents.
3. **General Responsibilities of Component Presidents or Chairs, and Steering Committees**
   (a) Each Component shall have a President or Chair who will lead a Steering Committee.
   (b) The Component's President or Chair is responsible for the scientific development within the Component's field of interest. The Component's President or Chair shall:

i. coordinate the work of the subcomponents;
ii. keep the officers of the Component as well as the IAG Bureau and IAG Executive Committee informed of the Component's activities on an annual basis;
iii. collect reports of the subcomponents two months before each IAG General and Scientific Assembly for publication in the "Travaux de l'Association Internationale de Géodésie";
iv. receive suggestions for new subcomponents, and suggestions for continuation of existing ones; and
v. recommend changes to subcomponents to the IAG Executive Committee for approval.

(c) The Component's Steering Committee is expected to meet at least once per year and at least once during each IAG General Assembly.
(d) The Component's Steering Committee shall review at one of its meetings (usually the IAG General Assembly, or the IAG Scientific Assembly):
i. the activities of the subcomponents over the past period;
ii. the structure of the subcomponents; and
iii. the programs for the forthcoming period for those subcomponents that will be recommended for continuation.
(e) The Component's Steering Committee shall inform the Secretary General about all relevant issues.
(f) The Component's Steering Committee may organize scientific and organizational meetings and workshops provided that they are readily distinguished as being of a more limited scope than IAG Scientific Symposia or IAG Sponsored Symposia as described in Bylaws 28 and 29.

4. **Commission Responsibilities**
Commissions shall promote the advancement of science, technology and international cooperation in their field. They establish the necessary links with sister disciplines and with the relevant Services. Commissions shall represent the Association in all scientific domains related to their field of geodesy.

5. **Commission Steering Committee**
(a) The Commission Steering Committee shall be established at each IAG General Assembly, following the election of the Association officers.
(b) The Steering Committee shall have the following voting members:
i. Commission President.
ii. Commission Vice President.
iii. Chairs of the Sub-commissions and Commission Projects.
iv. Up to three representatives of the Services relevant to the work of the Commission.
v. Up to two Members-at-Large to balance geographical and member country representation.
(c) The Steering Committee may also have non-voting members who represent organizations external to the IAG, as appropriate.

6. **Appointment of Commission Officers**
   (a) The Commission President shall be elected by the IAG Council for one period without reappointment, except where exceptional circumstances justify reappointment.
   (b) The Commission Vice President shall be appointed by the IAG Executive Committee for one period without reappointment, except where exceptional circumstances justify reappointment.
   (c) Chairs of the Sub-commissions and Commission Projects shall be nominated by the Commission President and Vice President within two months following the General Assembly.
   (d) The representatives of the Services shall be appointed by the Commission President and Vice President upon proposal of the Services.
   (e) The representatives of the external organizations shall be appointed by the Commission President and Vice President upon proposal of the external organizations.
   (f) The Members-at-Large shall be nominated by the Commission President and Vice President within two months following the IAG General Assembly.
   (g) The appointments of Members-at-Large and Chairs of Sub-commissions and Commission Projects take effect on approval of the nominations by the IAG Executive Committee.
7. **Tasks of Commission Steering Committee**
   The Commission Steering Committee is subject to the general responsibilities of component Steering Committees in Bylaw 3(c), 3(d), 3(e), and 3(f). In particular, its tasks are to:
   (a) Review the Commission's field of interests and objectives.
   (b) Liaise with the other IAG Commissions, the Inter-commission Committees, and with similar organizations outside the IAG, as appropriate.
   (c) Foster active participation of early career geodesists and geodesists from underrepresented countries.
   (d) Coordinate and review the work of its components and report at the time of the Scientific Assembly to the IAG Executive Committee on the progress and performance of the components.
   (e) Encourage and organize Commission and interdisciplinary symposia and/or sessions at major geodesy related international meetings.
   (f) Maintain a Commission website and email service.
   (g) As requested, nominate editors for the Journal of Geodesy.
8. **Current Commissions**
   On the approval of these Bylaws, there shall be four Commissions with areas of scientific responsibility as outlined below.
   Commission 1 : Reference Frames
   (a) Establishment, maintenance, improvement of the geodetic reference frames.
   (b) Advanced terrestrial and space geodetic techniques for the above purposes.
   (c) International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories.
   (d) Theory and coordination of astrometric observation for reference frame purposes.

(e) Collaboration with space geodesy/reference frame related international services, agencies and organizations.

Commission 2: Gravity Field

(a) Terrestrial, marine, and airborne gravimetry.
(b) Satellite gravity and altimetry observations.
(c) Gravity field modelling.
(d) Time-variable gravity field.
(e) Geoid determination and height systems.
(f) Satellite orbit modelling and determination.

Commission 3: Earth Rotation and Geodynamics

(a) Earth orientation (UT1 and LOD, polar motion, precession-nutation).
(b) Earth tides and tidal loading.
(c) Crustal deformation, seismo-geodesy, volcano-geodesy and seafloor-geodesy.
(d) Earth's response to non-tidal surface loading (including glacial isostatic adjustment).
(e) Sea level changes over various timescales.

Commission 4: Positioning and Applications

(a) Terrestrial and satellite-based positioning systems development, including sensor and information fusion.
(b) Navigation and guidance of platforms.
(c) Interferometric laser and radar applications.
(d) Applications of geodetic positioning using geodetic networks, including monitoring of deformations.
(e) Applications of geodesy to engineering.
(f) Atmospheric investigations using space geodetic techniques.

9. **Commission Subcomponents and Joint Subcomponents**
   (a) Commission subcomponents are Sub-commissions, Commission Projects, Study Groups, and Working Groups, which all belong to one Commission.
   (b) If more than one component is involved in a subcomponent, the term "joint subcomponent" will be used, e.g. Joint Sub-commission, Joint Commission Project, Joint Study Group, Joint Working Group.
10. **Sub-commissions and Joint Sub-commission**
   (a) A Sub-commission may be set up for topics where the Commission plays a leading or coordinating role.
   (b) Where a topic relates to the scientific responsibilities of more than one IAG component, a Joint Sub-commission shall be established under the lead of one Commission.
   (c) A Sub-commission is expected to be established for several periods.
   (d) Sub-commissions are established and terminated by the IAG Executive Committee upon recommendation from the Commission President.
   (e) A proposal to the IAG Executive Committee for a Joint Sub-commission requires the recommendation of the Presidents of all contributing components.
11. **Commission Projects and Joint Projects**
   (a) A Commission Project may be established when a new scientific method or a new technique is being developed, or when it seems appropriate to apply an existing technique to a specific geographic area where international collaboration is required.

(b) Where a topic for a Commission Project relates to the scientific responsibilities of more than one Commission, or a Commission and a Service, a Joint Commission Project shall be established under the lead of one Commission.
(c) A Commission Project is established for one period and may be extended for another period subject to a positive review.
(d) Commission Projects are established, extended and terminated by the IAG Executive Committee upon recommendation from the Commission President.
(e) A proposal to the IAG Executive Committee for a Joint Commission Project requires the recommendation of the Presidents of all contributing components.

12. **Inter-commission Committees (ICCs)**
(a) Inter-commission Committees shall be responsible for well-defined, important and permanent tasks involving all Commissions.
(b) Each ICC shall have a Steering Committee, which shall include the following members:
i. President appointed by the IAG Executive Committee.
ii. Vice President appointed by the IAG Executive Committee on the recommendation of the President.
iii. One representative appointed by each Commission.
(c) The Terms of Reference for each ICC shall be developed by a planning group appointed by the IAG Executive Committee, for approval by the Executive Committee.
(d) ICCs will be established for at least two periods and shall be reviewed by the IAG Executive Committee every eight years.
(e) ICCs shall report to the IAG Executive Committee.
(f) The President of an ICC shall hold office for one period, but is eligible to be re-elected for one further period.

Inter-commission Committee for Climate Research (ICCC)
The mission of the ICCC is to interact and collaborate with other IAG components, in particular the Commissions and GGOS, in order to further the objectives of the ICCC:
(a) to be the international focal point of geodesy for climate research;
(b) to encourage and initiate activities to intensify the interaction between geodesy and climate science; and
(c) to monitor research developments related to the use of geodetic data for climate research.

Inter-Commission Committee on Marine Geodesy (ICCM)
The ICCM mission is to collaborate and interoperate with the IAG Commissions and GGOS to realize the objectives of ICCM:
(a) to close the gaps between theory and applications in marine geodesy;
(b) to connect the seafloor geodetic network component to the ITRF;
(c) to develop multi-marine geodetic observations; and
(d) to establish international conventions for marine geodetic data processing and standards.

Inter-commission Committee on Theory (ICCT)
The mission of the ICCT is to interact and collaborate with other IAG components, in particular the Commissions and GGOS, in order to further the objectives of the ICCT:

(a) to be the international focal point of theoretical geodesy;
(b) to encourage and initiate activities to further geodetic theory in all branches of geodesy; and
(c) to monitor research developments in geodetic modelling.

13. **IAG Services**
(a) IAG Services (see Bylaw 14) generate products, using their own observations and/or observations of other services, relevant for geodesy and for other sciences and applications. Accuracy and robustness of products, quality control, timeliness, and state-of-the-art quality are the essential aspects of the Services.
(b) Each IAG Service shall define its Terms of Reference as appropriate to accomplish its mission and shall submit the Terms of Reference to the IAG Executive Committee for approval.
(c) Each IAG Service shall have an IAG representative, appointed by the IAG Executive Committee, as a voting member of its directing or governing board.
(d) IAG Services are linked to at least one of the Commissions and may be also linked to other scientific organizations, such as the ISC World Data System (WDS) or the International Astronomical Union (IAU).
(e) IAG Services should collaborate on a scientific basis with the Commissions, establish Joint Commission Projects and Joint Study Groups and help compile the Commissions' list of themes for Study Groups.
(f) Three representatives shall be elected in accordance with Bylaw 39 to the IAG Executive Committee to serve the interests of all Services.
(g) On any matter relating to the products of a Service, the Service shall represent the IAG.

14. **Current IAG Services**
There are twelve IAG Services at the time of adoption of these Bylaws:
(a) International Gravimetric Bureau (BGI)
(b) International Centre for Global Earth Models (ICGEM)
(c) International Digital Elevation Models Service (IDEMS)
(d) International DORIS Service (IDS)
(e) International Earth Rotation and Reference Systems Service (IERS)
(f) International Geodynamics and Earth Tides Service (IGETS)
(g) International Gravity Field Service (IGFS)
(h) International GNSS Service (IGS)
(i) International Laser Ranging Service (ILRS)
(j) International Service for the Geoid (ISG)
(k) International VLBI Service for Geodesy and Astrometry (IVS)
(l) Permanent Service for Mean Sea Level (PSMSL)

15. **The Global Geodetic Observing System (GGOS)**
(a) GGOS is IAG's observing system to monitor the geodetic and global geodynamic properties of the Earth as a system.
(b) The GGOS works with all IAG components, such as the Services, the Commissions, the Inter-Commission Committees and the Projects, to provide unique, mutually consistent, and easily accessible geodetic products (including the geodetic reference frames and gravity field models) and relevant geodetic constants for science and society. In addition, GGOS undertakes activities directed

at improving the geodetic infrastructure that underpins the geodetic products. Further, GGOS works in concert with the Commissions, the ICCs and the Projects concerning new developments, and keeps other IAG components informed of the work of GGOS.

(c) GGOS operates under its own Terms of Reference, defined by the GGOS Governing Board and approved by the IAG Executive Committee. The GGOS procedures for the nomination and election of its Officers are specified in its Terms of Reference.

(d) The GGOS President is elected by the IAG Executive Committee from a slate of candidates nominated by the GGOS Governing Board and the IAG Executive Committee. The President is appointed for one period, which may be renewed once.

16. **The Communication and Outreach Branch (COB)**

(a) The function of the Communication and Out-reach Branch (COB) is to provide the Association with communication, educational/public information and outreach links to the membership, to other scientific organizations and to the world as a whole.

(b) The responsibilities of the COB shall include the following:
   i. Promote the recognition and usefulness of geodesy in general and the IAG in particular.
   ii. Publications (such as newsletters) and social media platforms.
   iii. Membership development.
   iv. General information service and outreach.

(c) The COB shall also assist the IAG Secretary General in the following tasks as required:
   i. Maintenance of the IAG website.
   ii. Setting up Association schools.
   iii. Organizing meetings and conferences.

(d) The IAG Executive Committee establishes the COB on a long-term basis by issuing a Call for Participation. The responding organization(s) and the IAG Executive Committee shall then negotiate the Terms of Reference and other conditions.

(e) The President of the COB shall be elected by the IAG Council after consideration of a COB proposal.

(f) Major decisions related to the operations of the COB shall be made by a Steering Committee consisting of the following voting members:
   i. COB President.
   ii. IAG Secretary General.
   iii. Editor-in-Chief of the Journal of Geodesy.
   iv. Editor-in-Chief of the IAG Symposia Series.
   v. Up to five other members appointed by the IAG Executive Committee on the recommendation of the President of the COB.

17. **IAG Projects**

(a) IAG Projects are flagship long-term projects of broad scope and of significant interest for the entire field of geodesy.

(b) The establishment of an IAG Project shall be carried out by a planning group appointed by the IAG Executive Committee.

(c) The Project Steering Committee shall have the following voting members:
   i. The Project Chair appointed by the IAG Executive Committee.
   ii. One member from each Commission appointed by each Commission's Steering Committee.
   iii. Two Members-at-Large proposed by the members of the Project Steering Committee identified in clause (i) and (ii) above and approved by the IAG Executive Committee.
   iv. Chairs of the IAG Project Working Groups (if any).
   v. Representatives of other IAG components, as appropriate.

(d) IAG Project subcomponents are known as Working Groups.

18. **Study Groups, Working Groups, Joint Study Groups and Joint Working Groups**

(a) A Study Group or Working Group may be established at any time to address clearly defined well-focused scientific topics of limited scope within the field of the Component. A Study Group is dealing with more theoretical issues and a Working Group with more practical realizations.

(b) Where a topic for a Study Group or Working Group relates to the scientific responsibilities of more than one Component, a Joint Study Group or a Joint Working Group shall be established.

(c) A Study Group or Working Group is established for a maximum of one period.

(d) Study Groups and Working Groups, including the position of the group Chair, are established and terminated by the IAG Executive Committee upon recommendation of the Component President.

(e) A proposal to the IAG Executive Committee for a Joint Study Group or Joint Working Group requires the recommendation of the Presidents of all contributing components.

(f) The Chair of a Study Group or Working Group is responsible for initiating and directing its work and appointing its members.

(g) Study Group and Working Group membership should be balanced so as to reflect international cooperation in its subject.

(h) A Study Group or Working Group may have at most 20 full members and an unlimited number of correspondent members.

(i) The Chair of each Study Group or Working Group shall issue a brief description of the work to be performed and a list of members, to be published in the Geodesist's Handbook after each IAG General Assembly.

(j) The Chair of each Study Group or Working Group shall report annually to its members and the Commission Steering Committee, on results achieved and outstanding problems.

19. **IAG Publications**
    (a) The IAG publications include the Journal of Geodesy, the IAG Symposia Series, the Geodesist's Handbook, the "Travaux de l'Association Internationale de Géodésie", the IAG Newsletter, and IAG Special Publications.
    (b) The Association's journal is the Journal of Geodesy, hereinafter referred to as the Journal. The Journal is published monthly through an agreement between the Association and a publishing company, or by other arrangement approved by the IAG Executive Committee. The terms of any agreement for publication of the Journal shall be negotiated by the President of the Communications and Outreach Branch and ratified by the IAG Executive Committee.
    (c) The Journal publishes peer-reviewed papers, covering the whole range of geodesy.
    (d) After each IAG General Assembly, a special issue of the Journal shall be published under the name of "The Geodesist's Handbook". This issue provides the actual information on the Association, including the reports of the IAG President and Secretary General presented at the previous IAG General Assembly, the resolutions taken at that assembly, and the Association structure listing all components and subcomponents for the running period, rules for the IAG Fund, IAG Awards and for the conduct of scientific meetings as well as relevant scientific information.
    (e) The IAG Symposia Series publishes peer-reviewed papers related to presentations made at IAG Symposia and/or IAG Sponsored Symposia, provided that sufficient number of papers are submitted and accepted for publication.
    (f) After each IAG General Assembly, a collection of the reports by the Association components shall be published in the "Travaux de l'Association Internationale de Géodésie". This publication is supplied free of charge to the officers of the Association and to the adhering body of each member country.
    (g) At every IAG General Assembly each member country is encouraged to submit a National Report on geodetic work done since the previous General Assembly to be placed on the IAG website.
    (h) The IAG Newsletter is under the editorial responsibility of the Communication and Outreach Branch. It should be published on the IAG website and distributed to members electronically.
20. **Editor-in-Chief and Editorial Board**
    (a) There shall be one Editor-in-Chief for the Journal of Geodesy, hereinafter referred to as the Journal Editor. An Assistant Editor-in-Chief may assist the Journal Editor. The Journal Editor shall be advised and assisted by an Editorial Board. To ensure broad expertise, each of the Commissions may nominate up to three members of the Editorial Board.
    (b) The Journal Editor shall be responsible for the scientific content of the Journal. The Journal Editor or the Assistant Editor-in-Chief shall make the final decision on whether a refereed scientific manuscript is accepted for publication. The Journal Editor shall keep the IAG Executive Committee informed of the activities and status of operations of the Journal.
    (c) Nine months before each IAG General Assembly, the IAG Secretary General shall establish a search committee for the Journal Editor and the Assistant Editor for the next period. The search committee will include at least the IAG

Secretary General and one member of the Editorial Board. In case that the Journal Editor is not eligible to be re-elected for one further period, he/she will also be a member of the search committee. Three months before the IAG General assembly, the search committee will select the candidate Journal Editor and the candidate Assistant Editor for the next period.

(d) Three months before each IAG General Assembly, the Journal Editor, in consultation with the IAG Bureau, shall recommend a preliminary list of candidates for the new Editorial Board. This list shall be published on the IAG website at least two months in advance of the IAG General Assembly to solicit additional nominations for the Editorial Board from the IAG Components, Members, Fellows, Honorary Offices, and Council.

(e) At the IAG General Assembly, the current Editorial Board in consultation with the candidate Journal Editor and the candidate Assistant Editor shall select the members of the new Editorial Board from those recommended. After taking office, the IAG Executive Committee shall approve the new Journal Editor, the new Assistant Editor, and the Editorial Board for the next period.

(f) The Journal Editor, the Assistant Editor, and the members of the Editorial Board shall each hold office for one period, but are eligible to be re-elected for one further period.

(g) There shall be one Editor-in-Chief for the IAG Symposia Series, hereinafter referred to as the Series Editor. He/she is appointed by the IAG Executive Committee for one period. An assistant Editor-in-Chief may also be appointed.

(h) The Series Editor shall be responsible for the scientific content of the IAG Symposia Series. On the recommendation of the volume editor(s), the Series Editor shall make the final decision on whether a refereed scientific manuscript is accepted for publication. The Series Editor shall keep the IAG Executive Committee informed of the activities and status of the IAG Symposia Series.

(i) Each volume of the IAG Symposia Series may have additional Volume Editors.

21. **IAG Individual Membership**

(a) Individuals engaged in geodesy, can become individual members of the IAG on application and payment of the membership fee.

(b) Applications for individual membership are submitted to the IAG Secretary General.

(c) The decision on the membership application shall be made by the IAG Bureau.

(d) Benefits of membership include:

i. Reduction in the individual subscription rate to the Journal of Geodesy.

ii. The right to participate in the IAG election process both as a nominator and a nominee.

iii. Upon application, correspondent membership in a Sub-commission or Study Group of choice.

iv. Reduction in the registration fee for IAG meetings as set under Bylaws 26(d) and 27(b).

(e) The membership fee per annum is set by the IAG Executive Committee.

(f) In individual cases, the Secretary General may consider a discount or full remission of membership fees on application by the member.

(g) Where a member provides a donation in excess of the membership fee, the excess shall be assigned to the IAG Fund.

(h) Membership is terminated if the membership fee is not paid or if an application for discount or full remission has not been received one year after the fee was due.

22. **Honorary Officers, Fellows**
    (a) The IAG Executive Committee may appoint a merited past IAG President as Honorary President or a merited IAG Secretary General as Honorary Secretary General.
    (b) The IAG Executive Committee may appoint past officers of the IAG as Fellows.
23. **IAG Fund**
    The IAG Executive Committee may establish an IAG Fund for supporting specific IAG activities as defined in the IAG Fund Rules, published in the Geodesist's Handbook. The Fund is under the direct responsibility of the President. The Fund's resources are administered by the Secretary General.
24. **IAG Awards**
    The IAG Executive Committee may establish Awards for outstanding contributions to geodesy and distinguished service to the IAG. The rules for the awards are to be published in "The Geodesist's Handbook".
25. **Administration of the IAG General Assemblies**
    (a) The IAG General Assembly will be held at the same time and at the same place as the International Union of Geodesy and Geophysics (IUGG) General Assembly.
    (b) Before any IAG General Assembly, the IAG Bureau shall prepare detailed agendas for the IAG Council meetings, IAG Executive Committee meetings, and the opening and closing sessions.
    (c) The IAG Executive Committee shall prepare the agenda for the scientific program. Joint Symposia covering topics of interest to two or more IUGG Associations may be arranged.
    (d) The agendas developed according to (b) and (c) above are sent to the member countries and to all officers of the Association so as to reach them at least two months prior to the IAG General Assembly. In principle, only matters on the agenda may be considered during the sessions, unless a decision to do otherwise is passed by a two-thirds majority of the IAG Council.
    (e) At each IAG General Assembly, the IAG President shall present a report on the scientific work of the Association during their tenure. The IAG Secretary General shall present a report on the administrative work and on the finances of the Association for the same period. The President and Secretary General should include in their reports proposals for work to be undertaken during the coming period, within the limits of expected resources. These reports shall be published in "The Geodesist's Handbook".
    (f) At each IAG General Assembly, the work of each Commission, each Intercommission Committee, each Service, the Global Geodetic Observing System, the Communication and Outreach Branch, and each IAG Project shall be reported on by its President or Chair. IAG Representatives to other scientific bodies shall report to the IAG Executive Committee.
26. **Scientific Meetings**
    (a) Scientific meetings of the IAG are:

i. the Scientific Symposia held during an IAG General Assembly;
ii. Scientific Assemblies, including IAG Scientific Symposia; and
iii. IAG Sponsored Symposia.

(b) The IAG Newsletter shall include a calendar of IAG Symposia and other scientific meetings organized or sponsored by the IAG or its components.

(c) The IAG Executive Committee shall appoint an IAG Scientific Meeting Representative for each of the scientific meetings other than the General Assembly and the Scientific Assembly to be governed by these Bylaws. The representative is obliged to remind the organizers to adhere to the Bylaws for scientific meetings and to report back to the IAG Executive Committee.

(d) A reduced registration fee shall be offered for individual members in accordance with Bylaw 21(d) (iv).

27. **IAG Scientific Assemblies**

(a) IAG Scientific Assemblies are held in between two IAG General Assemblies and shall consist of a group of component meetings and/or a group of scientific symposia, held at the same time and place.

(b) A reduced registration fee shall be offered for individual members in accordance with Bylaw 21(d)(iv).

28. **IAG Scientific Symposia**

(a) Scientific symposia take place at the IAG General Assembly and the IAG Scientific Assembly. In general, they shall be organized by IAG components and subcomponents, and be led by their respective Presidents or Chairs.

(b) The study of some questions may require joint meetings of several components under a Chair, appointed by the IAG Executive Committee. A committee consisting of the component Chairs shall decide on the agenda and on the inclusion of scientific presentations.

(c) At each IUGG General Assembly, Joint Scientific Symposia covering topics of interest to two or more Associations within the IUGG and/or other international scientific organizations may be convened. Though the IAG may be asked to act as convenor or co-convenor, these symposia shall follow the rules established by the IUGG. The IAG may participate also in joint symposia at any other time outside of the IAG General Assembly and governed by the same procedures.

(d) The planning of a scientific symposium shall be subject to the usual approval procedure provided by "The Geodesist's Handbook".

29. **IAG Sponsored Symposia**

(a) The IAG may sponsor a symposium covering broad parts of geodesy and having large attendance at any suitable time outside the IAG General Assemblies or IAG Scientific Assemblies, and shall call it an IAG Sponsored Symposium, provided the following conditions are fulfilled:
i. One or more IAG components or subcomponents, or at least two Study Groups, shall sponsor it.
ii. Host organization of the symposium shall accept an IAG representative in the Scientific Organizing Committee (SOC) appointed by the IAG Executive Committee.
iii. The symposium shall be open to all bona-fide scientists in accordance with the International Science Council (ISC) rules.

(b) The SOC appointed under Bylaw 29(a)(ii) shall be responsible for the quality of science of the symposium being at a high level. A Local Organizing Committee (LOC) shall be responsible for the organization and logistics.
(c) Applications for approval of an IAG Symposium should be submitted to the Secretary General at least one year before the intended date of the meeting.

30. **International Cooperation**
(a) The IAG may participate in joint bodies of the IUGG and other scientific organizations, especially those belonging to the ISC.
(b) The IAG shall initiate international cooperation in scientific work of international and interdisciplinary character. This includes the adequate participation in international programs and projects and the representation at scientific congresses, symposia, etc., of organizations with related activities.
(c) Representatives to international programs and projects shall be appointed by the IAG Executive Committee and shall inform the IAG Executive Committee on the activities, on a biannual basis. The representatives shall also prepare a report for presentation at the IAG General Assembly.
(d) The IAG Components shall have close cooperation with inter-governmental organizations responsible for services and scientific products of particular interest to the Association (e.g. BIPM, ISO, UNOOSA/ ICG, UN-GGIM).

31. **Responsibilities of the IAG Council**
(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the IAG Council shall:
i. Examine questions of general scientific policy or administration, and propose actions deemed necessary.
ii. Elect the voting members of the IAG Executive Committee, with the exception of the GGOS President (Bylaw 15(d)) and the ICC Presidents, (Bylaw 12(b)(i)).
iii. Receive reports from the Secretary General and consider for approval the decisions or actions taken by the IAG Bureau and the IAG Executive Committee since the last IAG Council meeting.
iv. Establish and dissolve IAG components.
v. Appoint the three members of the ad hoc (audit) committee created for examining the finances of the IAG, consider its recommendations and adopt the final budget.
vi. Consider proposals for changes in the IAG Statutes and Bylaws.
vii. Decide on the venue of the next IAG Scientific Assembly.
viii. Approve the establishment of Inter-commission Committees & IAG Projects.
(b) IAG Council meetings shall be convened by the IAG President, and shall meet at least once during each IAG General Assembly. The IAG Council may be convened at other times, normally coinciding with the IAG Scientific Assembly. If circumstances do not allow an in person meeting of the Council, a virtual meeting is also possible.

32. **Responsibilities of the IAG Executive Committee**
(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the IAG Executive Committee shall:
i. Initiate actions and issue guidelines, as required, to guide the IAG towards the achievement of its scientific objectives.

ii. Fill vacancies occurring between IAG General Assemblies, in accordance with the Statutes and Bylaws.
iii. Approve the internal structure of IAG components.
iv. Make recommendations to the IAG Council on matters of general policy of the IAG and on the implementation of its objectives.
v. Appoint Honorary Officers and Fellows of the IAG, upon the recommendation of the IAG Bureau.
vi. Appoint planning groups for Inter-commission Committees and IAG Projects.
vii. Establish Inter-commission Committees and IAG Projects.
viii. Appoint a Committee, known as the Cassinis Committee, for reviewing and updating the IAG Statutes and Bylaws when deemed necessary.
ix. Confirm the Assistant Secretaries (if any) of the IAG.
x. Confirm the links between Commissions and Services.
xi. Approve the level of the membership fee.
xii. Appoint the Vice President of each Commission, the President of GGOS, and the President of each ICC.
xiii. Appoint representatives to external bodies.

(b) IAG Executive Committee meetings shall be convened by the IAG President. It shall meet at IAG General Assemblies and its members are expected to attend the meetings of the IAG Council, with voice but without vote. It shall also meet normally at least once a year, especially one year before the IAG General Assembly, in order to prepare the scientific agenda and timetable of the next IAG General Assembly. IAG Executive Committee meetings can be held in person or virtually.

(c) At a meeting of the IAG Executive Committee, no member may be represented by any other person, except by the corresponding Vice Presidents or Vice Chairs of the IAG components represented in the Executive Committee. In order that the deliberations of the IAG Executive Committee shall be valid, a quorum of at least half of its members must be present or represented.

(d) The agenda for each meeting of the IAG Executive Committee shall be prepared by the IAG Bureau and sent to the members at least two months prior to the meeting.

33. **Responsibilities of the IAG Bureau**

(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the IAG Bureau shall:

i. Draw up the agenda of the meetings of the IAG Council and IAG Executive Committee and send these to the members at least two months prior to the meeting.
ii. Ensure the adequate administration of the IAG.
iii. Receive applications for individual memberships and accept individuals as members of the IAG.
iv. Recommend Honorary Officers and Fellows to the IAG Executive Committee.

(b) The IAG Bureau shall normally meet before each meeting of the IAG Executive Committee.

34. **Responsibilities of the President**
In addition to any other functions, powers and duties provided in other IAG Statutes and Bylaws, the IAG President shall:
(a) Provide general leadership for the IAG in all matters.
(b) Convene and preside over the IAG General Assembly and over all meetings of the IAG Council, IAG Executive Committee and IAG Bureau.
(c) Represent the IAG in IUGG meetings and forums.
(d) Represent the IAG in its dealing with national or international organizations or institutions.
(e) Submit a report to the IAG General Assembly on the scientific work of the IAG during their tenure.

35. **Responsibilities of the Vice President**
In addition to any other functions, powers and duties provided in other IAG Statutes and Bylaws, the IAG Vice President shall act on behalf of the IAG President whenever the IAG President is not present or is unable to perform any of the President's duties, and shall perform such tasks as may be assigned by the IAG President, the IAG Executive Committee or the IAG Council.

36. **Responsibilities of the Secretary General**
In addition to any other functions, powers and duties provided in other IAG Statutes and Bylaws, the IAG Secretary General shall:
(a) Serve as secretary of the IAG General Assembly, the IAG Scientific Assembly, the IAG Council, the IAG Executive Committee and the IAG Bureau; and arrange for meetings of these bodies, distribute promptly the agenda and prepare and distribute the minutes of all their meetings.
(b) Act as Director of the IAG Office.
(c) Manage the affairs of the IAG, including finances as per Bylaw 42(b), attend to correspondence, and preserve the records of the IAG.
(d) Circulate all appropriate information related to the IAG.
(e) Prepare the reports of the IAG's activities.
(f) Coordinate with the COB.
(g) Perform such other duties as may be assigned by the IAG Bureau.
(h) The function of the Secretary General is unpaid and only expenses incurred in connection with the functions and duties may be reimbursed.

37. **Assistant Secretaries**
(a) The IAG Secretary General may be assisted by one or more Assistant Secretaries.
(b) The position(s) of Assistant Secretary is unpaid and only expenses incurred in connection with the functions and duties may be reimbursed.

38. **IAG Office**
To assist the IAG Secretary General, the IAG establishes the IAG Office in the country in which the Secretary General resides. The IAG Executive Committee negotiates logistical and financial support with the host country or institution.

39. **Procedure for Nomination and Election of IAG Officers**
(a) Elections shall take place by electronic voting before each IAG General Assembly and should be completed at least two months before the assembly.

(b) The IAG President, after taking advice from the IAG Executive Committee, shall appoint a Nominating Committee consisting of a Chair and three other members.

(c) The Nominating Committee, after taking advice from the Council Delegates, the Officers, Fellows, and Individual members of the IAG, shall normally propose at least two candidates for each position to be filled by election of the IAG Council. Candidates shall be asked to signify their acceptance of nomination and to prepare a short resume, outlining their position, research interests and activities relating to the IAG.

(d) The Council Delegates, Officers, Fellows and Individual members of the IAG shall be informed of these nominations at least four months before the IAG General Assembly.

(e) During the following month further nominations can be submitted by the Council Delegates. Such additional nominations shall be in writing, shall be supported by at least two Council Delegates, and shall be submitted with resumes to the Chair of the Nominating Committee.

(f) Nominations shall be checked against the eligibility criteria in Bylaw 40 by the Nominating Committee. Ineligible nominations will not be accepted and the members of the IAG Council who supported the nomination will be advised of the reason for its rejection.

(g) Delegates shall be informed of these further eligible nominations and resumes and of their supporters.

(h) The Chair of the Nominating Committee shall write to all Services asking them for nominations from each Service for the Service representatives on the IAG Executive Committee. The Nominating Committee shall recommend a minimum of two nominees for each of the Services' three positions, considering appropriate scientific and geographic distribution. The procedure for seeking additional nominations in subclause (e) above does not apply to these positions.

(i) If candidates have been nominated for more than one position, they will be asked prior to the election to make a decision for which position they will allow their name to stand.

(j) Elections shall be by electronic ballot. The winner must receive an outright majority (number of votes being greater than the total combined votes of the other candidates). If there are three or more candidates for a position and no candidate has an outright majority, then the top two ranked candidates will be retained and a second round of votes conducted to elect the winner. Ties will be broken by the IAG President's vote.

(k) The Members-at-Large shall be elected in a subsequent round after the other members of the IAG Executive Committee have been elected, in order to fulfil the condition of geographical, gender and organizational balance (see Statute 12a).

40. **Eligibility & Terms of Office**

(a) No person may hold more than one of the following offices at the same time: IAG President, Vice President, Secretary General, IAG immediate Past President, President of a Commission, President of an Inter-commission Commit-

tee, Chair of a Service, President of GGOS, President of the COB, Executive Committee Member-at-Large, or Chair of an IAG Project.

(b) A member of the IUGG Bureau or of the IUGG Finance Committee may not occupy the post of President, Vice President or Secretary General of the IAG.

(c) The IAG President is elected for one period and may not be immediately re-elected to the same office.

(d) The Vice President is elected for one period and may not be re-elected to the same office.

(e) The Secretary General is elected for one period initially. He/she may be re-elected for up to two additional periods.

41. **Extraordinary Vacancies**

(a) Should the position of IAG President become vacant during the period between two IAG General Assemblies, their duties and responsibilities devolve to the Vice President until the closure of the next IAG General Assembly.

(b) Should the post of Secretary General become vacant, the IAG President shall arrange without delay for the IAG Executive Committee to propose a replacement and for the IAG Council to appoint a new Secretary General so as to ensure the continuity of the work of the IAG Office. This appointment has effect until the closure of the next IAG General Assembly and shall not be counted in the restriction of eligibility for re-election of the Secretary General under Bylaw 40(e).

42. **Finances**

(a) The Finances of the IAG derive from the following sources:

i. Contributions of IUGG Adhering Bodies of which a portion, determined by the IUGG Council on recommendation of its Finance Committee, is paid to the IAG by the IUGG Treasurer.

ii. Sale of publications.

iii. IAG Fund collected from individual contributions for specific purposes.

iv. Membership fees.

v. A portion of the registration fee charged at IAG symposia.

vi. Other sources, e.g. grants, interests, and funds remaining after a symposium.

(b) The Secretary General is responsible to the IAG Bureau and to the IAG Council for managing the funds in accordance with the Statutes and Bylaws. The Secretary General alone shall be responsible for the day-to-day financial operations of the IAG.

(c) At each IAG General Assembly the budget proposal for the next period shall be presented by the Secretary General and submitted for approval to the IAG Council. The budget as approved by the IAG Council shall be implemented by the Secretary General.

(d) During each IAG General Assembly, the IAG Council shall examine all expenditures during the preceding period to ensure that they were in accordance with the approved budget. This examination shall be carried out by an ad hoc (audit) committee appointed by the IAG Council; see also Bylaw 31(a)(v).

(e) In addition, the accounts shall be audited and shall then be reported to the IUGG Treasurer, as prescribed in Article 20 of the IUGG Bylaws.

IAG Rules

1 Definition of an Early Career Scientist (ECS)

IAG has adopted the IUGG definition of an Early Career Scientist (ECS): An ECS is a student, a PhD candidate, or a practising scientist who received their highest academic degree within the past 10 years. This period can be extended because of career interruptions.

2 Rules for IAG Scientific Meetings

1. IAG scientific meetings are organized by IAG components (Commissions, Intercommission Committees, Services, IAG Projects and the Global Geodetic Observing System) or IAG sub-components (Sub-commissions, Commission Projects, Study Groups, Working Groups). They may take place:
   a) during IAG General Assemblies, held in conjunction with the IUGG General Assemblies,
   b) during IAG Scientific Assemblies, held in-between successive General Assemblies, or
   c) at any time and place apart from the General or Scientific Assemblies.
2. During the General or Scientific Assemblies symposia and other meetings are in general organized by IAG components or sub-components. For specific topics there may be joint symposia of several components or sub-components under a convener appointed by the IAG Executive Committee. The inclusion of scientific papers for presentation at a General or Scientific Assembly is decided by a Scientific Committee established by the IAG Executive Committee.
3. At General Assemblies joint symposia covering topics of two or more Associations within the IUGG and/or other international scientific organizations may be organized. Though the IAG may act as convener or co-convener, these symposia follow the IUGG rules.
4. The IAG may also participate in joint symposia with other Associations at any other time outside the General Assemblies, following the same procedures.
5. The IAG may sponsor symposia covering appropriate topics of Geodesy at any time outside the General or Scientific Assemblies. It shall be called "IAG sponsored Symposium" if the following conditions are fulfilled:
   - The symposium has to be organized by at least one component or two subcomponents of the IAG.
   - The host organization of the symposium must accept a representative in the Scientific Organizing Committee appointed by the IAG Executive Committee.
   - The symposium must be open to all bonafide scientists in accordance with the ICSU rules.
   - The proceedings of the symposium shall be published.

- For symposia other than those during General or Scientific Assemblies, a fixed amount must be included in the registration fee for the publication costs of the proceedings.
- If there is a registration fee, it must be reduced for IAG members by at least 10%.
- Immediately after the end of the Symposium the chairperson of the Scientific Committee shall prepare a summary to be published in the IAG Newsletter.

6. Applications for approval to be designated as "IAG Symposium" should be submitted to the Secretary General of the IAG at least twelve months before the proposed date of the Symposium. The following information must be provided in the application for approval:
   a) Title
   b) Date and duration
   c) Location
   d) Sponsoring IAG (sub-)components
   e) Other co-sponsoring scientific organizations with letters enclosed
   f) Suggested composition of the Scientific Organizing Committee
   g) Local Organizing Committee, host organization, contact name and address, etc.
   h) Estimated number of participants
   i) Financial support expected from sources other than the IAG
   j) Names of proposed editors of the proceedings
   k) Draft scientific program
   l) A detailed account of why the proposed symposium is useful and necessary at the time proposed, and its relationship with other meetings.
7. Guidelines for the organization of the symposium:
   (a) The Scientific Organizing Committee is responsible for ensuring a high standard of scientific value of the symposium. The Chair of the Committee:
      - invites participants after the symposium is approved by the IAG Executive Committee,
      - invites contributions and sets a deadline for submissions of abstracts, and
      - informs the IAG Secretary General of all important matters pertaining to the symposium.

   (b) The Local Organizing Committee is responsible for the smooth running of the symposium. It does not receive financial assistance from the IAG, with all the necessary expenses being met by local funds or by contributions from the participants. The requirements for local organizations are generally as follows:
      - providing meeting rooms suitable for the expected number of participants
      - providing the facilities for oral and visual presentations
      - provide adequate space and logistical support for poster sessions (if any)
      - reproduction of participants' documents (if necessary)
      - organize publication of proceedings or production of electronic version
      - sufficient secretarial and technical assistance
      - undertake full responsibility for registration of participants, maintaining a web page, printing of brochures and programmes, etc.
      - collect at registration and make available to IAG the following data from the participants:

a) country of affiliation,
b) gender (male/female/non-binary/other),
c) year of most recent university degree (master or PhD) i.e. information on participant's ECS status,

- information on accommodation (hostels, hotels, etc...), sent to the IAG Executive Committee for acceptance, and to prospective participants
- organizing receptions and excursions during free periods within the meeting, or just before or after the meeting.

8. The IAG Executive Committee shall recognize scientific meetings other than symposia (workshops, schools etc.) organized by IAG (sub-)components alone or jointly with other international and national groups and bodies, at any time outside the General Assemblies, if they have been approved by the Executive Committee. The Meeting may be announced as "International Meeting, organized by the (sub-)component..... of IAG". It is not permitted to use the term "IAG Symposium".
9. The IAG may recognize scientific meetings, organized by national bodies as important scientific events with benefit for the international geodetic community, and sponsor them if the meeting is open to all scientists according to the ISC Rules, if it will be sponsored by at least one IAG (sub-)component, and if the organizer undertakes to maintain the expected standard for IAG Symposia.
   These Meetings may be announced as "International Meeting, organized by ....., sponsored by IAG". It is not permitted to use the term "IAG Symposium". Sponsorship by the IAG means only official recognition and does not imply financial support by the IAG. The IAG may appoint an official representative to that meeting. The IAG expects that, if proceedings are published, they will be prepared by the local organizers and published within 6-8 months after the end of the meeting. Applications for sponsorship should be submitted to the IAG Secretary General not later than 12 months before the intended date of the meeting.
10. In its decision whether to approve and/or sponsor a scientific meeting, the IAG Executive Committee takes into account the need for a balanced selection of meetings, a representative coverage of subjects, and a good geographical distribution. The IAG wishes to avoid duplication of symposia or meetings, and to discourage those with overlapping themes that are held too frequently. The IAG Secretary General shall publish a calendar of IAG Symposia and other scientific meetings organized or sponsored by IAG components or sub-components in the IAG Newsletter, in the Journal of Geodesy, and on the IAG Website.

3 Rules for the IAG Levallois Medal

Purpose

The Levallois Medal was established by the International Association of Geodesy in 1979 to honour Jean-Jacques Levallois, and to recognize his outstanding contribution to the IAG, particularly his long service as Secretary General, 1960-1975. The award of the Medal will be made in recognition of distinguished service to the Association, and/or to the science of geodesy in general. The Medal is normally awarded at four year intervals, on the occasion of the General Assemblies of the IAG and IUGG; but

the award may be omitted if it is considered that there is no candidature of sufficient merit, and an additional award may be given at any time, if justified by exceptional circumstances.

Nomination and selection

A nomination for the award shall be made by an ad hoc committee consisting of the Honorary Presidents and must be confirmed by the IAG Executive Committee. The ad hoc committee shall prepare a citation, suitable for publication, setting out the grounds for the proposed award before the General Assembly.

4 Rules for the IAG Guy Bomford Prize

Purpose

The Guy Bomford Prize is awarded by the IAG for outstanding contribution to Geodesy. It was established by the British National Com-mittee for Geodesy and Geophysics to mark the contributions to geodesy of Brigadier G. Bomford, formerly of the University of Oxford and a Past President of the International Association of Geodesy. It has been inaugurated by the IAG in 1975. The Prize is normally awarded at intervals of four years on the occasion of the General Assembly of the IAG held concurrently with the General Assembly of the IUGG. The following rules for the award of the Guy Bomford Prize may be altered by the IAG Executive Committee if a majority of its voting members sees a necessity to do so.

Eligibility

The Guy Bomford Prize is awarded to a young scientist or to a team of young scientists for outstanding theoretical or applied contributions to geodetic studies particularly in the four year period preceding the General Assembly at which the award is given. Eligible are scientists who are under 40 years of age on December, 31, of the year preceding the Assembly at which the award is given.

Nominations

Nominations will be invited by the IAG Bureau from all National Committees of IUGG member countries at least one year ahead of the General Assembly. Each committee can make one nomination, not necessarily from its own country. The deadline for nominations will normally be six months before the next General Assembly and will be explicitly stated in the letter of invitation. Nominations must be accompanied by:

- The full name, address, age, academic and/or professional qualifications and position of the candidates and the name of the National Committee making the nomination.
- An outline of the reasons for the nomination including a general summary of the career and scientific achievements of the candidate.

- A review of recent achievements of the candidates which would merit the award, including references to key papers, published, alone or jointly, during the preceding four-year period.
- A curriculum vitae, publication list, and copies of up to two key papers to justify the candidature.
- The name and address of two referees who can be consulted.

Selection procedure

A selection committee will consist of the presidents of the IAG commissions and two other members to be appointed by the IAG Bureau. Based on the material submitted by the National Committees, each member of the selection committee will rank the nominations and select the candidate to be awarded the Guy Bomford prize. The decision (not the detailed ranking) will be communicated to all National Committees and to the selected candidate. The prize may be withheld if, in the opinion of the selection committee, there are no sufficiently qualified candidates available.

Presentation of the award

The Prize consists of a certificate and a cheque of 2500 Euros. The Prize shall be presented to the successful candidate at the opening Plenary Session of the IAG Assembly. He or she shall be invited to deliver a lecture during the course of the IAG Assembly.

5 Rules for the IAG Young Authors Award

Purpose

The award is to draw attention to important contributions by young scientists in the Journal of Geodesy and to foster excellence in scientific writing.

Eligibility

When submitting the paper for the competition, the applicant must be up to 35 years of age or an Early Career Scientist (ECS) (i.e. having received the highest academic degree within the past 10 years, with possible extension due to career interruptions). The paper must present his or her own research, and must have been published in the two annual volumes of the Journal of Geodesy preceding either the IAG General Assembly or the Scientific Assembly. Although multiple author papers will be considered, single author papers will be given more weight in the selection process.

Award

The award consists of a certificate and a cheque of 1000 Euros. Presentation of the awards will be made at each IAG General Assembly and each Scientific Assembly. Up

to two awards will be presented on each occasion for the two-year period corresponding to the annual volumes specified above.

Nominations and selection procedure

For each two-year period the Editor-in-Chief of the Journal of Geodesy will propose a minimum of three candidates for the award. In addition, proposals made by at least three IAG Fellows will be considered for the competition. Each year the conditions for the award will be announced in the Journal of Geodesy. Nominations should be sent to the Secretary General of the IAG, giving name, address, and age of the author (at date of submission), the title of the paper on which nomination is based, and a brief justification. Nominations must be received by March 1 of the year in which either an IAG General Assembly or an IAG Scientific Assembly takes place. The voting members of the IAG Executive Committee will make the final selection. It will be based on the importance of the scientific contribution, which may be either theoretical or practical, and on the quality of the presentation. The name and picture of the award winner and a short biography will be published in Journal of Geodesy.

6 Rules for the IAG Best Reviewer Award

Purpose

The award is to officially recognize the important work of excellent reviewing for the Journal of Geodesy in the advancement of geodetic science.

Eligibility

The awardees are selected from the reviewers for the Journal of Geodesy in the preceding two years corresponding to two annual volumes of the Journal. Up to two best reviewers will be presented with the IAG Best Reviewer Award.

Award

The award consists of a certificate and a cheque of 1000 Euros. It will be presented either at IAG General Assembly or IAG Scientific Assembly.

Nominations and selection procedure

For each two-year period, the Editor-in-Chief of the Journal of Geodesy calls for nominations by the Editorial Board members and proposes three top candidates for the award to the IAG Executive Committee (EC). Nominations should address and appraise professionalism, fairness, constructiveness, thoroughness, timeliness, realism, and conclusiveness in the candidates‘ work as a reviewer for the Journal of Geodesy. The IAG EC will make the final decision on the award. The names and pictures of the award winners with a short biography will be published in the Journal of Geodesy. The Journal Editorial Board members are not qualified to be nominated for the award.

7 Rules for the IAG Travel Awards

Purpose

The award is established to assist young scientists from IAG member countries to present results of their research at IAG meetings (assemblies, symposia, workshops, etc.).

Eligibility

The applicant must present results of his or her research at the meeting. At the date of the application, the applicant must be up to 35 years of age or an Early Career Scientist (ECS) (i.e. having received the highest academic degree within the past 10 years, with possible extension due to career interruptions). The application must be supported by at least one IAG Fellow.

Types of awards

There are two awards, one for meetings in the applicant's own country, and the other for meetings outside the applicant's country. The first is called IAG National Travel Award and has a maximum financial value of 750 Euros. The second is called IAG International Travel Award and has a maximum financial support of 1500 Euros. The amounts can be occasionally adjusted by the IAG Executive Committee. It was last adjusted in 2023.

Additional benefits

The IAG encourages the organizers of the meetings to waive the registration fees for all IAG Travel Award winners.

Application procedure

Applicants shall send their application at least three months before the meeting to the IAG Secretary General, IAG-Office@bkg.bund.de. The application must contain:

- Full name of the applicant, address and e-mail address
- Institution and degree/position of the applicant (e.g. University XX, PhD Student)
- Date of birth
- Proof of ECS status of the applicant (if applicable)
- IAG meeting name, city, country, date
- Title, authors, and abstract of the paper to be presented
- letter of acceptance of the presentation by the organising committee (if available, otherwise it has to be submitted as soon as available)
- Travel budget and sources of additional funding
- Name(s) of supporting person(s); the letter(s) of support from at least one IAG Fellow should be sent separately by the supporter(s).

By sending the application, the applicant agrees that his/her data are stored internally in the IAG records. Data are used only for award-related purposes.

Selection procedure and criteria

Selection of applicants and the amount granted will be done by the IAG Bureau. It will be based on the paper to be presented, the letter(s) of support, and the applicant's ability to actually attend the meeting. Priority will be given to candidates from low and mid economy countries. IAG Secretary General will agree with the winners upon the details of the payment. Normally, it cannot be paid before the meeting.

IAG Fund and IAG Membership

IAG Fund

The fund was established by the IAG Executive Committee at its meeting in Columbus, Ohio, 1992 (see Bulletin Géodésique, Vol. 68, pp. 41-42, 1994). The IAG Fund aims at supporting specific IAG activities. Its primary goals are:

- to provide travel support for young scientists to attend IAG Symposia and workshops,
- to assist in the organisation of IAG workshops in developing countries, and
- to provide an annual IAG Best Publication Award for young scientists.

Contributors are divided in 3 groups:

- Presidents Club (cumulative contributions $\geq$ USD 1000 or equivalent in EUR).
- Special contributors (annual contributions USD 100 ... 1000 or equivalent in EUR).
- Contributors (annual contributions $<$ USD 100 or equivalent in EUR).

How to donate:

- In connection of the membership fee: In the membership application form on the IAG Website (www.iag-aig.org/doc/IAG_Membership_Application_Form.pdf), there is a specific place for donations.
- Donations paid separately: Please, contact the IAG Secretary General for payment instructions.
- The donation can be of any amount. Please, notify the IAG Secretary General in advance for donations higher than USD 100 (or equivalent in EUR).

IAG Membership

Individuals engaged in geodesy can become individual members of the IAG upon application and payment of the membership fee. Applications for individual membership are submitted to the IAG Secretary General. The application form is available on the IAG Website: www.iag-aig.org/doc/IAG_Membership_Application_Form.pdf.

The payment can be for one calendar year or four years. To minimize possible transfer fees, several membership fees can be paid at the same time. In that case, the list of names/addresses shall be sent separately to the Secretary General. The payment can be made by bank transfer or with a credit card, as indicated in the invoice from the IAG Secretary General. After the payment, the membership certificate and receipt of the payment will be sent by e-mail to the member(s).

Benefits of the membership include:

- Reduction in the individual subscription rate to the Journal of Geodesy.
- The right to participate in the IAG election process both as a nominator and a nominee.
- Upon application, correspondent membership in a Sub-commission or Working Group or Study Group of choice.
- Reduction in the registration fee for IAG meetings.

The membership fee per annum is set by the IAG Executive Committee. In individual cases, the Secretary General may consider a discount or full remission of membership fees upon application by the member. There are two specific cases mentioned on the membership fee form:

- *Student member*: Students in Universities/Colleges will have annual free membership of IAG. They must submit University/College certificate separately every year to the IAG Secretary General to get the benefit.
- *Retired member*: Retired people shall send a request to the Secretary General for getting the exemption.

Task Force on Inclusion

https://doi.org/10.82507/iag-gh2024_tfi

Chair: Rebekka Steffen (Sweden)

1 Charter

The IAG Task Force on Inclusion was created by the IAG Executive Committee at its meeting on July 20, 2023, in order to explore different ways and means of making the IAG more inclusive. Among the areas to be addressed by the Task Force are:

- Gender balance
- Geographic balance
- Generational balance

This is not an exhaustive list and the Task Force should explore other areas of the IAG that need to be made more inclusive as appropriate. The Task Force should recommend actions that the IAG could take in order to achieve the goal of making the IAG more inclusive. In order for the current IAG Executive Committee to be able to respond to its recommendations, the Task Force is asked to complete its deliberations by July 2025.

Like the other components of the IAG, the Task Force is requested to report on its activities at IAG Executive Committee meetings.

2 Members

The following members of the IAG Executive Committee are part of the IAG Task Force on Inclusion (given in alphabetical order):

Srinivas Bettadpur (USA)
Mattia Crespi (Italy)
Annette Eicker (Germany)
Masato Furuya (Japan)
Maria Virginia Mackern (Argentina)
Rebekka Steffen (Sweden); Chair
Szabolcs Rozsa (Hungary)
Peter Teunissen (Netherlands)
Daniela Thaller (Germany)
Paweł Wielgosz (Poland)

3 Planned activities

The Task Force is expected to meet frequently to provide recommendations to the IAG Executive Committee so as to increase the diversity within IAG. The following activities are planned:

- Collecting statistics on the previous structure of IAG components in terms of gender and geographical background (see Section 3.2);
- Encouraging Chairs and presidents of IAG components to nominate an Early Career Scientist (ECS) representative (see Section 3.1) as a separate position in their steering committee (as a non-voting member for the term 2023 - 2027);
- Establishing an ECS group within IAG (see Section 3.1);
- Increasing the visibility of ECS within IAG by working towards official voting positions of ECS representatives in the IAG Executive Committee as well as within the steering committees of all IAG components;
- Cooperating with the ECS groups of the European Geosciences Union (EGU) and the American Geophysical Union (AGU);
- Providing recommendations for the organisation of IAG sponsored symposia and meetings;
- Working closely with the International Federation of Surveyors (FIG), in particular with the Young Surveyors Network and the FIG Task Force on Diversity and Inclusion;
- Motivating Chairs and presidents of IAG components to organize symposia/meetings/workshops/schools in Asia, Africa or Latin America at least once per four-year term;
- Suggesting equality-friendly (i. e., color-blind friendly) guidelines for the IAG publications "Journal of Geodesy" and "IAG Symposia Series";
- Providing suggestions to increase the number of individual IAG memberships;
- Incorporating ideas and recommendations from colleagues and IAG members.

3.1 IAG ECS group

IAG has adopted the IUGG definition of an Early Career Scientist (ECS): *An ECS is a student, a PhD candidate, or a practising scientist who received their highest academic degree within the past 10 years. This period can be extended because of career interruptions.*

As a first step of the new Task Force, the Chairs and presidents of the IAG components were encouraged to nominate an ECS representative to their steering committee (as a non-voting member for the term 2023-2027). The nominated ECS representatives form the newly established ECS group, which is organised by Rebekka Steffen (Sweden). The goal is to increase the visibility and engagement of ECS within IAG. The ECS representative should organise, together with ECS representatives of other IAG components, events for ECSs at IUGG and/or IAG sponsored meetings, foster international exchange between IAG ECSs, engage ECSs to become active within IAG, increase the visibility of IAG activities for ECSs, and make sure that ECSs are well represented in, for example, sub-commissions, working groups and study groups. Suggestions and ideas of the IAG ECS group will be forwarded to the Task Force as well

as to the IAG Executive Committee via the spokesperson Rebekka Steffen. Below is a list of the IAG ECS group for the term 2023-2027.

Members of the IAG ECS group

Anna Kłos (Poland); Commission 1
Athina Peidou (USA); Commission 2
Anna Riddell (Australia); Commission 3
Artur Fischer (Poland); Commission 4
Julia Koch (Switzerland); GGOS
Michela Ravanelli (Italy); ICCT
Pierre Sakic (France); ICCM
Franck Ghomsi (South Africa); ICCC
Öykü Koç (Italy); QuGe
Rebekka Steffen (Sweden); spokesperson

3.2 Statistics

Statistics regarding the geographical location and gender of researchers in the IAG Executive Committee (EC), as well as in the four IAG Commissions, were collected. The collection of statistics on gender is only approximate because exact numbers do not exist and differentiation was done solely based on first names. Therefore, the values may be slightly lower or higher. In the future, the gender statistics will be collected directly for each year and IAG Commission presidents are asked to forward the number of men, women, non-binary, and/or other to the IAG office of the Secretary General. Statistics on ECS could not been made, as no information about the career stage for the members of the IAG EC and/or the IAG Commissions is available. The IAG EC primarily comprises researchers from Europe, with a decrease in the number of researchers from North America and an increase from Asia during the last three IAG terms (Fig. 1). Researchers from Africa were not represented in the IAG EC during the last term (2019 - 2023), and only one member represented Africa in the past terms (2011 - 2015 and 2015 - 2019). The number of researchers identified as women is very small (less than 15 %) for all terms. Both the number of non-male scientists and the number of researchers from African, Latin American and Oceanic regions need to be increased in the upcoming terms, while decreasing the percentage of European researchers in the IAG EC.

A large portion of European researchers is visible in the statistics for the four IAG Commissions for the last term 2019 - 2023 (Fig. 2). Only IAG Commissions 1 and 2 were able to include researchers from Africa in their steering committees, thanks to their regional sub-commissions. However, the percentage of researchers identified as women in their steering committee is very low. A higher percentage of researchers identified as women is found for IAG Commissions 3 and 4. IAG Commission 3 works jointly with other IUGG associations (e. g., IACS, IAVCEI), that have a higher number of active researchers who can be identified as women. The higher percentage of non-male researchers as well as membes from Oceania in IAG Commission 4 can be explained by having had a female Commission president (Allison Kealy) from Australia in the last term.

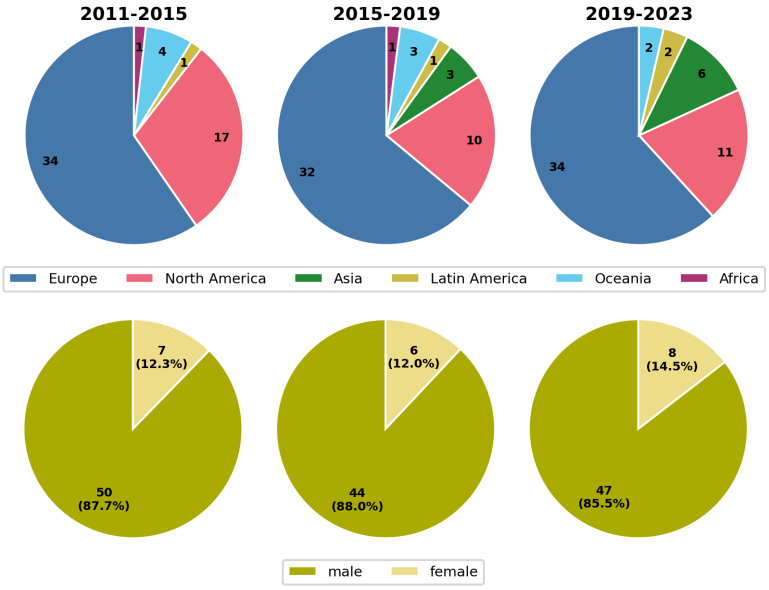

Fig. 1. Pie chart showing the distribution of scientists within the IAG Executive committee for the last three IAG terms (2011 - 2015, 2015 - 2019, 2019 - 2023) in terms of geographic location (top row) and gender (bottom row). Division in male and female genders was based solely on first names and may not be completely accurate.

The number of IAG-affiliated researchers attending IUGG General Assemblies reflects the location of the meeting (Fig. 3). Again, only the number of female versus male and the geographical location was considered here, as the career stage has not been requested from the registered participants. In addition, gender requests were not made for all categories, so we divided researchers only into female and male groups. However, upcoming IAG-related meetings are requested to ask at registration for male, female, non-binary, and/or other genders. While a large number of North American scientists attended the meeting in Montreal (Canada) in 2019, the number of Europeans was much higher in Berlin (Germany) in 2023. In general, there is a good representation of attendees from Asia, which is not reflected in the convener roles, where mainly Europeans and North Americans dominate. The number of African scientists increased when the meeting was closer to Africa. The location of both IUGGs inhibited researchers from Latin America from attending. Most of the IAG-affiliated conveners at the IUGGs in 2019 and 2023 were male, but there is an observable increase of conveners identified as women, which aligns with the rise of female researchers in the IAG Commissions (in particular Commissions 3 and 4).

To summarize, the representation of researchers being involved in IAG, as well as attending IAG-related meetings, is very low when the researchers are located in the southern hemisphere and/or are non-male.

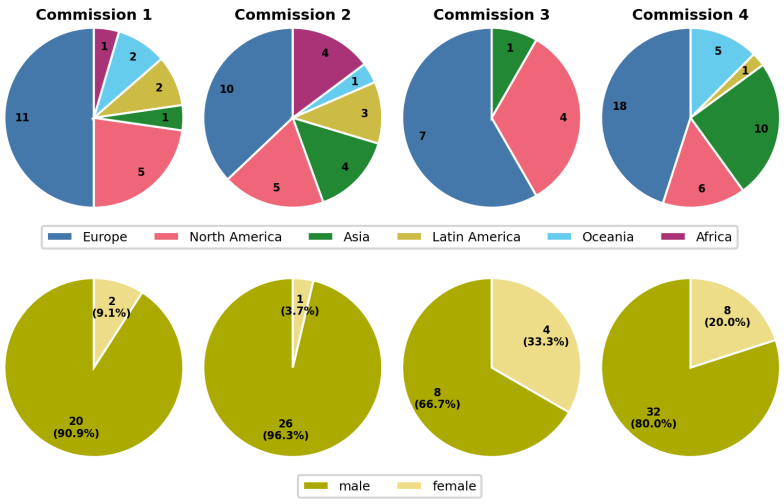

Fig. 2. Pie chart showing the distribution of scientists within the steering committees of the four IAG Commissions in 2019 - 2023 in terms of geographic location (top row) and gender (bottom row). Division in male and female was based solely on first names and may not be completely accurate.

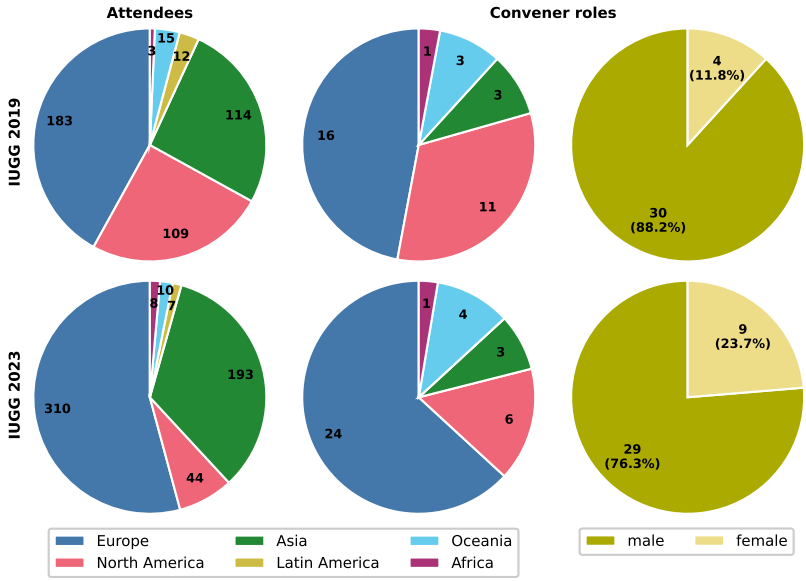

Fig. 3. Pie chart showing the distribution of IAG scientists who attended the IUGG General Assemblies 2019 (in Montreal, Canada; top row) and 2023 (in Berlin, Germany; bottom row) based on their geographic location (left column) as well as the distribution of IAG conveners based on their geographic location (middle column) and gender (right column). Division in male and female participants and conveners is based solely on first names from the IUGG registration databases and may not be completely accurate.

Part II

The XXVIII IUGG General Assembly

IAG Presidential Address at the XXVIII IUGG General Assembly, Berlin, Germany, July 2023

Zuheir Altamimi

Dear Colleagues and Friends,

It is my great pleasure to welcome you all to the opening of the International Association of Geodesy General Assembly, at the occasion of the IUGG General Assembly in Berlin, Germany, 2023.

As an outgoing IAG President, it was a great honour for me to preside the IAG Executive Committee during the past four years, and an enjoyable period of time serving our association. Despite the COVID-19 situation, the IAG EC has achieved a number of developments during the past quadrennial 2019-2023 thanks to the work of IAG Commissions, Services and various other components. The main highlights during the past quadrennial 2019-2023 follow.

Monthly IAG Bureau meetings to discuss and decide upon urgent IAG activities, and to prepare the agendas of the EC meetings. My gratitude to Richard Gross (as Vice President) and Markku Poutanen (as Secretary General) for their valuable contribution to the monthly meetings. It was a great pleasure for me working with you, Richard and Markku.

IAG EC meetings: 10 EC meetings took place in total, 5 of them were conducted virtually, due to the COVID-19 period. Fig. 1 immortalizes the 4th EC virtual meeting held on March 23 & 26, 2021.

IAG Scientific Assembly 2021 (Geodesy for a Sustainable Earth), was organized by the Chinese Society for Geodesy, Photogrammetry and Cartography and took place virtually (with some in-person attendees in Beijing) from June 28 to July 2, 2021. Despite the pandemic situation and unpredictable times, we were proud to see a very high number of participants, more than 1000, a first-time record in the history of the scientific assemblies of our association. The IAG SA was also sponsored by the Chinese Ministry of Natural Resources.

Commission 1 - Reference Frames: Convening the Reference Frames for Applications in Geosciences (REFAG) Symposium 2022, Oct 17-21, in Thessaloniki, Greece.

Commission 2 - Gravity Field: Convening the GGHS2022 - Gravity, Geoid and Height Systems, hosted by the University of Texas at Austin, September 2022). Progress in the definition and realization of the International Terrestrial Gravity Reference System (ITGRS).

Commission 3 - Earth Rotation & Geodynamics: Enhancement of cooperation between the IAG and other IUGG associations (IAVCEI, IACS, IASPEI). Organization of Volcano-Geodesy workshop and of the 20th Wegener Assembly in 2023.

Commission 4 - Positioning & Applications: The priorities during the period 2019-2023 were: promote research and development, facilitate international collaboration, enhance communication and dissemination, foster international benchmarking and guidelines.

Inter-Commission Committees on

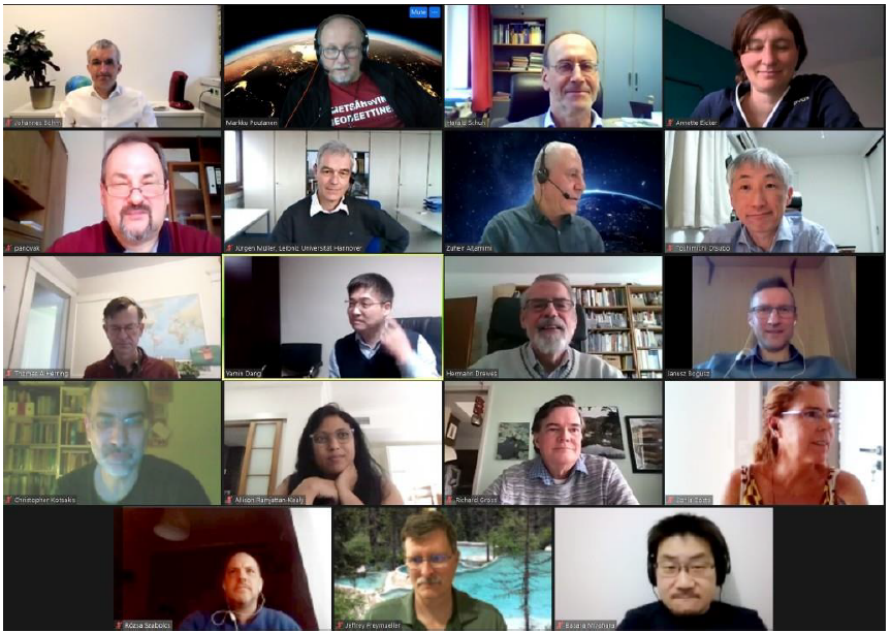

Fig. 1. Screen shot of the participants to the 4th EC meeting, which was held virtually in March 2021.

- **Theory (ICCT):** Convening the 10th Hotine-Marussi Symposium, in Milan, 13-17 June 2022.
- **Climate Research (ICCC):** Two online Workshops "Geodesy for Climate Research", March 29-31, 2021 and March 28-29, 2023.
- **Marine Geodesy (ICCM):** Special issue in Marine Geodesy published in 2021, and a number of workshops, seminars and conferences took place on marine/seafloor geodesy.

IAG Project-Novel Sensors & quantum technology for geodesy (QuGe): With its 3 working groups, the QuGe organized workshops on quantum gravimetry in 2021 and on clock networks for geodetic applications in 2023.

IAG Services: One of the main highlights was the preparation by the IAG geometric services (IDS, IGS, ILRS, IVS) of their input solutions and contributions to the ITRF2020, that was published in 2022 by the IERS ITRS Center.

IAG Global Geodetic Observing System (GGOS): Great emphasis on geodesy outreach and advocacy to the outside: Short film on the importance of geodesy for science and society, translated into 12 different languages and available through GGOS youtube; GGOS Focus Areas: defined strategy for the implementation of the International Height Reference System (IHRS); Development of the initiative "GNSS enhancement to tsunami early warning systems (GTEWS)"; Geodetic Space Weather Research, with 4 dedicated working groups; 10 years GGOS Strategic Goals & Ob-

jectives were identified though community survey & SWOT analysis, which will be reflected in an updated GGOS strategic plan.

IAG Communication and Outreach Branch: Management and regular update of the IAG website: a single website serving the majority of commissions and ICCs, together with a monthly Newsletter.

IAG Publications:

- Journal of Geodesy: With its impact factor of about 4.8 in average during the past 4 years, we can really be proud of our journal, thanks to the hard work of its Editor in Chief and Editorial Board.
- IAG Symposia Series: The collection of the IAG Symposia Series is an important scientific documentation of our association. All the papers and volumes are open access, and this facilitates the free access to the IAG scientific articles to all geodesists around the world. Many thanks to the Editor in Chief and the Assistant Editor in Chief.

UN-GGIM Subcommittee on Geodesy: During my term as IAG President, I represented our association in the subcommittee on Geodesy, and did a number of interventions at the UN-GGIM Sessions. My intervention at the 12th Session of UN-GGIM reads:

"The International Association of Geodesy commends the work accomplished by the Subcommittee on Geodesy during the intersessional period, and in particular its continued efforts in advocating the importance of the GGRF, as a global geodetic infrastructure for the benefit of science and society. As the work of the Subcommittee reaches the point of implementing the ambitions of the UN GA resolution on the GGRF for sustainable development, through the creation of a Global Geodetic Center of Excellence (GGCE), IAG calls for more involvement and interaction with the Subcommittee and the GGCE, by elevating its position within the Subcommittee to a more engaging membership role. Recalling that IAG has more than 150 years of history in bringing together geodetic institutions of Member States, and in providing fundamental geodetic products that constitute the main ingredients of the GGRF, IAG is looking forward to extensive coordination with the GGCE. In this regard, IAG is ready to take part to the GGCE activities, as a member of the International Advisory Committee. IAG also recognizes the importance of developing communication and advocacy mechanisms to attract contributions from Member States and other relevant geodetic stakeholders to the GGCE."

Obituaries: During the past quadrennial, a number of our IAG Officers and outstanding geodesist colleagues passed away. Among them, three eminent and giant geodesists, namely Helmut Moritz, Ivan Mueller and Erik Grafarend deserve a special tribute for their incredibly valuable contributions to IAG, to geodesy, and to science in general. They will always be remembered by the entire IAG community who pays respect to them.

Levallois Medal Laudation for Hermann Drewes

Harald Schuh

The Levallois Medal was established in 1979 to honor Jean-Jacques Levallois (1911-2001) for his long service from 1960 to 1975 as Secretary General of the International Association of Geodesy (IAG). The medal is usually awarded every four years at the IAG General Assemblies, and is presented in recognition of distinguished service to the association and/or to the science of geodesy in general.

A committee of eight past Presidents of the IAG, namely Harald Schuh (Committee President), Chris Rizos, Michael Sideris, Gerhard Beutler, Fernando Sanso, Wolfgang Torge, Ivan Mueller and Helmut Moritz, recommended in 2022 to award two medals at the General Assembly 2023 in Berlin, one to Hermann Drewes and one to Georges Balmino. Both medalists served as Secretaries General, the former of the IAG, the latter of IUGG, the International Union of Geodesy and Geophysics.

Hermann Drewes, born in 1944 in Breddorf, Northern Germany, spent his youth in the region around Bremen. Already during his military service (1963 – 1965), he received first instructions in geodetic and astronomic positioning. He studied geodesy at the Technical University Hanover (1965 – 1970) where he also defended his thesis entitled "Regional geoid determination using least squares collocation" in 1975.

In the late seventies Hermann was seriously drawn to distant grounds: He spent several years (1977 – 1979) in Venezuela where he worked as university professor in Maracaibo and scientific advisor at the national cartographic service in Caracas. Coming back to Europe in 1979, Hermann made Munich his ultimate base.

He joined the German Geodetic Research Institute DGFI, whose director he was to become 15 years later in 1994. Herrmann's major projects at DGFI were his initiative to set up the Geocentric Reference System for South America (Sistema de Referencia Geocéntrico para América del Sur, SIRGAS), which was later extended to all the Americas, the Velocity Model for South America (VEMOS) and the Combination Center of the International Terrestrial Reference Frame (ITRF). As DGFI director, Hermann also successfully initiated a reorganization of the DGFI research program with the aim of investigating the global dynamics of the Earth's body. He officially retired as DGFI's director in 2012, but for many more years he remained being very active in IAG.

Hermann Drewes' fields of interest are gravimetry, physical geodesy (geoid determination), geodetic geodynamics, tectonic plate kinematics, satellite geodesy and reference systems and frames on global and regional scale.

For almost three decades he gave lectures on satellite geodesy and geodetic geodynamics at the Technical University of Munich, where he became an Honorary professor in 1994, and at the University of the Federal Armed Forces in Munich.

Hermann Drewes is an exceptionally deserving recipient of the IAG's Levallois Medal. This fact rests, in my opinion, on four pillars:

1. Hermann was an "Officer" of the IAG for 25 years, as Section Chair, then Commission Chair and then Secretary General. It is well possible that this is the longest period anyone has ever been an officer in the IAG! In all the positions he has held,

Hermann has been full of energy and expertise and has made invaluable contributions to strengthening the services of the IAG. His major positions include:

- Secretary/President of the IAG/COSPAR Commission on "International Coordination of Space Techniques for Geodesy and Geodynamics" (CSTG; 1995 – 2003)
- Member of the International Laser Ranging Service (ILRS) Governing Board (1999 –2007)
- Member of the Bureau of the ICSU International Lithosphere Project (ILP; 2001 –2008)
- President of IAG Commission 1 "Reference Frames" (2003 – 2007)
- Representative of the International Union for Geodesy and Geophysics (IUGG) to the United Nations Cartographic Bureau (2003 – 2007)
- IUGG Representative to Pan-American Institute for Geography and History (PAIGH; 2003 – 2011)
- Representative of IAG to the "Group on Earth Observation" (GEO), Committee on Capacity Building (2004 – 2009)
- Steering Committee of IAG's Global Geodetic Observing System (GGOS; 2005 – 2009)
- Secretary General of the IAG (2007 – 2019)
- IUGG Representative to the United Nations Geospatial Information Section (2015 – 2019)
- last, but not least, he was Representative of IAG to the SIRGAS (since 1994), which leads to pillar No. 2:

2. SIRGAS, of course. Without Hermann, no SIRGAS. As Representative of IAG to the Sistema de Referencia Geocéntrico para las Américas (SIRGAS), he was responsible for the first ever unification of all South American geodetic reference systems in a common unified reference framework. He thus created the basis for the coordinate inventories and official map series. In Europe, this had already been realized in the years after World War II. In the meantime, SIRGAS has been extended beyond land surveying to include plate tectonics, gravimetry and sea level fluctuations. This created a comprehensive picture of the geotectonic surface processes in South America.
3. His contribution to the founding of the IERS. As far as I know, also the current name was suggested by Hermann.
4. Finally, the 4th pillar has possibly exerted Hermann's greatest impact on the future of IAG: Hermann Drewes was, together with Gerhard Beutler, Rainer Rummel and Chris Reigber, on the original planning committee of IGGOS (later called GGOS) and thus contributed significantly to the founding of GGOS.

Levallois Medal Laudation for Georges Balmino

Gerhard Beutler

The Levallois Medal was established in 1979 to honor Jean-Jacques Levallois (1911-2001) for his long service from 1960 to 1975 as Secretary General of the International Association of Geodesy (IAG). The medal is usually awarded every four years at the IAG General Assemblies, and is presented in recognition of distinguished service to the association and/or to the science of geodesy in general.

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Georges Balmino, born on February 9, 1945, attended between 1963 and 1967 in St. Cloud, a suburb of Paris, the Ecole Normale Supérieure, from where he graduated in Mathematics. From the same institution he holds a post-graduate degree in Celestial Mechanics & Relativity and a Master Degree in Astronomy. From Paris University he received his doctoral degree in 1969 with a thesis titled "Contribution à la connaissance du potentiel terrestre. Choix d'une représentation. Techniques nouvelles de détermination", which indicates his interests and the direction of his future career. He rounded up his academic education at Paris University with a state doctorate in Physics, in particular in Potential Theory and Applications in 1973.

In parallel, Georges worked as a trainee at Meudon Observatory, where he got in contact with visual and photographic satellite observations, and their reduction. Photographic astrometry was the dominating observation technique in satellite geodesy at that time. In 1967 he became a staff member of Meudon Observatory, in the frame of the CNRS (Centre National de la Recherche Scientifique). After a research stay at the Smithsonian Astrophysical Observatory (SAO) in 1968, he worked in Meudon as a research assistant between 1969 and 1972. Since 1973 Georges is a scientist of the Centre National d'Etudes Spatiales (CNES), the French Space Agency. From 1984 to 1994 Georges was the head of the Department of Terrestrial and Planetary Geodesy of CNES, from 1995 to 2004 of the CNES Division of Satellite Geodesy, and from 2004 to 2005 of the CNES Satellite Geodesy team. Since 2006 he is Scientist Emeritus at CNES.

In addition to his career at CNES, Georges Balmino held many "external" obligations: between 1979 and 1999 he was the Director of the Bureau Gravimetrique International (BGI), between 1991 and 1999 the Secretary General of IUGG. His election in 1991 as IUGG Secretary General at the 20th IUGG General Assembly in Vienna came as a surprise, because Georges directly applied for the position, without having served as a high-ranking officer in one of the IUGG Associations before. He owed his election to his outstanding international and scientific profile already in 1991. Between 1997 and 2004 he also acted as Executive Director of the GRGS, the Groupe de Recherche de Géodésie Spatiale in France. On top of all these responsibilities he

had numerous teaching obligations at French Universities, in particular in Toulouse and Paris.

Georges Balmino is highly respected, nationally and internationally: Already in 1976 he received NASA's GEOS-3 Special Achievement Award, in 1977 the CNES Bronze Medal, in 1983 the Prix Gustave Roux of the French Academy of Science, in 1996 the CNRS Silver medal, in 1998 the Ordre National du Mérite, and in 2002 the Vening-Meinesz Medal of the European Geophysical Union (EGU). In 1996 he was promoted to Doctor Honoris Causa by the Technical University of Graz.

Georges Balmino is a member of numereous scientific committees. He became in particular member of the Academia Europaea in 1999, of the Academy of Air and Space in 2003, and corresponding member of the Académie des Sciences, Inscriptions, et Belles Lettres in Toulouse in 2010. Georges is member of the American Geophysical Union (AGU), of IAG, of IUGG, of the American Astronomical Society (AAS), and of the Société Astronomique de France (SAF). In 2005 he became Fellow of the AGU, in 2015 Fellow of IUGG.

Georges Balmino's fields of interest are satellite geodesy, physical-mathematical geodesy, celestial mechanics and astronomy. Mainly he worked upon the determination of the Earth's, the Moon's and other planets' gravity fields. The GRIM Earth models originate from him and were steadily improved in collaboration with the DGFI, the Deutsches Geodätisches ForschungsInstitut in Munich, later on with the GFZ (GeoForschungsZentrum in Potsdam). According to Georges, the acronym GRIM unofficially stands for Groupe de Recherche Institute Munich and documents this fruitful collaboration. In the 1980s and 1990s Georges played a key role in the planning phase of the dedicated Earth's gravity field mission GOCE. Georges Balmino contributed substantially to establish and consolidate the French-German friendship in the frame of very successful scientific collaboration.

Georges Balmino's bibliography lists more than 150 publications, more than 80 with him as first author, more than 100 in refereed journals. Many of his articles deserve the labels innovative and influential, at times even visionary. This is not the place to give even a superficial overview of his written oeuvre. I cannot resist the temptation, however, to mention the very first entry in the bibliography of Georges, titled "Animal Tracking from Satellites", which was published as a SAO Special Report: it is close to a miracle, that a French student at the age of 23 years became the first author of a SAO Special Report in 1968. The report deserves the label visionary – animal tracking from satellites became an important issue much later on, using modern satellite navigation systems like GPS, Galileo, etc. Many of Georges Balmino's publications are related to what René Descartes called in 1637 Discours de la méthode: Numerous and substantial were in particular his mathematical contributions to global gravity modelling in general and to the significant improvement of efficiency and precision in the mathematical procedures.

Cher Georges, I learned a lot from writing this laudation and I was impressed very much by the depth and originality of your work. I thank you and the IAG Office for giving me the opportunity to illuminate your career and oeuvre to a large audience at the opening ceremony of the IAG General Assemby on July 12, 2023, in Berlin.

Guy Bomford Prize Lecture 2023

Amir Khodabandeh

The University of Melbourne, Australia

Geodetic Mixed-Integer Models: GNSS Network Estimability, PPP-RTK and Beyond

Geodesy plays a pivotal role in various scientific disciplines, engineering applications, and everyday activities reliant on accurate positioning and understanding of the Earth's shape, gravitational field, and dynamics. In an attempt to describe geodetic phenomena, geodesists have to constantly observe and interpret sensory data, develop mathematical frameworks describing physical reality, and predict the phenomena through often simplified models. Such models are characterised with a number of unknown parameters whose trustworthy estimation enables us to make valid inferences about the observational process. Estimation of the model parameters is, however, intricate as it involves integrating heterogeneous and redundant data that are accompanied by uncertainty. It was this very intricacy that struck me during my Bachelor studies. I was (and still am) fascinated by how easily uncertain data can sometimes deceive us into making unsound conclusions, leading to parameter estimates that are completely off target. In pursuing a prime example of such geodetic data, I was confronted with Global Navigation Satellite Systems (GNSS). I picked GNSS technology as a "tool" for my research since not only does GNSS technology contribute to the objectives of geodesy, but it also underpins navigation and timing services which billions of people rely on globally. Notably, I was excited to discover that geodesists were the first to recognise the importance of carrier phase signals in high-precision GNSS positioning in the 1980s, see e.g., Remondi (1984) and Beutler et al. (1984).

Since then, we have witnessed enormous progress in the development of GNSS models and algorithms. Yet, GNSS still offers fertile grounds for various research opportunities and inferential challenges. For instance, the system of GNSS observation equations, like several other interferometric measuring systems, contains parameters of which some are integer, i.e. the carrier phase ambiguities. Despite a rich and well-documented literature on the concept of parameter estimability, we showed that the concept is insufficient for dealing with such overparameterized mixed-integer models.

To address the lack of information content in the GNSS observation equations, my colleagues and I applied Baarda's S-system theory and identified estimable parameters that can be estimated via different models of the state-of-the-art GNSS method of PPP-RTK. While such parameters, in their estimable forms, enable us to determine the transformational links between different PPP-RTK methods, they may not necessarily preserve the integer-property of the phase ambiguities. On the basis of Teunissen's Z-transformations, we therefore generalised the standard concept of estimability to integer-estimability and determined the necessary and sufficient conditions that need to be satisfied for parameter functions to be integer-estimable. This generalization enables the extension of standard GNSS integer ambiguity resolution (IAR) methods, like LAMBDA, to non-conventional carrier phase signals of opportunity, e.g., such as those of Low-Earth-Orbiting (LEO) communication satellites or terrestrial Long-Term Evolution (LTE) transmitters.

Next to a proper understanding of the integer-estimability of GNSS parameters, one needs to address how the quality of their solutions meets certain demands. For instance, if we narrow down the notion of quality to precision, one should have a firm idea about the expected precision of various GNSS parameter solutions, given a fixed number of network receivers tracking GNSS satellites. To address this, we introduced a four-block canonical decomposition of the multivariate GNSS model, addressing how the ultra-precise ambiguity-resolved carrier phase measurements contribute to various GNSS network parameter solutions, ranging from positioning and atmospheric solutions to timing and instrumental bias solutions. With the aid of such decomposition, one can measure the precision gain of GNSS parameters after performing IAR. Accordingly, certain parameters are shown to have an IAR response that differ significantly from the IAR benefit that positioning and zenith tropospheric delay (ZTD) parameters enjoy. As such, timing parameters (i.e. receiver and satellite clock offsets) benefit from IAR only through the positioning and ZTD parameters. In case the stated parameters are a priori known, the clock solutions become uncorrelated with the double-differenced float ambiguities, thus remaining intact after IAR.

Recognising carrier phase IAR as a key enabler not only in GNSS applications but also in various high-precision interferometric measuring systems, it becomes necessary for existing integer parameter estimation theory to accommodate new mixed-integer models with bounded biases. For instance, the positioning models for emerging LEO frequency-varying signals often include integer-estimable ambiguities that cannot significantly improve the precision of the positioning solutions. This is because a set of phase ambiguities, which are critical for positioning, have already been sacrificed and absorbed by the instrumental biases. We therefore extended integer estimation theory by introducing a new admissible integer estimator. The estimator follows the principle of integer least squares estimation, and its search method is coined as the method of "Bias-bounded Estimation of AmbiguiTy" (BEAT). The proposed estimator accounts for the presence of such unaccounted biases in the model, by incorporating the prior knowledge of their bounded set into the estimation process. The proposed estimator challenges the argument that GNSS pseudo-range data must accompany their carrier phase counterparts to achieve instantaneous positioning. On the contrary, we demonstrated for the first time that single-epoch, phase-only positioning is feasible with real-world satellite signals.

As my research has primarily focused on mixed-integer GNSS parameter estimability and solution precision, I would like to conclude this talk by briefly discussing existing challenges and the outlook of GNSS. With the rapid increase in the number of new GNSS users equipped with low-cost sensors, recent technological breakthroughs such as optical clocks and optical inter-satellite communication have the potential to reshape the architecture of current GNSS constellations. Existing GNSS parameter estimation involves the calibration and determination of numerous clock offsets and instrumental biases, which in turn requires a large number of ground control stations. Novel GNSS architectures with inter-satellite links may offer a solution to this challenge. However, the growing availability of low-cost software-defined radios also presents a new concern, as it becomes easier for attackers to implement signal spoofing and deceive GNSS users by sending counterfeit signals. Enthusiastic researchers, who are interested in geodetic data processing and modelling, shall take up the above challenges and research opportunities.

Acknowledgements

It is a great honour and pleasure for me to receive the Guy Bomford Prize 2023 of the International Association of Geodesy (IAG). I would like to take this opportunity to thank the IAG selection committee for granting me such prestigious prize. My sincere gratitude goes to my PhD advisor and mentor, Professor Peter J.G. Teunissen, who taught me how to conduct research. Special thanks go to my BSc/MSc supervisor, Professor Alireza Amiri-Simkooei, who introduced estimation theory to me. My PhD co-supervisor, Dr. Dennis Odijk, is gratefully acknowledged for his research guidance. I wish to acknowledge the late Dr. Vahab Nafisi, whose dedication to education profoundly shaped my academic journey. I would also like to thank the IAG National Committees of The Netherlands and Australia for the nomination. I am very much thankful to my friends and colleagues at the Curtin GNSS Research Centre for their support and collaboration during the period of 2011-2018. Last but not least, I am sincerely grateful to my wife, Dr. Safoora Zaminpardaz, who always corrects my mistakes.

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IAG Young Authors Awards 2019-2022

IAG Young Authors Award 2019
Citation for Susanne Glaser

The IAG Young Authors Award 2019 is presented to **Prof. Dr.-Ing. Susanne Glaser** for her paper: Susanne Glaser, Rolf König, Karl Hans Neumayer, Tobias Nilsson, Robert Heinkelmann, Frank Flechtner and Harald Schuh, *On the impact of local ties on the datum realization of global terrestrial reference frames*, Journal of Geodesy 93: 655–667 (2019).

Susanne Glaser, studied Geodesy at Technische Universität Dresden, Germany and finished in 2009 with the Diploma degree. She received her Doctor of Engineering (Dr.-Ing.) in Geodesy at Technische Universität Dresden in 2014. The title of the dissertation is "On the optimization of the combination strategy of different geodetic satellite techniques to realize a global terrestrial reference system" with the focus on the combination of GNSS (Global Navigation Satellite Systems) and SLR (Satellite Laser Ranging). She worked then as a research associate at Technische Universität Berlin and Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences - on the simulation and combination of GPS, SLR, and VLBI (Very Long Baseline Interferometry). In December 2021 she became head of the working group "Combination of space geodetic techniques" at GFZ Potsdam Sec. 1.1. "Space geodetic techniques". In September 2023, she took over the professorship "Space Geodesy" at the Institute of Geodesy and Geoinformation at the University of Bonn. Her main research areas deal with different combination strategies and technological developments in the space geodetic techniques to improve global terrestrial reference frames (TRFs) towards the requirements set by the Global Geodetic Observing System (GGOS).

In the study presented in the award-winning paper, the impact of random and systematic errors as well as a selection of local ties (LTs) on the datum realization of global TRFs is investigated. It is based on a thorough simulation study covering GPS, SLR, and VLBI over seven years. These investigations have widespread implications for our understanding of the errors in contemporary TRFs.

The results presented in the paper suggest that the standard deviations of the LTs should be better than 1 cm to keep the changes in the TRF-defining parameters below 1 mm. Since VLBI, in its standard mode of observing only extragalactic radio sources, is inherently not sensitive to the origin of the TRF, the origin information

for the VLBI stations has to be transferred from the satellite techniques, such as SLR, to VLBI solely by using LTs. Therefore, it is of special importance, that the standard deviations of the VLBI LTs are smaller than 1 cm. The simulation of biased LTs demonstrates that single biased LTs do not result in large changes in the TRF-defining parameters. However, if all LTs of one technique are biased, it was shown that the biased LTs at the GPS stations have the largest impact on the TRF-defining parameters. Furthermore, it underlines the importance of GPS in the combination of the space geodetic techniques using LTs. Using different sets of selected LTs reveals that the LTs on the southern hemisphere play a very important role, especially for the scale realization.

In the case of the standard combination approach using LTs, this study emphasizes that a homogeneous global distribution of high-quality LTs is essential for a TRF fulfilling the demanding GGOS requirements.

IAG Young Authors Award 2020 Citation for Khosro Ghobadi-Far

The IAG Young Authors Award 2020 is presented to **Dr. Khosro Ghobadi-Far** for his paper: Ghobadi-Far, K., Han, S.-C., Allgeyer, S., Tregoning, P., Sauber, J., Behzadpour S., Mayer-Guerr T., Sneeuw N. and Okal E., *GRACE gravitational measurements of tsunamis after the 2004, 2010, and 2011 great earthquakes*, Journal of Geodesy 94: 65 (2020).

Khosro Ghobadi-Far received his bachelor's degree in geomatics and master's degree in geodesy from Iran. He completed his PhD thesis on analysis of time-variable gravity signals from GRACE satellites at the University of Newcastle, Australia, under supervision of Prof. Shin-Chan Han. After doing a postdoc at Virginia Tech working on monitoring of freshwater resources using space geodesy techniques, he took over a faculty position in August 2023 as an assistant professor in the Department of Aerospace Engineering Sciences at the University of Colorado Boulder.

GRACE satellite mission revolutionized our understanding of mass changes in the Earth system by measuring time-variable gravity field with unprecedented accuracy. The conventional data products of GRACE are global monthly-mean snapshots of time-variable gravity and surface mass change. The global monthly fields are obtained from the fundamental measurements of inter-satellite ranging acquired by the K-band ranging (KBR) system. Relying exclusively on the monthly data confines the application of GRACE to geophysical processes that are mainly characterized by seasonal and interannual variations.

Khosro Ghobadi-Far developed a novel method of directly analyzing the inter-satellite ranging observations from GRACE satellites. When GRACE satellites fly over a region, the perturbation in inter-satellite range reflects the *instantaneous* gravitational signal caused by mass changes happening beneath the satellites. This approach allows for detecting new geophysical mass changes at timescales of significantly less than one month, such as tsunamis. By directly examining the inter-satellite ranging data when GRACE satellites flew over the tsunami waves generated by the 2004 Sumatra, 2010 Maule and 2011 Tohoku great earthquakes, the award-winning paper demonstrates the first-ever gravitational measurement of tsunamis from space. GRACE provides an independent source of information useful to evaluate various seismic source models.

In contrast to point-wise ocean bottom pressure measurements and cross-sectional satellite altimeter profiling of tsunami heights, the GRACE gravimetric observations provide regional averages of tsunami-induced gravity changes in the open ocean. The GRACE satellites observe the long-wavelength components of tsunami (spatial scales of a few thousands km and larger), which transcend the domain accessible by seis-

mological studies. Therefore, GRACE observation of large tsunamis has the potential to explore their properties (and hence of their parent earthquakes) in a hitherto unexplored domain of frequencies. Being unusually sensitive to the regional scale of tsunamis, the GRACE data can be used for assessing early models of earthquakes and tsunamis after the events, to provide independent estimates of the overall tsunami size.

This paper highlights in particular the potential of GRACE Follow-On to deliver low-latency gravimetric observations for monitoring transient mass change due to rapid, extreme events such as tsunamis, hurricanes, and floods.

IAG Young Authors Award 2021
Citation for Radosław Zajdel

The IAG Young Authors Award 2021 is presented to Dr. Radosław Zajdel for his paper: *Sub-daily polar motion from GPS, GLONASS, and Galileo*, Journal of Geodesy, 95:3 (2021). The article is co-authored by Krzysztof Sośnica, Grzegorz Bury, Rolf Dach, Lars Prange and Kamil Kaźmierski representing two scientific institutions.

Radosław Zajdel is a geodesist who graduated from Wrocław University of Environmental and Life Sciences (UPWr, Poland) in 2017. In 2021, he obtained his Ph.D. in satellite geodesy with a thesis entitled "Determination of Global Geodetic Parameters Using the GPS, GLONASS, and Galileo Satellite Systems". In the same year, he was recognized as one of the top five young scientists in Poland and awarded the START 2021 prize by the Foundation for Polish Science for his contributions to enhancing our understanding of natural phenomena on Earth using the Galileo system. He has also received a scholarship for outstanding young scientists from the Minister of Science and Higher Education in Poland and the Jan Mozrzymas Scholarship by the Mayor of Wrocław, for his exceptional achievements in interdisciplinary science and promotion of the region. He developed his scientific and academic experience in international groups, including the Astronomical Institute of the University of Bern (AIUB) in Switzerland, the Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Germany, and the Helmholtz-Zentrum Potsdam - Deutsches GeoForschungsZentrum (GFZ) in Germany. Currently, he is employed at UPWr in Poland as an Assistant Professor and Researcher at the Geodetic Observatory Pecný in the Czech Republic, where he coordinates the implementation of the MSCA-COFUND MERIT Postdoctoral Programme.

Radosław Zajdel's research interests revolve around analyzing Global Navigation Satellite System (GNSS) data, with a particular focus on precise orbit determination and monitoring of natural phenomena in the Earth system based on GNSS products. He exploits the benefits of using multi-GNSS constellations and develops the evolving navigation systems of Galileo, BeiDou, and QZSS. Additionally, his expertise includes understanding the role of global geodetic observation techniques in Earth's reference systems and linking geodesy to Earth sciences.

The award-winning article delves into the development of an empirical model to analyze the sub-daily polar motion (PM) of the Earth, utilizing observations from the GPS, GLONASS, and Galileo satellite systems. For this study, the authors combined data from multiple GNSS over three years from 2017 to 2020, capturing observations at two-hour intervals, to provide a comprehensive understanding of the Earth's polar motion. The study first outlines the differences observed in the PM estimates when derived from individual satellite systems and contrasts these with combined multi-GNSS solutions. It then assesses the accuracy of these GNSS-based PM estimates by

comparing them with three independent models. These reference models include the model from the International Earth Rotation and Reference Systems Service (IERS) 2010 Conventions (Petit and Luzum, 2010), the Desai–Sibois model (Desai and Sibois, 2016), and the Gipson model (Gipson, 2017), each offering an independent perspective on the high-frequency Earth's rotation.

One of the key findings from the research is the presence of artificial non-tidal signals in the GNSS-based sub-daily PM observations, which are predominantly due to resonances between the satellites' orbital periods and the Earth's rotation period. The strong spurious signals are observed with periods of about 34h, 21h, and 24h for Galileo, GLONASS, and GPS, respectively. In the case of the GPS constellation, it is difficult to quantify the impact of this effect as the GPS orbital period aligns with the K1 tide. Thus, one can conclude that the estimation of the K1 tide, as well as other tidal terms in the diurnal band, is directly affected in the GPS-based solution.

However, the study highlights that a combined approach, which integrates data from all three GNSS (GPS, GLONASS, and Galileo), significantly mitigates these errors. The multi-GNSS solution not only is less affected by non-tidal orbital artifacts but also aligns better with the external geophysical and empirical models used for comparison. This indicates the robustness of a combined GNSS approach over using any single satellite system for sub-daily PM recovery.

Furthermore, the research demonstrates that the new Desai–Sibois model offers improved consistency over the model recommended in IERS 2010 Conventions. This suggests that updates to the IERS Conventions would be beneficial. Overall, the article emphasizes the effectiveness of using a multi-GNSS approach for studying sub-daily polar motion, highlighting its importance in refining our understanding of geophysical processes and improving the models of Earth rotation.

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IAG Young Authors Award 2022 Citation for Matthias Willen

The IAG Young Author Award 2022 is presented to **Dr. Matthias Willen** for his paper: Willen, M.O., Horwath, M., Groh, A., Helm, V., Uebbing, B., Kusche, J., *Feasibility of a global inversion for spatially resolved glacial isostatic adjustment and ice sheet mass changes proven in simulation experiments*, Journal of Geodesy, 96: 75 (2022).

Matthias Willen studied Geoscience as well as Geophysics and received a Bachelor and Master degree from Friedrich-Schiller-University Jena. He received the President's Exam Award for his very successfully completed Master's programme. In 2017 he started a PhD at the group of Geodetic Earth System Research at TU Dresden supervised by Martin Horwath and Andreas Groh. He defended his doctoral thesis "On the quantification of ice sheet mass changes and glacial isostatic adjustment effects by combining satellite data" with *summa cum laude* at the beginning of 2023. From spring 2023, he worked as a PostDoc at Delft University of Technology together with Bert Wouters and Taco Broerse. Since February 2024, he has returned to TU Dresden as a PostDoc on a staff position with the aim of completing his habilitation.

The award-winning publication is a contribution towards resolving the inverse problem of spatio-temporal signal separation over ice sheets by combining satellite gravimetry and satellite altimetry data with regional climate and firn modelling outputs. Solving the inverse problem, i.e. the inversion, by parameter estimation implies the challenges to find a careful parametrization, i.e. the formulation of the model with the parameters to be determined, together with careful consideration of data limitations. The paper focuses on the spatial separation of ice mass changes, glacial isostatic adjustment (GIA) and changing firn air content in a global framework while accounting for spatially correlated errors of the input data sets. Observations and parameters are linked in a Gauss Markov model which is solved by generalized least squares adjustment.

An essential aspect of the paper is the advancement of the GIA fingerprint parametrization according to Rietbroek et al. (2016) based on findings from Sasgen et al. (2017) and Gunter et al. (2014). The parametrization implemented for GIA in Antarctica aims to spatially resolve the GIA effect. This is done to potentially resolve GIA effects that are not predicted by GIA modelling. In Antarctica, the predicted patterns of GIA forward modelling are incompatible with geodetic observations due to deficient knowledge of the rheological Earth structure and ice loading history that govern the present-day GIA effects (Whitehouse et al., 2019). In the other regions of the world, it is assumed that the spatial patterns of modelled present-day GIA effects largely

capture present-day GIA effects. In this way, the study explored the scope of a more robust, i.e. more model-dependent GIA parameterization e.g. in Greenland, up to a more model-independent GIA parametrization in Antarctica. The GIA parametrization in Greenland may include modelling errors and the one in Antarctica is more sensitive to observational errors.

Besides the parameterization, another essential aspect is the characterization of the spatially correlated errors of the observations and the investigation of the feasibility of the global inversion approach in the presence of these errors. The uncertainty of the input data has been characterized using real-world observations.

The simulation experiments showed that in this global framework it is possible to co-estimate present-day GIA, ice mass change and firn air content change over both ice sheets by integrating information from satellite gravimetry, satellite altimetry, regional climate modelling and firn modelling. However, this only holds if the spatial error covariance information is rigorously taken into account. Otherwise, the detected signals may vanish in the noise of the estimate.

After demonstrating the feasibility of the methodology with simulations, Willen et al. (2024) built upon this article and applied it to real-world data. It was found that the error covariance information considered was insufficient to account for the actual errors. However, with a regularization of Antarctic GIA parameters, it was possible to suppress the sensitivity to these errors, so that a GIA result could be found that fits better to independent GNSS data than previous modelling-based or observation-based GIA estimates.

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Report of the IAG Secretary General

Markku Poutanen: IAG Secretay General 2019-2023

According to the IAG Bylaws, the Secretary General (SG) fulfills the role of secretary for several key bodies within the organization, namely the General Assembly, the Scientific Assembly, the Council, the Executive Committee, and the Bureau. The SG's responsibilities include arranging meetings for these bodies, promptly distributing agendas, and preparing and disseminating the minutes of all meetings. Additionally, the SG serves as the Director of the IAG Office and oversees the association's affairs, including financial matters. The SG is also responsible for managing IAG correspondence, maintaining records, and circulating all pertinent information related to the association. Furthermore, the SG has to prepare reports on IAG activities and carry out any other duties assigned by the Bureau, the Council, or the Executive Committee.

1 Administrative work

The administrative efforts between 2019 and 2023 were primarily focused on two major tasks: the organization and execution of the IAG Scientific Assembly 2021 and the IUGG General Assembly 2023. Additionally, significant work went into producing the Geodesist's Handbook 2020 and editing IAG Reports Vol. 42 and Vol. 43 (Travaux de l'AIG 2019–2021 and 2019–2023), as well as coordinating ten meetings of the IAG Executive Committee.

Due to the COVID-19 pandemic, many regular activities such as meetings and symposia were either canceled, postponed, or shifted to online formats between 2020 and 2022, including the 2021 Scientific Assembly.

Financial management responsibilities encompassed all aspects of IAG accounting, including the Journal of Geodesy and IAG Symposia Series, IUGG-sponsored Projects and Symposia, and the administration of individual IAG memberships. During this period, 28 travel awards were granted to young scientists for participation in IAG symposia (2019, 2022-2023), and 88 travel awards were provided to students and early-career scientists, primarily from low/mid-economy countries, to attend the IUGG General Assembly 2023.

1.1 Scientific Assembly

The Scientific Assembly of the IAG took place in Beijing, China, from June 28 to July 2, 2021. The primary local organizer was the Chinese Society for Geodesy, Photogrammetry, and Cartography (CSGPC), with over 20 co-organizers across China. Due to the COVID-19 pandemic, the Assembly was conducted as a hybrid conference, with an option for Chinese participants to physically attend in Beijing.

A record-breaking 1269 participants registered for the event, more than double the previous record. Among them, 435 were students and early-career scientists, approximately one-third of all attendees.

A total of 615 abstracts were submitted. Oral presentations were limited to five minutes each, with approximately half of the session time allocated for questions and discussions to compensate for the lack of in-person interactions. Each day featured three parallel oral sessions and one poster session, allowing for around 150 daily presentations, with oral presentations accounting for about 42% of the total.

The Assembly's theme was *Geodesy for a Sustainable Earth*, with a total of 36 sessions organized under seven symposia, covering a wide range of topics.

1. Reference Frames;
2. Earth's Static Gravity Field;
3. Earth's Time-variable Gravity Field;
4. Earth Rotation and Geodynamics;
5. Positioning and applications;
6. Global Geodetic Observing System (GGOS);
7. The ICC symposium with 3 Inter-Commission Committees and the IAG Project.

The proceedings book, titled *Geodesy for a Sustainable Earth*, was published in 2023 as Volume 154 in the IAG Symposia Series (Springer). This series is Open Access and undergoes full peer review process.

1.2 General Assembly

The 28^{th} IUGG General Assembly took place from July 11 to July 20, 2023, in Berlin, Germany. It attracted a total of 5198 participants, setting a new record for IUGG General Assemblies. The number of participants with IAG priority was 580, also marking a record. A total of 88 IAG travel awards were provided to students and early-career scientists, primarily from low/mid-economy countries.

In total, 661 abstracts were submitted. Six symposia dedicated solely to geodesy were organized.

1. Reference Systems and Frames;
2. Static Gravity Field and Height Systems;
3. Time-variable Gravity Field;
4. Earth Rotation and Geodynamics;
5. Multi-signal positioning, Remote Sensing and Applications;
6. Monitoring and Understanding the Dynamic Earth with Geodetic Observations.

Additionally, there were seven joint geodesy-lead symposia

1. Interactions of the Solid Earth With Ice Sheets and Sea Level (IAG, IACS, IASPEI);
2. Theory and Methods of Potential Fields (IAG, IAGA);
3. Remote Sensing and Modelling of the Atmosphere (IAG, IAGA, IAMAS, IAVCEI);
4. Satellite Gravimetry for Groundwater Monitoring (IAG, IAHS);
5. Geodesy for Climate Research (IAG, IAMAS, IACS, IAPSO, IAHS);
6. Monitoring Sea Level Changes by Satellite and In-Situ Measurements (IAG, IAPSO);

7. Modern Gravimetric Techniques for Geosciences (IAG, IAVCEI, IAPSO, IASPEI).

Geoffrey Blewitt gave the IAG Union lecture, titled *It's About Time*. The Proceedings will be published in the IAG Symposia series.

Fig. 1. IAG participants' meeting in Berlin, in July 2023

1.3 Council

The IAG Council comprises delegates appointed by the Adhering Bodies of IUGG member countries and is responsible for the governance, strategic policy, and direction of the IAG. The SG regularly informs them on current IAG activities and events.

Due to the COVID-19 pandemic, no Council meeting was organized in relation to the Scientific Assembly in 2021. Instead, an online meeting and voting were held in September 2021 to elect the venue for the 2025 IAG Scientific Assembly which will be held in Rimini, Italy.

The Council conducted electronic voting to elect and approve new officers during the winter/spring of 2023. This included the President, Vice President, Secretary General, presidents of the Commissions, Inter-commission Committees, COB, and GGOS. An in-person meeting was held during the General Assembly on July 12 and 19, 2023. The agenda included approving the finances for the period 2019-2022 and the budget for 2023-2027, endorsement of changes in the IAG Statutes and Bylaws, and approving the IAG resolutions.

1.4 IAG Executive Committee (EC)

The voting members of the Executive Committee (EC) include the IAG President, Vice President, Secretary General, immediate Past President, immediate Past Secretary General, the four Commission Presidents, the President of GGOS, the President of ICCT, the President of COB, three representatives of the Services, and two Members-at-Large.

During the period of 2019-2023, the EC held its initial meeting in 2019 during the IUGG General Assembly in Montreal, followed by a second meeting in San Francisco in December 2019. However, the COVID-19 Pandemic hindered in-person gatherings until December 2022, when the first hybrid meeting was held in Paris. In the interim, biannual online meetings were conducted, supplemented by various information emails and electronic ballots as required. The 2023 meetings were convened in Vienna in April 2023, and the last two meetings during the General Assembly in Berlin.

1.5 IAG Bureau

The IAG Bureau consists of the IAG President, the Vice President and the Secretary General. It holds regular monthly online meetings to administer the day-to-day affairs. The President and the Secretary General participated in the meetings of the IUGG Executive Committee and represented the IAG at international meetings of allied scientific bodies.

1.6 IAG Office

The IAG Office (Secretary General, with the Treasurer and the "Finnish IAG Secretariat Association", a registered non-profit Society in Finland concerning financial matters) managed the IAG finances, membership matters, daily contacts/correspondence within IAG and to IUGG or other external bodies, prepared meetings and minutes of Council, EC and Bureau, and prepared reports to IUGG. The Finnish Geospatial Research Institute FGI of the National Land Survey hosted the Office.

1.7 Individual Membership

At the end of 2023, the total membership count was 239, with 38 being students and 43 retired members. Both students and retired members are exempt from the annual fee. The annual membership fee is 50 Euros, with an option to pay 150 Euros for a four-year period. Membership offers benefits such as discounts on the participation fee for IAG Symposia and Scientific Assemblies.

1.8 Publications

The IAG Newsletter was published monthly online and is accessible on the IAG website. The IAG official Journal, the Journal of Geodesy (JoG) is published monthly by Springer Verlag. The impact factor is 4.4 (2022), and the annual number of papers published is more than 300. The JoG is within the top ten geosciences-related journals. The Geodesist's Handbook 2020 was published in the November 2020 issue of the JoG.

The biannual IAG Reports were published in Vol. 42 and Vol. 43 (Travaux de l'AIG 2019–2021 and 2019–2023) and can be found on the IAG web site. Annual IAG reports are published in the IUGG Annual Reports and Yearbooks.

Based on the agreement with Springer Verlag, IAG Symposia Series will be open access, and free of charge to the Symposia participants. The following volumes were published or are in preparation:

Vol. 150 Stelios P. Mertikas, Roland Pail (Eds., 2020) Fiducial Reference Measurements for Altimetry. Proceedings of the International Review Workshop on Satellite Altimetry Cal/Val Activities and Applications. (DOI:https://doi.org/10.1007/978-3-030-39438-7 10.1007/978-3-030-39438-7)

Vol. 151 Pavel Novák, Mattia Crespi, Nico Sneeuw, Fernando Sansò (Eds., 2021) IX Hotine-Marussi Symposium on Mathematical Geodesy. Proceedings of the Symposium in Rome, June 18-22, 2018. (DOI:https://doi.org/10.1007/978-3-030-54267-210.1007/978-3-030-54267-2)

Vol. 152 Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2022) Beyond 100: The Next Century in Geodesy. Proceedings of the IAG General Assembly, Montreal, Canada, July 8-18, 2019. (DOI:https://doi.org/10.1007/978-3-031-09857-410.1007/978-3-031-09857-4)

Vol. 153 Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2023) 5th Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TG-SMM 2019). Proceedings of the Symposium in Saint Petersburg, Russia, October 1-4, 2019. (DOI:https://doi.org/10.1007/978-3-031-25902-910.1007/978-3-031-25902-9)

Vol. 154 Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2023) Geodesy for a Sustainable Earth. Proceedings of the 2021 Scientific Assembly of the IAG, Beijing, China, June 28-July 2, 2021.(DOI:https://doi.org/10.1007/978-3-031-29507-210.1007/978-3-031-29507-2)

Vol. 155 Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2024) X Hotine-Marussi Symposium on Mathematical Geodesy. Proceedings of the Symposium in Milan, Italy, June 13-17, 2022. (DOI:https://doi.org/10.1007/978-3-031-55360-810.1007/978-3-031-55360-8)

Vol. 156 Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2024) Gravity, Positioning and Reference Frames (2024). Proceedings of the IAG Symposia - GGHS2022: Gravity, Geoid, and Height Systems 2022, Austin, TX, United States of America, September 12-14, 2022; IAG Commission 4: Positioning and Applications, Potsdam, Germany, September 5-8, 2022; REFAG2022: Reference Frames for Applications in Geosciences, Thessaloniki, Greece, October 17-20, 2022.

1.9 IAG Awards

There are four IAG Awards for meritorious work.The Awards are presented at the IAG Scientific and General Assemblies (see https://www.iag-aig.org/awards). Additionally, IAG Fellows are nominated at the General Assembly.

- Levallois Medal for distinguished service to the IAG and/or to the science of geodesy in general. In 2023, it was granted to Professor Georges Balmino and Professor Hermann Drewes.
- Guy Bomford Prize for outstanding contributions of a young scientist to geodetic studies. In 2023, it was granted to Dr. Amir Khodabandeh.

- Young Authors Awards for the best publications in the Journal of Geodesy. For 2019 it was granted to Dr.-Ing. Susanne Glaser, 2020 to Dr. Khosro Ghobadi-Far, 2021 to Dr. Radosław Zajdel and 2022 to Dr. Matthias Willen.
- The Best Reviewer Award was established in 2023. The Award is to recognize the important work of reviewing for Journal of Geodesy, and the Award 2021-2022 was granted to Dr. Jan Martin Brockmann.
- The IAG Executive Committee designates former officers of the IAG as Fellows in recognition of their contributions to IAG. Fellows nominated in 2023 were: Graham Appleby (UK), Kyriakos Balidakis (Germany), Elmar Brockmann (Switzerland), Sonia Costa (Brazil), Yamin Dang (China), Wei Feng (China), Gabriel do Nascimento Guimarães (Brazil), Ryan Hippenstiel (USA), Xiaopeng Li (USA), Martin Lidberg (Sweden), Ulrich Meyer (Switzerland), Basara Miyahara (Japan), Emily Montgomery-Brown (USA), Takuya Nishimura (Japan), Jean-Mathieu Nocquet (France), Toshimichi Otsubo (Japan), Paul Rebischung (France), Laura Ruotsalainen (Finland), Alvaro Santamaría-Gómez (France), Zheng-Kang Shen (USA), Wenbin Shen (China), Rebekka Steffen (Sweden), Derek van Westrum (USA).

2 IAG Symposia, Workshops and Schools

The number of symposia and other activities has been lower than usual due to the COVID-19 pandemic. Throughout 2020-2021, all in-person meetings were cancelled. From 2022 onwards, several meetings were either conducted online or in a hybrid format. Below is a list of the most significant meetings organized by IAG components or sponsored by IAG.

- 27th IUGG General Assembly; Montreal, Canada (2019 07 08-19)
- DORIS Analysis Working Group meeting; Paris, France (2019 09 30-10 01)
- ILRS Analysis Standing Committee (ASC) meeting; Paris, France (2019 10 01)
- 5th IAG Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TG SMM 2019); Saint Petersburg, Russia (2019 10 01-04)
- GGOS/IERS Unified Analysis Workshop; Paris, France (2019 10 02-04)
- BIPM Workshop on Advanced Time and Frequency Transfer; Sèvres, France (2019 10 10)
- ILRS Technical Workshop; Stuttgart, Germany (2019 10 21-25)
- GGOS Days 2019; Rio de Janeiro, Brazil (2019 11 11-14)
- SIRGAS Symposium 2019; Rio de Janeiro, Brazil (2019 11 11-14)
- Kick-off meeting of the IAG SC 1.4/IAU/IERS joint working group on the "Consistent realization of TRF, CRF and EOP", Online (2020 06 09)
- IAG SC 1.3e/UN-GGIM-AP (Geodetic reference frame of the Asia-Pacific region) Online (2020 11 03)
- Geodynamics and Earth Tides. Wuhan, China. IAG Subcommission 3.1 meeting (2021 06 23-26)
- IAG Scientific Assembly, Beijing, China. Hybrid (2021 06 28-07 02)
- IVS Training School, Helsinki, Finland. Online (2022 03 22-25)
- 12th IVS General Meeting March 28-April 1, 2022, Helsinki Finland. Online (2022 03 28-04 01)

- IGRF Workshop 2022, Leipzig, Germany. Hybrid (2022 04 11-13)
- EUREF 2022 Symposium, June 1-4, 2022, Zagreb, Croatia. Online (2022 06 01-04)
- X. Hotine-Marussi Symposium on Mathematical Geodesy, Milan, Italy. (2022 06 13-17)
- IGS Workshop "IGS 2022: Science from Earth to Space", Boulder CO, USA (2022 06 27-07 01)
- 2nd International Symposium: Positioning and Applications, Potsdam, Germany. Hybrid (2022 09 05-09)
- Gravity, Geoid, and Height Systems 2022 (GGHS2022), Austin TX, USA. Hybrid (2022 09 12-16)
- REFAG 2022, Thessaloniki, Greece (2022 10 17-21)
- Unified Analysis Workshop (UAW) Thessaloniki, Greece. Hybrid (2022 10 22-25)
- IDS Workshop 2022, Venice, Italy. (2022 10 31-11 02)
- 22nd International Workshop on Laser Ranging, Guadalajara, Spain. Hybrid (2022 11 07-11)
- SIRGAS Symposium, Santiago de Chile. Hybrid (2022 11 07-09)
- GGOS Days 2022, Munich Germany. Hybrid (2022 11 14-16)
- 2nd Workshop of the Intercommission Committee on Geodesy for Climate Research (ICCC). Online (2023 03 28-30)
- IUGG General Assembly, Berlin, Germany (2023 07 11-20)

3 Finances

In what follows, the financial reports for 2019-2022 (Fig. 2), the budget 2023-2026 (Fig. 3) and the report of the Audit Committee are given. Audit Committee members appointed by the IAG Council at the meeting held at IUGG GA 2023 in Berlin, on July 12, 2023: *Mattia Crespi, Xiaoli Deng, Ismael Foroughi, Jyri Näränen.*

1. The Audit Committee performed the following functions:
   (a) Noted that the accounts had previously been reviewed by the "Finnish IAG Secretariat Association" and Päivi Koponen from the Financial Department of the National Land Survey of Finland (NLS). The account is in Euros.
   (b) Examined the receipts and bank statements for the period 2019-2022. Checked the balance reports presented by the IAG Secretary General, Markku Poutanen.
   (c) Examined expenditure to ensure conformity with the 2019-2022 budget as approved at the IUGG General Assembly in Montreal, 2019.
   (d) Examined the budget proposed for the period 2023-2026.
2. The Audit Committee makes the following comments on the IAG budgets:
   (a) The budgets were well presented and the expenditures fully supported by receipts and bank statements.
   (b) During this period, the IAG made an unplanned surplus of 79724,43 Euro, mainly due to COVID-19 pandemic, which forced to cancel a lot of events, in contrast to the 60000 Euro deficit that was forecasted. The difference between forecasted and actual budget of 139724,43 Euro is relevant considering the total turnover was 236598 Euro.

Budget for the period 1.1.2019 - 31.12.2022 in EUR

	Expenditures	budget	actual		Receipts	budget	actual
11.2	Administration, Equipment	3 000 €	152 €	15	IUGG Allocation	80 000 €	117 132 €
11.5	Administration, Travel	25 000 €	2 731 €	1	Membership Fee	15 000 €	18 622 €
11.6	Administration, Representation	10 000 €	3 051 €	2	Other Grants (Scientific Assembly)	4 000 €	0 €
12.1	Publications, Outreach	7 000 €	0 €	3	Sales of Publications		0 €
12.2	Publications, IAG Symp. Series	40 000 €	26 040 €	3.1	IAG Symposia Series	0 €	0 €
13.1	Assemblies, Organization	20 000 €	12 437 €	3.2	Journal of Geodesy	20 000 €	20 000 €
13.2	Assemblies, Travel	10 000 €	9 373 €	4	Miscellaneous		0 €
14.2	Symposia, Travel Awards	60 000 €	15 071 €	4.1	IAG Fund	1 000 €	1 097 €
16.2	Prizes, Young Authors Awards	4 000 €	5 352 €			0 €	22 €
18.6	Services	1 000 €	2 942 €				0 €
19	Total Expenditures	180 000 €	77 150 €	6	Total Receipts	120 000 €	156 874 €
					Deficit	-60 000 €	79 724 €
	Total	180 000 €	77 150 €		Total	60 000 €	236 598 €

Net Capital 31.12.2022 in EUR

					Open 1.1.2019	195 000 €	195 000 €
	Balance 31.12.2022	135 000 €	274 724 €		Deficit	-60 000 €	79 724 €
	Total	135 000 €	274 724 €		Total	135 000 €	274 724 €

Fig. 2. IAG Finances 2019-2022

(c) The 2019-2022 surplus increases the IAG reserve from 194602,33 to 274326,76 Euro.
(d) The budget for the next period (2023-2026) forecasts a deficit of 83000 Euro.

3. The Audit Committee makes the following comments/recommendations:
   (a) The budget is appropriate and the forecasted deficit is prudent to reduce the balance of the IAG reserve.
   (b) The budget is clear and complete, it is recommended to approve it.

Proposal of the Budget for the period 1.1.2023 - 31.12.2026 in EUR

	Expenditures			**Receipts**	
11.2	Administration, Equipment	3 000 €	15	IUGG Allocation	75 000 €
11.5	Administration, Travel	25 000 €	1	Membership Fee	15 000 €
11.6	Administration, Representation	10 000 €	2	Other Grants (Scientific Assembly)	0 €
12.1	Publications, Outreach	7 000 €	3	Sales of Publications	0 €
12.2	Publications, IAG Symposia Series	50 000 €	3.1	IAG Symposia Series	25 000 €
13.1	Assemblies, Organization	20 000 €	3.2	Journal of Geodesy	20 000 €
13.2	Assemblies, Travel	15 000 €	4	Miscellaneous	0 €
14.2	Symposia, Travel Awards	80 000 €	4.1	IAG Fund	1 000 €
16.2	Prizes, Young Authors Awards	6 000 €			
18.6	Services	3 000 €			
19	**Total Expenditures**	219 000 €	6	Total Receipts	136 000 €
				Deficit	-83 000 €
	Total	**219 000 €**		**Total**	**219 000 €**

Net Capital 2022 in EUR

			Open 1.1.2023	274 000 €
	Balance 31.12.2022	191 000 €	Deficit	-83 000 €
	Total	**191 000 €**	**Total**	**191 000 €**

Fig. 3. IAG Budget 2023-2026

4. On behalf of the IAG Council the Committee makes the following acknowledgements:
   (a) *Markku Poutanen*, past Secretary General, for his clear and efficient administration and management of IAG Office.
   (b) The Financial Department of NLS for the support and checking to the accounts.

The audit committee wishes *Daniela Thaller*, the new Secretary General, a successful administration.
Mattia Crespi, Xiaoli Deng, Ismael Foroughi, Jyri Näränen
Berlin, 15 July, 2023

Minutes of the IAG Council Sessions

Markku Poutanen: IAG Secretay General 2019-2023

1 IAG Council Meeting, Session 1 at the IUGG General Assembly, Berlin 2023

Place: Messe Berlin – City Cube, Room M1, July 12, 2023, 08:30-10:15

Agenda

1. Welcome and adoption of the agenda (ZA)
2. IUGG2023 Organisational issues (MP)
3. Agenda of the Opening and Closing Sessions (MP)
4. Information on IAG Awards (MP) (Levallois Medal, Guy Bomford Prize, Young Authors Awards, Best Reviewers Award)
5. Proposal of the IAG Budget 2023 – 2026 (MP)
6. Appointment of the Audit Committee (ZA)
7. Appointment of the Resolutions Committee (ZA)
8. Review of the 2023 election process and results (HS)
9. Review of IAG Statutes and Bylaws (Report of the Cassinis Committee) (HS)
10. Status of Journal of Geodesy and IAG Symposia Series (MP)
11. Status of IAG Reports (Travaux de l'AIG) and National Reports 2019-2023 (MP)
12. IAG Scientific Assembly 2025 (MP)
13. Any other business (all)
14. Adjourn

Participants

IAG National Delegates: Australia, *Xiaoli Deng*; Austria, *Johannes Böhm*; Canada, *Ismael Foroughi*; China, *Yamin Dang*; China-Taipei, *Ming Yang*; Czech Republic, *Pavel Novak*; Estonia, *Artu Ellmann*; Finland, *Jyri Näränen*; France, *Severine Rosat*; Germany, *Jürgen Müller*; Greece, *Ilias Tziavos*; Hungary, *Szabolcs Rózsa*; India, *Virendra Tiwari*; Indonesia, *Arief Syafii*; Italy, *Mattia Crespi*; Korea, *Jungho Cho*; Netherlands, *Peter Teunissen*; Poland, *Paweł Wielgosz*; Romania, *Lucian Besutiu*; Sweden, *Martin Lidberg*; Switzerland, *Elmar Brockmann*; UK, *Peter Clarke*; New Zealand, *Dione Hansen*
IAG Executive Committee Members: *Zuheir Altamimi* (IAG President); *Markku Poutanen* (IAG Secretary General); *Harald Schuh* (IAG Past President); *Hermann Drewes* (IAG Past Secretary General); *Richard Gross* (IAG Vice President); *Christopher Kotsakis* (IAG Comm. 1 President); *Adrian Jäggi* (IAG Comm. 2 President)
Guests: *Pierre Briole*; *Tao Jiang*; *Yan Anugrah Rahmawan*; *Pierre Sakic*; *Daniela Thaller* (incoming IAG Secretary General 2023-2027)

Agenda Items and Minutes

1. **Welcome and adoption of agenda**
   Zuheir Altamimi, President of IAG welcomed the participants and presented the Agenda.
2. **IUGG2023 Organisational issues**
   Markku Poutanen, IAG Secretary General summarised the organisational issues of the IUGG General Assembly 2023 and the IAG Scientific program.
3. **Agenda of the Opening and Closing Sessions**
   Markku Poutanen presented the Agenda for IAG Opening and Closing sessions.
4. **Information on IAG Awards**
   Markku Poutanen presented the IAG Awardees which will be awarded in the IAG Opening Ceremonies:
   IAG Young Author's Award 2021: Dr *Radosław Zajdel* (Poland)
   IAG Young Author's Award 2022: Dr *Matthias Willen* (Germany)
   IAG Best Reviewer Award 2021/22: Dr *Jan Martin Brockmann* (Germany)
   IAG Levallois Medal 2023: *Georges Balmino* (France) and *Hermann Drewes* (Germany)
   IAG Guy Bomford Prize: *Amir Khodabandeh* (Australia)
5. **Proposal of the IAG Budget 2023–2026**
   Markku Poutanen summarised the IAG financial report 2019-2022 which showed a surplus of 79000 Euro. This was due to the pandemic period when almost all activities were suspended for more than two years, and e.g. no meetings were organised. He presented the draft for the 2023-2026 budget which shows a deficit of 83000 Euro to get the balance of the IAG bank account. The budget will be discussed by the Audit committee and approved by the Council in its second session.
6. **Appointment of the Audit Committee**
   The Audit Committee should audit and approve the IAG Financial Report 2019-2022 and the IAG Budget 2023-2026 and present their findings in the second session of the Council. *Markku Poutanen* presented names, as proposed by the IAG Executive Committee and Bureau: *Mattia Crespi* (Italy, Chair of the Committee), *Xiaoli Deng* (Australia), *Ismael Foroughi* (Canada), and *Jyri Näränen* (Finland). The IAG Council Members approved the proposed members of the Audit Committee unanimously.
7. **Appointment of the Resolutions Committee**
   The Resolution Committee should prepare future IAG resolutions. *Zuheir Altamimi* presented names, as proposed by the IAG Executive Committee: *Christopher Kotsakis* (President of Comm. 1), *Adrian Jäggi* (President of Comm. 2), *Janusz Bogusz* (President of Comm. 3), *Allison Kealy* (President of Comm. 4), and *Basara Miyahara* (President of GGOS). The IAG Council Members approved the proposed members of the Resolutions Committee unanimously.
8. **Review of the 2023 election process and results**
   Harald Schuh, Chair of the IAG Nomination Committee presented the results of the IAG Officers election process 2023.
9. **Review of IAG Statutes and Bylaws (Report of the Cassinis Committee)**

Harald Schuh, Chair of the IAG Cassinis Committee, gave his report on the review of the IAG Statutes and Bylaws. IAG Council Delegates and Officers were invited to propose changes by 31 January 2023. The IAG Council was invited to make further comments from 21 March to 15 May 2023. The final version of the IAG Statutes and Bylaws was distributed among the Council one month before the General Assembly. The Council will adopt the Statutes and Bylaws in its second session.

10. **Status of Journal of Geodesy and IAG Symposia Series**
Markku Poutanen summarised the status of the Journal of Geodesy which is the official Journal of IAG, published by Springer. The impact factor is 4.8 (2021), and more than 100 articles/year are published. The Editorial Board consists currently of 27 members from 16 countries. The IAG Symposia Series is an open access publication. Papers therein are peer reviewed, and they are available online immediately after acceptance. Since the 2019 General Assembly, five books have been published, and two are in preparation.
11. **Status of IAG Reports (Travaux de l'AIG) and National Reports 2019-2023**
Markku Poutanen summarised that IAG Reports (Travaux de l'AIG) Vol. 41 (2019), Vol. 42 (2021), and Vol. 43 (2023) include detailed reports of all IAG components about their activities in the past period. The reports are available on the IAG website (https://www.iag-aig.org/travaux). National Reports are available on the IAG website. Their number has decreased year by year. National committees are encouraged to submit National Reports to the Secretary General.
12. **IAG Scientific Assembly 2025**
Markku Poutanen gave short information on the next IAG Scientific Assembly 2025. The IAG Council had an online meeting and e-voting in Sept.-Oct. 2021, and Rimini, Italy, was chosen. More information and the invitation by the Italian organisers will be given in the IAG Closing Session.
13. **Any other business (all)**
Zuheir Altamimi opened a discussion on how to communicate and outreach about geodesy and IAG to the general public at national level. Most national delegates agreed that it is highly important and some of them said that they are doing that and have even used some material that they can share with others. We also encouraged them to share and post such material on the IAG website.
14. **Adjourn**
Zuheir Altamimi thanked the participants and closed the session at 10:15.

2 IAG Council Meeting, Session 2 at the IUGG General Assembly, Berlin 2023

Place: Messe Berlin – City Cube, Room M1, July 19, 2023, 08:30-09:45

Agenda

1. Report of the Audit Committee and discharge of the management

2. Approval of the IAG Budget 2023-2026
3. Approval of the revised Statutes and Bylaws
4. Report of the IAG Resolutions Committee
5. Approval of Resolutions
6. Report from IUGG Council and Executive Committee
7. Preparation of the IAG and IUGG Closing Sessions
8. Any other business (all)
9. Closure

Participants

IAG National Delegates: Argentina, *Ezequiel Antokoletz*; Austria, *Franz Blauensteiner*; Belgium, *Juliette Legrand*; Canada, *Ismael Foroughi*; China, *Tao Jiang* Finland, *Jyri Näränen*; France, *Severine Rosat*; Germany, *Jürgen Müller*; Greece, *Ilias Tziavos*; Hungary, *Szabolcs Rózsa*; India, *Virendra Tiwari*; Italy, *Mattia Crespi*; Japan, *Masato Furuya*; Korea, *Jungho Cho*; Latvia, *Ivars Liepins*; Luxembourg, *Norman Teferle*; Netherlands, *Peter Teunissen*; Poland, *Paweł Wielgosz*; Portugal, *Helena Ribeiro*; Romania, *Lucian Besutiu*; Slovakia, *Juraj Janák*; Sweden, *Martin Lidberg*; Switzerland, *Elmar Brockmann*; UK, *Peter Clarke*; New Zealand, *Dione Hansen*;
IAG Executive Committee Members: *Zuheir Altamimi* (IAG President); *Markku Poutanen* (IAG Secretary General); *Harald Schuh* (IAG Past President); *Hermann Drewes* (IAG Past Secretary General); *Richard Gross* (IAG Vice President); *Adrian Jäggi* (IAG Comm. 2 President)
Guests: *Joel Grau Bellet*; *Pierre Briole*; *Daniela Thaller* (incoming IAG Secretary General 2023-2027) *Hartmut Wziontek*

Agenda Items and Minutes

1. **Report of the Audit Committee and discharge of the management**
   Mattia Crespi reported on behalf of the Audit Committee (*Mattia Crespi*; Chair, *Xiaoli Deng*, *Ismael Foroughi*, and *Jyri Näränen*). He applied for discharge of the Secretary General w.r.t. his financial management. The IAG Council Members approved the discharge unanimously.
2. **Approval of the IAG Budget 2023-2026**
   Mattia Crespi reported that the Audit Committee examined also the IAG Budget for 2023-2026 and moved for approval. The IAG Council Members approved it unanimously.
3. **Approval of the Revised Statutes and Bylaws**
   The IAG Council Members approved the revised Statutes and Bylaws unanimously. The revised texts will be placed on the IAG website and published in the Geodesist's Handbook 2024.
4. **Report of the IAG Resolutions Committee**
   Adrian Jäggi reported on behalf of the IAG Resolutions Committee (*Christopher Kotsakis*, *Adrian Jäggi*; Chair, *Janusz Bogusz*, *Allison Kealy*, and *Basara Miyahara*). There was one IAG resolution for the International Terrestrial Gravity Reference System (ITGRS). Moreover, Adrian Jäggi introduced two other resolutions, proposed by IAG and submitted to the IUGG for approval as the IUGG

resolutions. These were "Sustained Terrestrial Water Storage (TWS) Monitoring by Dedicated Gravity Satellite Constellations" and "Improve protection of geodetic observatories from active radio sources". The resolutions will be placed on the IAG website and published in the Geodesist's Handbook 2024.

5. **Approval of Resolutions**
   IAG's resolution for the ITGRS was unanimously approved by the IAG Council Members.
6. **Report from IUGG Council and Executive Committee**
   Zuheir Altamimi summarized the major outcome of the IUGG Council and Executive Committee Meetings and first numbers on the 2023 IUGG General Assembly. He presented the names of the newly elected members of the IUGG Bureau and Finance Committee (2023-2027), incl. *Mioara Mandea* as President-Elect, *Niels Andersen* as Treasurer, and *Jan Krynski* as Finance Committee Member from IAG. He mentioned that the IUGG General Assembly 2027 will be held in Incheon, Republic of Korea.
7. **Preparation of the IAG and IUGG Closing Sessions**
   Markku Poutanen announced the Closing Sessions of IAG and IUGG, which will be held on 19 July 2023, 15:00-16:45 and 17:30-19:00, respectively, and invited all assembly participants to attend. At the IAG Closing Session, all conveners of IAG-related symposia will summarize the highlights and the IAG Fellowship Certificates will be awarded.
8. **Any other business (all)**
   No other business
9. **Closure**
   Zuheir Altamimi thanked the participants for their contributions and closed the session at 9:45.

Summary of the IAG Executive Committee Sessions at the General Assembly 2023

Markku Poutanen: IAG Secretay General 2019-2023
Daniela Thaller: IAG Secretay General 2023-2027

1 Tenth meeting of the IAG EC 2019-2023, Berlin, July 11 & July 13, 2023, 8:30-12:00

Participants

Attendees (voting): *Zuheir Altamimi* (President); *Richard Gross* (Vice President); *Markku Poutanen* (Secretary General); *Harald Schuh* (Immediate Past President); *Hermann Drewes* (Immediate Past SG); *Christopher Kotsakis* (Comm. 1 President); *Adrian Jäggi* (Comm. 2 President); *Janusz Bogusz* (Comm. 3 President); *Allison Kealy* (Comm. 4 President); *Johannes Böhm* (Service Representative); *Tom Herring*$^{(a)}$ (Service Representative); *Toshimichi Otsubo* (Service Representative); *Sonia Costa*$^{(b)}$ (Member-at-Large); *Yamin Dang* (Member-at-Large); *Szabolcs Rózsa* (COB President); *Basara Miyahara* (GGOS President); *Pavel Novák* (ICCT President)
Attendees (non-voting): *Jeff Freymueller*$^{(a)}$ (Editor in Chief, IAG Symposia series); *Jürgen Kusche* (Editor in Chief, Journal of Geodesy); *Annette Eicker* (ICCC President); *Valérie Ballu*$^{(b)}$ (ICCM President); *Jürgen Müller* (QuGe President); **Guests:** *Daniela Thaller* (incoming SG); *Peter Teunissen* (incoming Vice President)
$^{(a)}$ Session 2 only; $^{(b)}$ Online

Agenda Items and Minutes

Session 1: July 11, 2023, 8:30-12:00

1. **Welcome and adoption of agenda (ZA)**
   Zuheir Altamimi welcomed the participants. In addition to the regular participants, Peter Teunissen, incoming IAG Vice President, and Daniela Thaller, incoming IAG Secretary General participated in the meeting.
   There was no addition to the Agenda.
2. **Minutes of the previous EC meeting and Action items (MP)**
   Markku Poutanen introduced the Minutes of the EC09 (March 2023/Vienna). Since they had only been available briefly, it was agreed that EC members would inform MP of any comments.
3. **IUGG2023 organizational issues (MP, HS)**
   Harald Schuh summarised general information of the IUGG GA, with almost 5000 participants which is the record in the history of GAs. Markku Poutanen informed the EC that there are six IAG-only Symposia and seven IAG-lead joint symposia. IAG granted a total of 88 travel Awards of about 60500 Euro, mostly to students and early-career scientists from low- and mid-economy countries.

4. **Agenda of the Council meetings, July 12 & July 19 (ZA, MP)**
   Markku Poutanen introduced the agendas of the coming Council meetings.
5. **Agenda of Opening and Closing Ceremonies, July 12 & July 19 (MP)**
   Markku Poutanen introduced the Agendas of the IAG Opening and Closing Sessions. There was a discussion on the agenda and procedures for numerous presentations and the tight schedule of the opening. MP introduced the Awardees and Medallists. ZA will give a memorial speech of passed away IAG members, with details to Erik Grafarend, Helmut Moritz, and Ivan Mueller.
6. **Report on the Financial status of the period 2019-2023 and budget plan 2023-2027 (for Council) (MP)**
   Markku Poutanen introduced the financial report for the period 2019-2022 and the budget plan for 2022-2026. The budget is similar to previous periods, but due to the Pandemic, there is a surplus which will be used e.g., to increase support for early career scientists in the period 2023-2027. The budget will be introduced to the Council, and the Audit Committee will make their proposal or any remarks for final approval in the second Council meeting.
7. **Proposal for members of the Audit Committee TBD by the Council (all)**
   Markku Poutanen introduced the preliminary list of three candidates for the Audit Committee, Xiaoli Deng (Australia), Ismael Foroughi (Canada), and Jyri Näränen (Finland). It was proposed additionally Mattia Crespi (Italy) be on the list to be presented to the Council. All had accepted the invitation. MP will present the list to the Council for approval or to propose any other members.
8. **Nomination of members of the Resolution Committee for IAG and IUGG (ZA)**
   Members of the Resolution Committee are proposed to be Christopher Kotsakis, Adrian Jäggi, Janusz Bogusz, Allison Kealy, and Basara Miyahara with Adrian Jäggi as the chair of the group. MP will present the list to the Council for approval.
9. **Discussion of proposed resolutions for approval by the IAG Council (all)**
   There are two IAG-related proposals for IUGG resolution, Sustained Terrestrial Water Storage (TWS) Monitoring by Dedicated Gravity Satellite Constellations and Improve protection of geodetic observatories from active radio services. There is one proposal for the IAG resolution, International Terrestrial Gravity Reference System (ITGRS). After a short discussion, the finalisation was left for the committee. Resolutions will be forwarded to the IUGG Council and the IAG Council.
10. **Report of the Journal of Geodesy Editor-in-chief** and
11. **Proposal of the new Board of Editors of JoG (JK)**
    Jürgen Kusche gave a short status report of the JoG. The journal looks healthy and the submissions in 2022 are slightly up from 2021 (349/338). Acceptance rate is 25%. Two special issues are in preparation. JK also gave information that the Springer publisher-editor Petra van Steenberger will retire from Springer and there will be a new one, currently temporarily Steffen Pauly. Renewal of the IAG-Springer Contract on JoG will be forwarded to the new EC.
    JK introduced the members of the new JoG Editorial Board to be approved in the meeting of the EB.

12. **Report of the Editor of the IAG Symposia Series** and
13. **Proposal of the 2023-2027 Editor and Assistant Editor of the IAG Symposia Series (JF)**
    The reports were moved to Session 2.
14. **Results of the 2023 IAG Officers election process**
15. **Report on the review of the IAG Statutes and Bylaws (Cassinis Committee) (HS)**
    Harald Schuh presented the results of the Nominating Committee. These were already introduced in the previous EC meeting (EC9), and are now finalised for the introduction to the Council. Cassinis Committee had prepared revised bylaws and statutes. The preliminary draft was introduced in EC9 and after that, there were practically no new changes. These will be presented in the Council meeting for approval. Mostly minor changes and updates, including in the Statues (i) use of electronic voting systems, in addition to voting by e-mail or correspondence; (ii) generalize "President of ICCT" to "President of Inter-commission Committees" and in the Bylaws updates of descriptions of Commission 3, ICCC, ICCM and GGOS. Additionally, a new procedure to elect the JoG Editor-in-Chief and the Editorial Board.
16. – 21. **Reports of the Commissions (CK, AJ, JB, AK), ICCT (PN), ICCC (AE), ICCM (VB), QuGe(JM), GGOS (BM), COB (SR), Services' representatives (JoB, TH, TO) and Members-at-Large (YD, SC)**
    The Quadrennial reports are the same which will be presented in the Opning Ceremonies, and they are not repeated here.

    Session 2: July 13, 2023, 8:30-12:00
22. **Approval of the new Board of Editors of the JoG (JK, ZA)**
    Jürgen Kusche introduced the list of the new Editorial Board elected by the old EB and to be endorsed in the first meeting of the new EC.
    Claudio Abbondanza (USA), Jerome Benveniste (Italy), Kristel Chanard (France), Sten Claessens (Australia), Mattia Crespi (Italy), Amir Khodabandeh (Australia), Anna Klos (Poland), Alberto Escapa (Spain), Susanne Glaser (Germany), Brian Gunter (USA), Urs Hugentobler (Germany), Frank Lemoine (USA), Xingxing Li (China), Volker Michel (Germany), Felipe Nievinski (Brazil), Robert Odolinski (New Zealand), Jacek Paziewski (Poland), Mirko Reguzzoni (Italy), Michael Schindelegger (Germany), Yunzhong Shen (China), Manoochehr Shirzaei (USA), Benedikt Soja (Switzerland), Yusuke Yokota (Japan), Baocheng Zhang (China). Elected Editor-in-Chief Peiliang Xu (Japan) and Assistant Editor-in-Chief Hansjörg Kutterer (Germany).
23. **Approval of the Editor in Chief of the IAG Symposia Series and an assistant Editor in Chief (ZA)**
    Continuation of the Editor-in-Chief Jeff Freymueller and Assistant Editor-in-Chief Laura Sanchez was unanimously approved.
24. **Appointment of the GGOS Chair for the period 2023-2027 (all)**
    Laura Sanchez was appointed the new President of GGOS based on the EC e-voting in spring 2023.
25. **Appointment of the ICCT, ICCM, ICCC, QuGe President for the period 2023-2027 (all)**

- ICCT: Terms of PN are full, Mattia Crespi (Italy) was proposed as a candidate for the new president by PN and the IAG Bureau.
- ICCC: Annette Eicker, agreed to continue
- ICCM: Valerie Ballu, agreed to continue
- QuGe: Jürgen Müller, agreed to continue

All candidates were approved unanimously.

26. **Appointment of IAG Representatives to IAG Services, IUGG Commissions & others (MP)**
    - ISC World Data System (WDS) Kirsten Elger (Germany)
    - World Meteorological Organization (WMO) Jens Wickert (Germany)
    - United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) IUGG representative Harald Schuh (Germany)
    - Pan American Institute of Geography and History (PAIGH) Laura Sanchez (Germany/Colombia)
    - Consultative Committee for Time and Frequency (CCTF) OPEN (Felix Perosanz will not continue)
    - ISC Committee on Space Research (COSPAR) Christopher Kotsakis willing to continue (t.b.c.)
    - GEO. Richard Gross and Allison Craddock are IAG representatives, and also on the GEO's Program Board.
27. **Status reports (ZA, MP)**
    Markku Poutanen and Zuheir Altamimi gave short reports on IAG and IUGG Council meetings on the previous day.
28. **Status of IAG Report 2019-2023 (Travaux de l'AIG 2019-2023) (MP)**
    Markku Poutanen informed EC that the 2019-2023 IAG report is ready, and he has informed also the Council. The report will be available on the IAG website.
29. **Status of reviewed Statutes and Bylaws (Cassinis Committee, HS)**
    No further information after item 12.
30. **Report on the UN-GGIM (Subcommittee on Geodesy, GGRF, GGIM-GS) (HS, ZA)**
    Harald Schuh informed that the Secretariat of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), in collaboration with the Federal Government of Germany, through its Federal Ministry of the Interior and Community (BMI) and the Federal Agency of Cartography and Geodesy (BKG), hosted the Opening Ceremony of the United Nations Global Geodetic Centre of Excellence (UN-GGCE) on 29 March 2023 at the UN Campus in Bonn, Germany. The agreement between the United Nations and the Federal Republic of Germany, which defines the modality of operationalization of the UN-GGCE, was finalized and signed. He also informed about the establishment of the International Advisory Committee with 20 stakeholder members, including IAG.
31. **Report on IUGG activities (HS)**
    Topics covered elsewhere, item to be removed here.
32. **Reports on liaised bodies (ABLOS, IAU Comm. 19, GEO, ISO, UN (HS, ZA, MP, all)**
    The topic was moved to the Agenda of the new EC.

33. **Status of the IAG Scientific Assembly 2025 (MP)**
The next IAG Scientific Assembly in 2025 will be in Rimini, Italy, as voted by the Council in 2021. Markku Poutanen has been regularly in contact with the local organisers, Susanna Zerbini and Stefano Gandolfo. Preparations have been started, and the Scientific Organising Committee must be established in early 2024. A short introduction to the venue and invitation to participate in the IAG Scientific Assembly 2025 will be given at the IAG Closing Ceremonies by the Italian representative.
34. **Report on Levallois Medal, Guy Bomford Prize, Young Authors and Best Reviewers' Awards (MP)**
    - **Levallois medals** were granted to Georges Balmino for his outstanding contributions to the IAG and to the science of Geodesy in general and Hermann Drewes for his outstanding contributions to the IAG and to the science of Geodesy in general.
    - **Guy Bomford Prize** was granted to Dr Amir Khodabandeh for his outstanding theoretical and applied contributions to geodetic studies.
    - **IAG Fellows 2023**: Graham Appleby (UK), Kyriakos Balidakis (Germany), Elmar Brockmann (Switzerland), Gabriel do Nascimento Guimarães (Brazil), Wei Feng (China), Ryan Hippenstiel (USA), Xiaopeng Li (USA), Martin Lidberg, (Sweden), Ulrich Meyer (Switzerland), Basara Miyahara (Japan), Emily Montgomery-Brown (USA), Takuya Nishimura (Japan), Jean-Mathieu Nocquet (France), Toshimichi Otsubo (Japan), Paul Rebischung (France), Laura Ruotsalainen (Finland), Alvaro Santamaría-Gómez (France), Zheng-Kang Shen (USA), Wenbin Shen (China), Rebekka Steffen (Sweden), Derek van Westrum (USA).
    - The Young Authors Award 2021 and 2022 were granted to Dr Radosław Zajdel and Dr Matthias Willen.
    - The IAG Best Reviewer Award was granted to Jan Martin Brockmann.
35. **Appointment of Honorary Officers (President, Secretary General, Fellows) (Bylaws 22) (ZA, MP)**
Past President Zuheir Altamimi and past Secretary-General Markku Poutanen were appointed as the IAG Honorary Officers. They will receive their certificates at the Closing Ceremonies.
36. **Preparation of the IAG Closing Session (MP, all)**
Markku Poutanen showed the draft of the Agenda for the Closing Ceremonies. There was a short discussion on procedures for presenting the session summaries by the conveners to keep the tight schedule. It was agreed that MP asks each convener to send beforehand one slide where the main points of a session are summarised. Also, the Certificates of the Fellows will be delivered on the occasion.
37. **Any other business (ZA)**
    - Error in the 1999 Birmingham resolution No. 3 to compute the group refractive index in the air for electronic distance measurement to better than one part per million (ppm) with visible and near-infrared waves in the atmosphere using the computer procedure published by Ciddor & Hill in Applied Optics (1999, Vol.38, No.9,1663-1667) and Ciddor in Applied Optics (1996,

Vol. 35, No.9, 1566-1573). Within the 18SIB01 GeoMetre project of the European Metrology Programme for Innovation and Research (EMPIR) in 2020 Florian Pollinger of PTB, Braunschweig, Germany pointed out that in the annex which provides the algorithm, there is a sign error which caused a deviation in results. The resulting group index of refraction deviates in about the correct order of magnitude from the group index but the deviation has the wrong sign. Explanation is published in: Pollinger, F. (2020) Refractive index of air. 2. Group index: comment Appl. Opt., OSA, 2020, 59, 9771-9772 https://doi.org/10.1364/AO.400796. It was agreed to add a note to the IAG website but not necessary to bring it to the Council.

- Discussion on how to get EC acceptance/opinion/comments on an article of the IAG Service or other IAG entity published by IAG (e.g. Newsletter) to ensure that it reflects the IAG values and opinions. No definite decision.

38. **Closing the EC of the legislative period 2019-2023 (ZA)**
This is the last meeting of the EC 2019-2023. ZA thanked the EC members for their valuable work and wished them all the best for the future.
39. **End and farewell to the EC members**

2 First meeting of the IAG EC 2023-2027, Berlin, July 20, 2023, 8:30-12:00

Participants

Attendees (voting): *Richard Gross* (President); *Peter Teunissen* (Vice President); *Daniela Thaller* (Secretary General); *Zuheir Altamimi*(Immediate Past President); *Markku Poutanen* (Immediate Past Secretary General); *Srinivas Bettadpur* (Comm. 2 President); *Rebekka Steffen* (Comm. 3 President); *Paweł Wielgosz* (Comm. 4 President); *Riccardo Barzaghi* (Service Representative); *Vincenza Luceri* (Service Representative); *Szabolcs Rózsa* (COB President); *Laura Sánchez* (GGOS President); *Maria Virginia Mackern*[(a)] (Member-at-Large); *Masato Furuya* (Member-at-Large); *Mattia Crespi* (ICCT President); *Annette Eicker* (ICCC President
Attendees (non-voting): *Jürgen Müller* (QuGe Project); *Peiliang Xu* (JoG Editor in Chief); *Hermann Drewes* (Past Secretary General); *Harald Schuh* (Past President)
Guests: *CK Shum* (IAS team); *Jérôme Benveniste* (IAS team); *Martin Sehnal* (GGOS Coordinating Office)
[(a)] Online

Agenda Items and Minutes

1. **Welcome and adoption of agenda**
   RG welcomes all IAG EC members and guests to the first EC meeting of the period 2023-2027. The quorum needed for voting is reached. The agenda is adopted.
2. **Introduction to the IAG EC 2023-2027**
   RG is introducing the EC for the IAG period 2023-2027. The members present introduce themselves. In terms of diversity in the EC: the gender balance is quite good, the global balance rather poor, the balance in view of career stage is not bad.
3. **IAG Outreach activities**
   SR and Martin Sehnal as guest present the plans for common IAG-GGOS outreach activities in order to benefit from synergies and to reach a common branding for all IAG components including GGOS. The IAG website should focus on IAG internal aspects whereas the GGOS website on external information. Changes in IAG Bylaws are required to establish the proposed new structure for outreach, i.e., it can be effective only 2027ff. The period 2023-2027 will be used as transition with the focus on website unifications. It is decided to establish and register new common domains: geodesy.science (redirecting to www.iag-aig.org), ggos.geodesy.science (redirecting to www.ggos.org) and products.geodesy.science (redirecting to www.ggos.org/products).
4. **International Altimetry Service (IAS): Proposal to establish Pilot Service**
   CKS and JB as guests present the proposal for establishing an International Altimetry Service (IAS), including structure, members, potential products. The EC approves the proposal and agrees on the following: (i) A planning committee is needed; (ii) Connection to other IUGG Services is important, but IAG should have

the lead; (iii) Guidance on "how to establish a Service" is needed for the IAS team; (iv) Measures of success should be defined; (v) Regular checks whether the preparations are going in the right direction; (vi) Establishment of combined products for validation is important. The IAS planning team should regularly report at the EC meetings.

5. **GGOS**
   - RG announces the result of the election of a new GGOS President: Laura Sánchez.
   - LS presents ideas for changes in the GGOS structure, mainly the merging of Consortium and Coordinating Board to a Governing Board, and the subsequent changes in the member list. The changes, as revised GGOS ToR, need to be approved by the IAG EC. This will be done by electronic voting. The new GGOS Strategic Plan will be finalized and adopted by the end of 2023.
   - A GGOS Focus Area may exist for long-term, whereas a Study Group is foreseen only for four years.
   - GGOS strives for open data policy by promoting and further developing FAIR principles and the usage of DOI.
6. **IAG Structure Review Committee**
   RG presents the results of the Committee:
   - Splitting Comm. 4: The structure of Comm. 4 reflects already in 2023-2027 the intended restructuring and will be further discussed in coming EC meetings. The separation into two commissions would take effort 2027ff.
   - Hydrogeodesy should become visible within the IAG structure. The topic is included in ICCC. An option would be to initiate an Inter-Association Committee with IAHS, but committees at IUGG level can be problematic. IAG should try to establish stronger link to other IUGG associations.
   - GGOS is mainly for advocating geodesy to external organizations (see also the Agenda item "IAG Outreach activities" above).
7. **General Procedure for establishing the IAG components 2023-2027**
   The procedure and time line for establishing all IAG components for the new period 2023-2027 is discussed. The first step is to choose Vice-president as he/she can help with the setup. At the moment, the EC does not see any need to change any of the sub-commissions. The finalized structure should be presented by the Presidents/Chairs of the IAG components at the EC meeting in December 2023.
8. **Structure of Commissions**
   Comm. 1: As UH is excused, his statement sent before the meeting is presented by DT. Comm. 2: SB presents the status. EC advises him to also contact the former Comm. 2 President for guidance. Comm. 3: RS presents the status. Setup developed in good cooperation with previous Comm. 3 President, few details are still missing. Comm. 4: PW presents the status. The potential future separation of Comm. 4 is already taken into account in the current setup, few details are still missing.
9. **Structure of ICCT**
   MC explains the status and some open questions.
10. **Structure of ICCC**
    AE presents the status: similar setup as in previous period; few details still open.

11. **Structure of ICCM**
    As VB is excused, her status report sent before the meeting is presented by DT.
12. **Structure of Project QuGe (JM)**
    JM presents the status.
13. **Representation of the Services to IAG EC (RB, TH, VL)**
    The responsibility of the three service representatives is distributed as follows: RB for IGFS, BGI, ICGEM, IDEMS, IGETS and ISG. TH for IGS, IERS and PSMSL. VL for IDS, ILRS and IVS. Besides, the IGFS has just elected RB as Chair.
14. **Representation to IAG services and external bodies**
    Not discussed due to lack of time. The topic will be followed up within the IAG Bureau meetings.
15. **Introduction of Members-at-Large**
    MVM and MF give a short statement about their contributions to IAG. They stress bringing IAG also into less developed regions.
16. **IAG publications with Springer (DT, PX, JF)**
    - A new contract with Springer has been developed. Many comments/questions are still open (mainly by Jürgen Kusche). It is left to the new IAG Bureau to check this contract, add comments etc. and finalize it with Springer.
    - It is important to shorten the time for review process in the Journal of Geodesy. An option would be to allow for a common review by student and supervisor.
    - The digitalization of Manuscripta Geodetica should be foreseen, involving Springer.
17. **Geodesist's Handbook 2024**
    DT shortly presents the time line for preparing the Geodesist's Handbook. The topic will be followed up in the next EC meetings.
18. **Increase diversity: Increase involvement of young scientists**
    - IAG is one of three IUGG associations which do not have ECS (Early Career Scientist) members in their EC. Changes in IAG Bylaws are required to include ECS in the EC: but within the current period, the IAG EC can invite ECS as guests.
    - According to the current IUGG rules: ECS is a person up to 10 years after PhD. This career stage information is not requested for IUGG registrations up to now, therefore, detailed statistics is not possible. But, it should be asked at registration for future IAG meetings.
19. **Increase diversity: Establishing Task Force for broadening the inclusion**
    EC decides to establish a dedicated Task Force for increasing diversity regarding "3G" = gender, geographical coverage, generation/career stage. Following EC members form the Task Force: RS, MC, AE, SR, SB, VM, MF, DT, PT, PW. The Task Force should meet online. It will regularly report at EC meetings.
20. **Any other business**
    The next EC meeting will take place the weekend before AGU in December 2023, in San Francisco.

Resolutions at the XXVIII IUGG General Assembly 2023

Resolution 1: Improving Protection of Geodetic Observatories from Active Radio Services

The International Union of Geodesy and Geophysics,

Considering

- that the United Nations General Assembly Resolution 69/266 "A global geodetic reference frame for sustainable development" invites member states "to commit to improving and maintaining appropriate national geodetic infrastructure as an essential means to enhance the global geodetic reference frame", and
- that the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) is based on geodetic observatories employing radio telescopes for the method of Very Long Baseline Interferometry (VLBI) which is fundamental for the Global Geodetic Reference Frame (GGRF),

Acknowledging

- that a multi-national best-effort endeavour to provide the needed products has been carried out by the International VLBI Service for Geodesy and Astrometry (IVS) since 1999, and
- that the IVS is developing a new observing system, the VLBI Global Observing System (VGOS), to improve and enhance the global network capabilities in order to meet the accuracy goals needed for geodesy in the context of sustainable development,

Noting

- that the use of the electromagnetic spectrum is administered globally by the International Telecommunication Union (ITU), depending on inputs from national administrations,
- that the electromagnetic spectrum is a limited resource, and the increasing number of ground and space-based transmitters endanger the undisturbed VLBI observations of cosmic radio sources in the universe, and hence endanger the GGRF, and
- that there is no supra-national administration for the protection of global networks such as the global network of geodetic observatories,

Urges

- the affiliated scientific associations to advocate spectrum management issues at national, regional and international administration levels for the protection of their interests in the use of the electromagnetic spectrum.

Resolves

- to support the introduction and conservation of local radio quiet zones or local coordination zones around the VLBI global network stations; and
- to bring this Resolution to the attention of the Director of the United Nations Statistical Commission (UNSC), to the Director of the United Nations Office for Outer Space Affairs (UNOOSA) and to the Secretary General of the ITU.

Resolution 2: Sustained Terrestrial Water Storage (TWS) Monitoring by Dedicated Gravity Satellite Constellations

The International Union of Geodesy and Geophysics,
Considering

- the interest of the IUGG scientific community to understand the processes of changes in global Terrestrial Water Storage (TWS), comprising all the water storage on the Earth's continental areas in frozen and liquid state, including ice caps, glaciers, snow cover, soil moisture, groundwater and the storage in surface water bodies and the interaction with ocean mass and sea level,
- that satellite gravimetry missions are a unique observing system to directly measure TWS on a regional to global scale,
- the ongoing efforts of national and international institutions and space agencies to extend the GRACE/GRACE-FO program of record that runs already for more than two decades and enhance it with improved satellite gravimetry products, and
- the significant efforts of the International Association of Geodesy (IAG) in developing and maintaining fundamental geodetic products, in particular snapshots of the Earth's time-variable gravity field providing TWS maps for scientific and societal benefits,

Acknowledging

- the adoption by the IUGG of Resolution 2 in Prague 2015 on Future Satellite Gravity and Magnetic Mission Constellations, and the adoption of TWS as a new Essential Climate Variable (ECV) in the implementation plan 2022 of the Global Climate Observing System (GCOS),

Noting

- that satellite gravimetry missions such as GRACE and GRACE-FO successfully demonstrated the ability to globally observe the spatial and temporal variations of TWS from time-variable gravity on all continental areas,
- that improved temporal and spatial resolution and significantly increased accuracy are urgently needed by the user community and by operational services for, e.g., flood and drought monitoring and forecasting and water resources management, and

- that new technologies have been developed (such as laser ranging interferometry) or are currently being investigated (such as quantum gravimetry),

Urges
national and international space agencies and decision makers to

- implement and maintain long-term sustained observing systems of the Earth's time-variable gravity field realized by dedicated gravity satellite constellations with improved measurement technology to enable new science and applications of enormous societal benefit; and
- evolve them into sustainable operational services in the longer term.

Resolution 3: Sharing Geophysical Data across Borders

The International Union of Geodesy and Geophysics,
Noting

- that geopolitical conflicts create restrictions in sharing geophysical data across borders for scientific use, and
- that the above restrictions have negative impact on international scientific research, services and collaboration,

Recognizing

- that sharing geophysical data across borders is an international norm, and
- that sharing geophysical data can enhance their scientific returns and benefit the entire world, including nations that are involved in geopolitical conflicts,

Urges

- National Committees and relevant national bodies to take necessary actions in their respective countries to support sharing of geophysical data across borders; and
- the International Science Council (ISC) and other relevant international bodies to support national authorities, including those involved in geopolitical conflicts, in efforts to share geophysical data across borders.

Resolution 4: Weather and Climate Engineering Based on the Addition of Aerosol Particles

The International Union of Geodesy and Geophysics,
Considering

- that anthropogenic greenhouse gas (GHG) emissions are increasing, leading to multi-decadal increases in global average temperature and other weather and climate impacts,

Recognizing

- that progress has been made in the understanding of the role of aerosol particles (AP) in Earth's weather and climate,
- that approaches to counteract the climate change of anthropogenic origin involving the interaction of AP with the atmosphere have been proposed, and
- that these concepts have become part of the discussion of weather and climate intervention (WCI) or geoengineering, the deliberate intervention in the regional and large-scale planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts,

Acknowledging

- that scientific research on detailed AP-based WCI techniques is relatively new and the current level of scientific knowledge about their feasibility and effects is poorly understood,
- that AP-based WCI can potentially damage biodiversity, ecosystems, agricultural production, water security, ecological services for society and sustainable development inside as well as outside target regions, and
- that given the current state of understanding, AP-based WCI cannot be considered a complement to or replacement for other mitigation approaches,

Noting

- that in addition to fundamental science questions, any attempt at AP-based WCI gives rise to societal, ethical, legal and governmental issues,

Recommends

- further research on the fundamental science and possible efficacy of AP-based WCI schemes, conducted in an open and independent manner that engages public participation, is used to assess properly the potential risks of regional and global climate change both with and without AP-based WCI.

Urges

- the research community and policymakers to consider and address the societal, ethical, legal and governmental implications of AP-based WCI and fully engage all stakeholders in the decision-making process; and
- the development of effective and inclusive national and global governance frameworks that can address and manage all these considerations, prior to any WCI activity.

Resolves
that currently AP-based WCI cannot be considered an acceptable complement to

- the rapid implementation of required large reductions in GHG and short-lived climate pollutants; and
- greatly enhanced resilience to mitigate the increasingly serious problem of global warming.

Resolution 5: Preservation and Dissemination of and Enhanced Access to Analogue Records

The International Union of Geodesy and Geophysics,

Considering

- the need for historical data preservation and open access in Earth sciences, and the risk of loss of large volumes of such data despite ongoing efforts devoted to their preservation,

Noting

- that the digital management of analogue data (seismograms, magnetograms, marigrams, meteorograms, etc.) will undoubtedly improve their future preservation and add a wealth of information to our analysis,
- that the management of analogue data is a challenging task for many scientific communities, and that some crucial data have already been lost forever, and
- the impending retirement of the last generation of geoscientists familiar with the use of analogue data, along with the loss of knowledge on how these data were recorded, calibrated, and analysed,

Recognizing

- the interdisciplinary consensus that all Earth science data, ranging from the deep Earth interior to the outer atmosphere, should be preserved, open, and freely accessible to the scientific community,
- the increasingly multidisciplinary nature of geoscience research,
- the rising value of long-term data series in geosciences for their long-term variability and short-term extremity,
- the increasing capabilities of modern computational infrastructure to facilitate storage, management, and access of data and information, and
- the growing recognition of the importance and benefits of the standardization of scientific data formats,

Encourages
the scientific community and their scientific bodies worldwide

- to participate continuously in the improvement of analogue data recovery, preservation, digitization, and open distribution using established standards and digital repositories to bridge the existing digital divide between researchers who only use digital records and those who are familiar with analogue ones;
- to document properly and include the procedures originally used to generate these records in their associated metadata; and
- to develop improved tools for their use.

Urges

- the International Science Council, UNESCO, WMO, and other relevant international bodies to assist national authorities in this mission;
- the funding agencies to support the effort to rescue valuable analogue data; and
- the scientific community to contribute to the development of unified standards as well as the coordination of digital repositories and their compatibility among themselves and with the WDS guidelines/policies while following FAIR principles.

Resolution 6: Thanks

The International Union of Geodesy and Geophysics,
Resolves

- To record gratefully its appreciation for the organization, arrangements, and hospitality at its 28th General Assembly.
- On behalf of all participants the Council expresses its warm thanks to the Local Organizing Committee, the Scientific Program Committee, the main organizer and host German Research Centre for Geosciences (GFZ) and its co-organizers: the Helmholtz Association, Geo.X, the Federal Institute for Geosciences and Natural Resources (BGR), the Federal Agency for Cartography and Geodesy (BKG), the GEOMAR Helmholtz Centre for Ocean Research Kiel and the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), the professional conference organizer company C-IN, and all others for making the 28th General Assembly an outstanding success in the beautiful city of Berlin.

IAG Resolutions at the XXVIII IUGG General Assembly 2023

IAG resolution for the International Terrestrial Gravity Reference System (ITGRS)

The International Association of Geodesy,

Noting

- the importance of an International Terrestrial Gravity Reference System (ITGRS) for geodesy and geosciences,
- that with state-of-the-art absolute gravimeters a relative accuracy of 10^{-8} and better is achievable,

Acknowledging

- the IAG resolution No. 9.2 and 16.3 adopted at the 18th IUGG General Assembly in Hamburg in August 1983, recommending the use of a common standard atmosphere and the zero-tide concept,
- the IAG Resolution No. 2 for the establishment of a global absolute gravity reference system adopted at the 26th IUGG General Assembly in Prague in July 2015,
- the IAG Resolution No. 4 on the establishment of the Infrastructure for the International Terrestrial Gravity Reference Frame, adopted at the 27th IUGG General Assembly in Montreal in July 2019,

Resolves

- that the definition of the ITGRS be based on the instantaneous acceleration of free-fall expressed in SI and related to the zero-tide concept, a standard atmosphere, and Earth orientation in the ITRS (International Terrestrial Reference System).

Recommends

- that the ITGRS be adopted as the reference system for gravity acceleration in geosciences and metrology.

Requests

- that Commission 2 (Gravity Field) together with IGFS (International Gravity Field Service), BGI (International Gravimetric Bureau) and IGETS (International Geodynamics and Earth Tide Service) prepare and disseminate guidelines and conventions for the establishment of the International Terrestrial Gravity Reference Frame (ITGRF) as the realization of the ITGRS.

Correction to the 1999 IAG resolution No. 3: On the calculation of group refractive index for EDM.

IAG Resolution 3 of the 1999 Birmingham IUGG General Assembly recommended to compute the group refractive index in air for electronic distance measurement to better than one part per million (ppm) with visible and near infrared waves in the atmosphere using the computer procedure published by Ciddor & Hill in Applied Optics (1999, Vol.38, No.9,1663-1667) and Ciddor in Applied Optics (1996, Vol. 35, No.9, 1566-1573).

However, within the 18SIB01 GeoMetre project of the European Metrology Programme for Innovation and Research (EMPIR) in 2020 Florian Pollinger of PTB, Braunschweig, Germany pointed out that in the annex which provides the algorithm, there is a sign error which cause a deviation in results. The resulting group index of refraction deviates in about the correct order of magnitude from the group index but the deviation has the wrong sign. Explanation is published in: Pollinger, F. (2020) Refractive index of air. 2. Group index: comment Appl. Opt., OSA, 2020, 59, 9771-9772 https://doi.org/10.1364/AO.400796.

IAG recommends to use the correction published by Pollinger (2020) when using the Ciddor and Hill Formula according to the IAG Resolution No.3 of 1999.

Part III

Structures for the Period 2023 – 2027

Structures for the Period 2023 - 2027

1 International Union of Geodesy and Geophysics (IUGG)

www.iugg.org/; secretariat@iugg.org

Refer to the current version of the IUGG Yearbook available at https://iugg.org/publications/yearbooks/ for additional information about the IUGG structure, the detailed composition of its components (such as Union Commissions, Inter-Unions Commission, the eight International Associations a.o.) as as well as for full contact data of all IUGG Officers, Liaison Officers and Representatives.

1.1 IUGG Executive Committee

IUGG Bureau:

President:	Chris Rizos	AUSTRALIA
President-Elect:	Mioara Mandea	FRANCE
Secretary General:	Alexander Rudloff	GERMANY
Treasurer	Niels Andersen	DENMARK
Members:	Athena Coustenis	FRANCE
	Andrew Mackintosh	AUSTRALIA
	Virendra Tiwari	INDIA

Immediate Past President (2019-2023):

	Kathryn Whaler	UK

Presidents of the International Associations:

IACS:	Liss M. Andreassen	NORWAY
IAG:	Richard Gross	USA
IAGA:	Andrew Yau	CANADA
IAHS:	Berit Arheimer	SWEDEN
IAMAS:	Andrea Flossmann	FRANCE
IAPSO:	Hans van Haren	NETHERLANDS
IASPEI:	Michelle Grobbelaar	SOUTH AFRICA
IAVCEI:	Costanza Bonadonna	SWITZERLAND

1.2 IUGG Finance Committee

Chair:	Jan Krynski	POLAND
Members:	Archana Bhattacharyya	INDIA
	Priscilla Grew	USA

1.3 IUGG Secretariat

The Secretariat is hosted at the Helmholtz Centre Potsdam,GFZ German Research Centre for Geosciences,Telegrafenberg, A17,14473 Potsdam, Germany. The Executive Secretary is a non-voting member of the IUGG Bureau.

Executive Secr.:	Franz G. Kuglitsch	GERMANY
Assistant:	Katrin Gundrum	GERMANY
Webmaster:	Jan Schubert	GERMANY

2 International Association of Geodesy (IAG)

www.iag-aig.org/; IAG-Office@bkg.bund.de

The IAG is organised, operates and works in accordance with its Statutes and Bylaws. The IAG structure comprises several components: four Commissions, the Inter-Commission Committees on Theory (ICCT), Climate Research (ICCC), and Marine Geodesy (ICCM), Project Novel Sensors and Quantum Technology for Geodesy (QuGe), twelve International Scientific Services, the Global Geodetic Observing System (GGOS), and the Communication and Outreach Branch (COB).

The Commissions include Sub-commissions, Working Groups (WG) and Study Groups (SG). The Inter Commission Committees (ICCs) and the Project investigate scientific geodetic-related problems in close cooperation with the Commissions. The ICCs and the Project also establish WG and SG. The Services generate scientific products by means of Operation, Data and Analysis Centres.

The GGOS is a component of IAG which works with the Services to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research. GGOS ensures the basis to maintain a stable, accurate and global reference frame, which is crucial for all Earth observation.

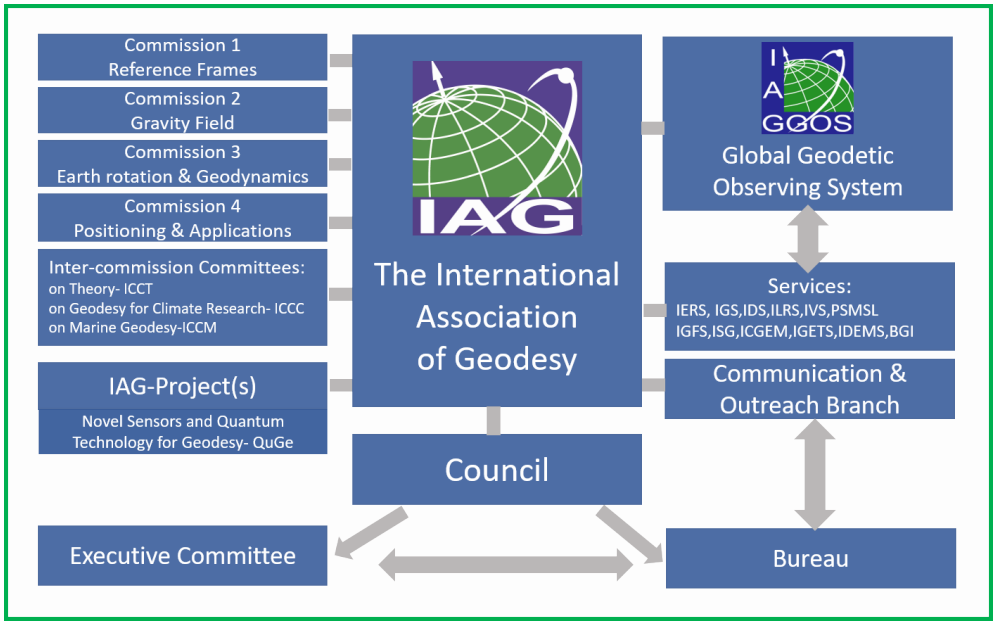

Fig. 1. Organizational structure of the IAG for 2023-2027

Joint Working Groups (JWG) and Joint Study Groups (JSG) are established for scientific topics relating to more than one IAG component. They are led by one IAG component, the other component(s) are jointly contributing.

The COB provides communication, public information and outreach links, in particular via the IAG website and the monthly Newsletters. The COB is responsible for the promotional activities of the IAG and the communication with its members, with other scientific organizations and with the world as a whole.

The administrative work of the IAG is performed by the General Assembly, the Council, the Executive Committee (EC), the Bureau and the IAG Office. The Council is composed by the delegates appointed by the national adhering bodies. The Council determines the strategy and elects the EC and the Bureau members. The EC consists of 17 elected members, 2 ex-officio members (immediate past President and Secretary General) and 5 non-voting members. The EC implements and advances the strategy. The Bureau administers the affairs of the IAG: it consists of the President, the Vice President and the Secretary General. To assist the Secretary General in his/her duties the IAG Office is established at his/her home institution.

The detailed programme of the IAG is published in the quadrennial *Geodesist's Handbook*, and bi-annual IAG Reports are published as *Travaux de l'Association de Géodésie*.

For contact information of the IAG Officers listed below, refer to the actual version of the IUGG Yearbook available at https://iugg.org/publications/yearbooks/.

2.1 IAG Executive Committee

Fig. 2. The new IAG EC for 2023-2027

IAG Bureau:

President:	Richard Gross	USA
Vice President:	Peter Teunissen	NETHERLANDS
Secretary General:	Daniela Thaller	GERMANY

IAG Immediate Past President:

President 2019-2023:	Zuheir Altamimi	FRANCE

IAG Immediate Past Secretary General:

Secr. General 2019-2023:	Markku Poutanen	FINLAND

IAG Commission Presidents:

Commission 1:	Urs Hugentobler	GERMANY
Commission 2:	Srinivas Bettadpur	USA
Commission 3:	Rebekka Steffen	SWEDEN
Commission 4:	Paweł Wielgosz	POLAND

President of the Inter-Commission Committee on Theory (ICCT):

	Mattia Crespi	ITALY

President of the Inter-Commission Committee for Climate Research (ICCC):

	Annette Eicker	GERMANY

President of the Inter-Commission Committee for Marine Geodesy (ICCM):

	Valérie Ballu	FRANCE

President of the Global Geodetic Observing System (GGOS):

	Laura Sánchez	GERMANY

President of the Communication and Outreach Branch:

	Szabolcs Rózsa	HUNGARY

Representatives of the IAG Services:

	Riccardo Barzaghi	ITALY
	Tom Herring	USA
	Vincenza Luceri	ITALY

IAG Members at Large:

	Masato Furuya	JAPAN
	Maria Virginia Mackern	ARGENTINA

Non-voting Members:

IAG Project QuGe:	Jürgen Müller	GERMANY
JoG Editor in Chief:	Peiliang Xu	JAPAN
Symposia Series Ed. in Chief:	Jeff Freymueller	USA
Past President:	Harald Schuh	GERMANY
Past Secretary General:	Hermann Drewes	GERMANY

2.2 IAG Commissions and Inter-Commission Committees

Commission 1: Reference Frames

President:	Urs Hugentobler	GERMANY
Vice President:	Xavier Collilieux	FRANCE

Commission 2: Gravity Field

President:	Srinivas Bettadpur	USA
Vice President:	Tao Jiang	CHINA

Commission 3: Earth Rotation and Geodynamics

President:	Rebekka Steffen	SWEDEN
Vice President:	Jose M. Ferrandiz	SPAIN

Commission 4: Positioning and Applications

President:	Paweł Wielgosz	POLAND
Vice President:	Xingxing Li	CHINA

Inter-Commission Committee on Theory (ICCT)

President:	Mattia Crespi	ITALY
Vice President:	Amir Khodabandeh	AUSTRALIA

Inter-Commission Committee for Climate Research (ICCC)

President:	Annette Eicker	GERMANY
Vice President:	Carmen Blackwood	USA

Inter-Commission Committee on Marine Geodesy (ICCM)

President:	Valérie Ballu	FRANCE
Vice President:	Heidrun Kopp	GERMANY

2.3 Project Novel Sensors & Quantum Technology for Geodesy (QuGe)

President:	Jürgen Müller	GERMANY
VicePresident:	Marcelo Santos	CANADA

2.4 IAG Global Geodetic Observing System

President:	Laura Sánchez	GERMANY
Vice President:	Anna Riddell	AUSTRALIA

2.5 IAG Office

The IAG Office is hosted at the Federal Agency of Cartography & Geodesy (BKG), Richard-Strauss-Allee 11, 60598 Frankfurt am Main, Germany.

Secretary General:	Daniela Thaller	GERMANY
Assistant Secretary:	Christina Dimopoulou	GERMANY
Assistant Secretary:	Martin Sehnal	AUSTRIA

2.6 IAG Communication & Outreach Branch

President:	Szabolcs Rózsa	HUNGARY
Secretary:	Martin Sehnal	AUSTRIA

2.7 Journal of Geodesy

Editor in Chief:	Peiliang Xu	JAPAN
Assistant Editor in Chief:	Hansjörg Kutterer	GERMANY

2.8 IAG Symposia Series

Editor in Chief:	Jeff Freymueller	USA

2.9 IAG Services

International Earth Rotation and Reference Systems Service (IERS):

Chair of Directing Board:	Tonie van Dam	USA
Director of Central Bureau:	Daniela Thaller	GERMANY

International GNSS Service (IGS):

Chair of Governing Board:	Rolf Dach	SWITZERLAND
Director of Central Bureau:	Allison Craddock	USA

International DORIS Service (IDS):

Chair of Governing Board:	Frank Lemoine	USA
Director of Central Bureau:	Laurent Soudarin	FRANCE

International Laser Ranging Service (ILRS):

Chair of Governing Board:	Stephen Merkowitz	USA
Director of Central Bureau:	Michael Pearlman	USA

International Service for Geodesy and Astrometry (IVS):

Chair of Directing Board:	Rüdiger Haas	SWEDEN
Director of Coordinating Centre:	Dirk Behrend	USA

Permanent Service for Mean Sea Level (PSMSL):

Head:	Elizabeth Bradshaw	UK

International Gravity Field Service (IGFS):

Chair:	Riccardo Barzaghi	ITALY
Director of Central Bureau:	Georgios Vergos	GREECE

International Service for the Geoid (ISG):

President:	Mirko Reguzzoni	ITALY
Director:	Daniela Carrion	ITALY

International Centre for Global Earth Models (ICGEM):

Director:	Elmas Sinem Ince	GERMANY

International Geodynamics and Earth Tide Service (IGETS):

Chair:	Marta Calvo	SPAIN
Director of Central Bureau:	Jean-Paul Boy	FRANCE

International Digital Elevation Model Service (IDEMS):

Director:	Kevin M. Kelly	USA

Bureau Gravimetrique International (BGI):

Director:	Sylvain Bonvalot	FRANCE

2.10 Overview of Joint Working Groups and Joint Study Groups

The JWG and JSG which have been established across several IAG components for the period 2023-2027 are summarized in Fig. 3 and in the list after it. The groups are led by one IAG component, the other component(s) are jointly contributing.

For descriptions of these groups, refer to the chapters of their lead components in this Handbook.

Lead → Joint with ↓	Comm 1	Comm 2	Comm 3	Comm 4	ICCT	ICCC	ICCM	GGOS
Comm 1			JSG 3.1		JSG T.40 JSG T.41 JSG T.43 JSG T.50		JWG M.2	
Comm 2			JSG 3.1		JSG T.38 JSG T.39 JSG T.40 JSG T.41 JSG T.42 JSG T.43 JSG T.45 JSG T.46 JSG T.47 JSG T.48	JWG C.2 JWG C.3 JWG C.4 JWG C.9 JWG C.10		GGOS.AI4G.JSG 2
Comm 3	JWG 1.2.3 JWG 1.4.1				JSG T.41 JSG T.42 JSG T.45 JSG T.46 JSG T.48	JWG C.1 JWG C.2	JWG M.2 JWG M.3 JWG M.6	GGOS.AI4G.JSG 3 GGOS.AI4G.JSG 4
Comm 4					JSG T.41 JSG T.44 JSG T.48 JSG T.49 JSG T.50	JWG C.4 JWG C.5 JWG C.6 JWG C.7 JWG C.8	JWG M.2 JWG M.4 JWG M.5	GGOS.GSWR.JSG 1 GGOS.GSWR.JSG 2 GGOS.GSWR.JSG 3 GGOS.AI4G.JSG 1
ICCT						JWG C.10		
ICCC		JWG 2.3.1					JWG M.3	GGOS.GSWR.JSG 2 GGOS.AI4G.JSG 1 GGOS.AI4G.JSG 2
GGOS	JWG 1.1.1 JWG 1.1.2 JWG 1.2.2			JWG 4.3.1 JWG 4.3.7	JSG T.44 JSG T.48 JSG T.49	All 10 groups JWG C.1 ....C.10	JWG M.1	
QuGe				JSG 4.1.7				
IERS	JWG 1.1.1 JWG 1.2.2 JWG 1.2.4 JWG 1.4.3					JWG C.1	JWG M.1 JWG M.5	
IGS	JWG 1.2.1			JWG 4.3.1 JWG 4.3.6		JWG C.7 JWG C.8		
IVS						JWG C.7		
IGFS		JWG 2.1.1 JWG 2.2.1			JSG T.38 JSG T.40 JSG T.43 JSG T.47	JWG C.10		
ICGEM					JSG T.39			
IGETS		JWG 2.1.1						
ISG		JWG 2.2.1						
BGI		JWG 2.1.1						
Other	JWG 1.1.3 JWG 1.4.3 with IAU		JWG 3.1 with IAU	JSG 4.1.7 with FIG				

Fig. 3. IAG JWG and JSG ordered according to their lead component in horizontal rows and the affiliated joint) components in vertical columns

JWG 1.1.1 GENESIS
joint with IERS, GGOS
Chair: Johannes Böhm

JWG 1.1.2 Atmospheric ties
joint with GGOS
Chair: Jungang Wang (Germany)

JWG 1.1.3 Lunar reference frames
joint with IAU
Chair: Agnès Fienga (France)

JWG 1.2.1 GNSS scale information for global reference frames
joint with IGS
Chair: Paul Rebishung (France)

JWG 1.2.2 Metrology of space geodetic infrastructure
joint with IERS, GGOS
Chair: Ryan Hippenstiel (USA)

JWG 1.2.3 Impact of geophysical models on reference frames
joint with Comm 3)
Chair: Jeff Freymueller (USA)

JWG 1.2.4 Evaluation of the terrestrial reference frames
joint with IERS
Chair: Guilhem Moreaux (France)

JWG 1.4.1 Improving and homogenisation of geophysical modeling for a better consistency of the reference frames
joint with Comm 3
Chair: Tobias Nilsson (Sweden)

JWG 1.4.3 Consistent realization of TRF, CRF and EOP
joint with IAU, IERS
Chair: Robert Heinkelmann (Germany)

JWG 2.1.1 Development of the International Terrestrial Gravity Reference Frame
joint with IGFS, BGI, IGETS
Chair: Hartmut Wziontek (Germany)

JWG 2.2.1 Comprehensive gravity data integration for the sub-cm geoid/quasi-geoid modelling
joint with IGFS, ISG
Chair: Ismael Foroughi (Canada)

JWG 2.3.1 Spatial Leakage Mitigation in Satellite Gravimetry
joint with ICCC
Chair: Eva Boergens (Germany)

JWG 3.1 Consistent improvement of the Earth's rotation theory
joint with IAU
Chair: José M. Ferrándiz (Spain)

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
joint with Comm 1, 2
Chair: Lambert Caron (USA)

JWG 4.3.1 Real-time ionosphere monitoring and modeling
joint with IGS, GGOS
Chair: Zishen Li (China)

JWG 4.3.6 Validation of ionospheric models for positioning applications
joint with IGS
Chair: Anna Krypiak-Gregorczyk (Poland)

JWG 4.3.7 Machine learning for the atmosphere
joint with GGOS
Chair: Yury Yasyukevich (Russia)

JSG 4.1.7 Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)
joint with QuGe and FIG
Chair: Allison Kealy (Australia)

JSG T.38 Exploring the similarities and dissimilarities among different geoid/quasigeoid modelling techniques in view of cm-precise and cm-accurate geoid/quasigeoid
joint with Comm 2, IGFS
Chair: Ropesh Goyal (India)

JSG T.39 Gravitational field modelling and analysis for oblate and prolate planetary bodies
joint with Comm 2, ICGEM
Chair: Michal Šprlák (Czech Republic)

JSG T.40 Modelling the gravity field of irregularly shaped celestial bodies
joint with Comm 1, 2, IGFS
Chair: Zhi Yin (China)

JSG T.41 Geodetic quality/integrity modelling, monitoring and design
joint with Comm 1, 2, 3, 4
Chair: Safoora Zaminpardaz (Australia)

JSG T.42 Theoretical developments and applications of combined methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics
joint with Comm 2, 3
Chair: Robert Tenzer (China-Hong Kong)

JSG T.43 Statistical methods in regional gravity field modelling
joint with Comm 1, 2, IGFS
Chair: Mehdi Eshagh (Czech Republic)

JSG T.44 Atmospheric coupling studies
joint with Comm 4, GGOS (GSWR)
Chair: Andres Calabia Aibar (Spain)

JSG T.45 Dynamic gravity modelling of given distributions
joint with Comm 2, 3
Chair: Dimitrios Tsoulis (Greece)

JSG T.46 Deformation, rotation and gravity field modeling for Earth and space
joint with Comm 2, 3
Chair: Yoshiyuki Tanaka (Japan)

JSG T.47 Height datum: Definition, New Concepts, and Standardization
joint with Comm 2, IGFS
Chair: Xiaopeng Li (USA)

JSG T.48 Theoretical Foundations of Machine and Deep Learning in Geodesy
joint with Comm 2, 3, 4, GGOS
Chair: Lotfi Massarweh (The Netherlands)

JSG T.49 High-resolution probing of the troposphere and ionosphere
joint with Comm 4, GGOS (Geohazards Monitoring, GSWR)
Chair: Michela Ravanelli (Italy)

JSG T.50 High-precision GNSS theory and algorithms
joint with Comm 1, 4
Chair: Dimitrios Psychas (The Netherlands)

JWG C.1 Climate Variability and Climate Change in Earth Orientation Parameters
joint with Comm 3, IERS, GGOS Chair: Henryk Dobslaw (Germany)
JWG C.2 Polar geodesy for understanding climate change
joint with Comm 2,3, GGOS
Chair: Ingo Sasgen (Germany)
JWG C.3 Assessing Earth's Energy Balance with geodetic observations
joint with Comm 2, GGOS
Chair: Maria Hakuba (USA)
JWG C.4 Hydrological loading: measuring and modeling
joint with Comm 2, 4, GGOS
Chair: Mohammad J. Tourian (Germany)
JWG C.5 Exploitation of ground-based GNSS Interferometric Reflectometry for climate applications
joint with Commission 4, GGOS
Chair: Makan Karegar (Germany)
JWG C.6 GNSS mass-market devices in climate and environmental sensing: approaches, opportunities, challenges, and social impact
joint with Comm 4, GGOS
Chair: Tobias Kersten (Germany)
JWG C.7 Ground-GNSS trends for climate models
joint with Comm 4, IGS, IVS, GGOS
Chair: Marcelo Santos (Canada)
JWG C.8 Optimal processing and homogenization of GNSS-PW climate data records
joint with Comm 4, IGS, GGOS
Chair: Olivier Bock (France)
JWG C.9 Climate Change Signals in High Resolution Surface Water Observations
joint with Comm 2, GGOS
Chair: Luciana Fenoglio (Germany)
JWG C.10 Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry
joint with Comm 2, ICCT, GGOS, IGFS
Chair: Marius Schlaak (Germany)

JWG M.1 Data and tools exchange
joint with IERS, GGOS
Chair: Pierre Sakic (France)
JWG M.2 GNSS-Acoustic technologies and experiments
joint with Comm 1, 3, 4
Chair: James Foster (Germany)
JWG M.3 Seafloor pressure - an essential variable for monitoring vertical deformation as well as ocean dynamics
joint with Comm 3, ICCC
Chair: Matt Wei (USA)

JWG M.4 Realtime and post-processed kinematic GNSS positioning: status and perspectives for seafloor and sea-surface positioning
joint with Comm 4
Chair: Tianhe Xu (China)

JWG M.5 Acoustic Delay Corrections for Submarine Geodesy
joint with Comm 4, IERS
Chair: Shuqiang Xue (China)

JWG M.6 How marine geodesy can better contribute to coastal hazards assessment and mitigation
joint with Comm 3
Chair: Morelia Urlaub (Germany)

GGOS.GSWR.JSG 1 Understanding Ionospheric and Plasmaspheric Processes
joint with Comm 4
Chair: Fabricio S. Prol (Finland)

GGOS.GSWR.JSG 2 Thermosphere modelling improvements and applications
joint with Comm 4, ICCC
Chair: Günther March (Netherlands)

GGOS.GSWR.JSG 3 Space Weather Monitoring and Prediction
joint with Comm 4
Chair: Haixia Lyu (China)

GGOS.AI4G.JSG 1 AI for GNSS Remote Sensing
joint with Comm 4, ICCC, GGOS FA-GSWR
Chair: Milad Asgarimehr (Germany)

GGOS.AI4G.JSG 2 AI for Gravity Field and Mass Change
joint with Comm 2, ICCC
Chair: Vacant; Vice-Chair: Saniya Behzadpour (Switzerland)

GGOS.AI4G.JSG 3 AI for Earth Orientation Parameter Prediction
joint with Comm 3
Chair: Sadegh Modiri (Germany)

GGOS.AI4G.JSG 4 AI for Geodetic Deformation Monitoring
joint with Comm 3
Chair: Mohammad Ali Sharifi (Iran)

Commission 1 - Reference Frames

https://doi.org/10.82507/iag-gh2024_com1

President: Urs Hugentobler (Germany)
Vice President: Xavier Collilieux (France)

Commission 1 website - www.com1.iag-aig.org

1 Terms of Reference

Reference systems and frames are of primary importance as metrological basis for Earth science based research and applications, satellite navigation and orbit determination as well as for practical applications in positioning, mapping and geo-information related fields. A precisely defined and realized reference frame is needed for an improved understanding of the Earth system, including its rotation and gravity field, sea level change with time, tectonic plate motion and deformation, glacial isostatic adjustment, geocenter motion, deformation due to earthquakes, local subsidence, and other crustal displacements. Commission 1 objectives and related activities deal with the theoretical and operational aspects of how best to define and realize reference systems and how those can be used for practical and scientific applications at different spatio-temporal scales on the deformable Earth. Commission 1 will closely interact with the other IAG Commissions and Services, the ICCT, the ICCC, and the GGOS components where reference system aspects are of concern, to address related problems for the realization of celestial and terrestrial reference systems in conformity with present and future accuracy needs. Commission 1 is also linked with the IUGG COSPAR joint Sub-Commission B2 (International Coordination of Space Techniques for Geodesy) with the aim to develop links and coordinate the work between various groups engaged in the field of space geodesy and geodynamics.

1.1 Objectives

The main objectives of Commission 1 are as listed in the IAG Bylaws:

- Definition, establishment, maintenance and improvement of the geodetic reference frames;
- Development of advanced terrestrial and space observation technique for the above purposes;
- International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories;
- Advancement of theory and coordination of astrometric observation for reference frame purposes;
- Collaboration with space geodesy/reference frame related international services, agencies and organizations;

- Promotion of the definition and establishment of vertical reference systems at global level, considering the advances in the regional sub-commissions;
- Working to maintain a reference frame that is valuable for global change studies.

1.2 Program of Activities

Commission 1 fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing symposia, either independently or at major conferences in geodesy, geophysics and geodynamics. Some events will be focused narrowly on the interests of the sub-commissions and other entities listed below, and others will have a broader commission-wide focus. More specifically, the program of activities for Commission 1 includes:

- Theoretical and applied research activities related to reference frames;
- Research and development activities that impact the reference frame determination and its accuracy, as well as, the best and optimal usage of reference frames in Earth Science applications;
- Development in the theory of the transformation between Celestial and Terrestrial Reference Systems and application of the theory to improve the consistency between ICRF, ITRF and EOPs, in cooperation with IVS and IERS;
- Exploration of advanced methodologies for the combination of products and raw observations of space geodetic techniques;
- Investigation of systematic error sources and factors limiting the precision of space geodetic techniques and their combination;
- Interaction with IAG Services IVS, IGS, ILRS, IDS and the IERS, including their Combination Centers and Working Groups as well as with GGOS;
- Encouraging and assisting regional sub-commission countries to re-define and modernize their national geodetic systems so as to become compatible with the ITRF.

The status of Commission 1 with links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the web site: https://com1.iag-aig.org/.

1.3 Structure

Sub-Commissions

SC 1.1 Coordination of Space Techniques
Chair: Krzysztof Sośnica (Poland)
SC 1.2 Global Reference Frames
Chair: Mathis Bloßfeld (Germany)
SC 1.3 Regional Reference Frames
Chair: Fernand Bale (Côte d'Ivoire)
SC 1.3a Europe
Chair: Martin Lidberg (Sweden)
SC 1.3b South and Central America
Chair: José Antonio Tarrío (Chile)

SC 1.3c North America
Co-Chairs: Jason Bond (Canada) and Phillip McFarland (USA)
SC 1.3d Africa
Chair: Elifuraha Saria (Tanzania)
SC 1.3e Asia-Pacific
Chair: Basara Miyahara (Japan)
SC 1.3f Antarctica
Chair: Martin Horwath (Germany)
SC 1.4 Interaction of Celestial and Terrestrial Reference Frames
Chair: Maria Karbon (Spain)

Working Groups

WG 1.4.2 Studying and modeling the structure of the AGNs and its evolution over time and frequency for the future CRFs
Chair: Minghui Xu (Germany)

Joint Working Groups

JWG 1.1.1 GENESIS
(joint with IERS, GGOS)
Chair: Johannes Böhm
JWG 1.1.2 Atmospheric ties
(joint with GGOS)
Chair: Jungang Wang (Germany)
JWG 1.1.3 Lunar reference frames
(joint with IAU)
Chair: Agnès Fienga (France)
JWG 1.2.1 GNSS scale information for global reference frames
(joint with IGS)
Chair: Paul Rebishung (France)
JWG 1.2.2 Metrology of space geodetic infrastructure
(joint with IERS, GGOS)
Chair: Ryan Hippenstiel (USA)
JWG 1.2.3 Impact of geophysical models on reference frames
(Joint with Comm 3)
Chair: Jeff Freymueller (USA)
JWG 1.2.4 Evaluation of the terrestrial reference frames
(joint with IERS)
Chair: Guilhem Moreaux (France)
JWG 1.4.1 Improving and homogenisation of geophysical modeling for a better consistency of the reference frames
(joint with Comm 3)
Chair: Tobias Nilsson (Sweden)
JWG 1.4.3 Consistent realization of TRF, CRF and EOP
(joint with IAU Commission A2 and IERS)
Chair: Robert Heinkelmann (Germany)

Joint Study Groups

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
(joint with Comm 2, Comm 3)
Chair: Lambert Caron (USA)

1.4 Steering Committee

The steering committee will meet at least once per year.

- President Commission 1: Urs Hugentobler (Germany)
- Vice President Comm. 1: Xavier Collilieux (France)
- Chair Sub-Comm. 1.1: Krzysztof Sośnica (Poland)
- Chair Sub-Comm. 1.2: Mathis Bloßfeld (Germany)
- Chair Sub-Comm. 1.3: Fernand Bale (Côte d'Ivoire)
- Chair Sub-Comm. 1.4: Maria Karbon (Spain)
- Representative of IERS: Claudio Abbondanza (USA)
- Representative of Early Career Scientists (non-voting): Anna Klos (Poland)

1.5 Overview of Working Groups and Study Groups

Groups related to SC 1.1

JWG 1.1.1 GENESIS
(joint with IERS, GGOS)
Chair: Johannes Böhm

JWG 1.1.2 Atmospheric ties
(joint with GGOS)
Chair: Jungang Wang (Germany)

JWG 1.1.3 Lunar reference frames
(joint with IAU)
Chair: Agnès Fienga (France)

Groups related to SC 1.2

JWG 1.2.1 GNSS scale information for global reference frames
(joint with IGS)
Chair: Paul Rebishung (France)

JWG 1.2.2 Metrology of space geodetic infrastructure
(joint with IERS, GGOS)
Chair: Ryan Hippenstiel (USA)

JWG 1.2.3 Impact of geophysical models on reference frames
(Joint with Comm 3)
Chair: Jeff Freymueller (USA)

JWG 1.2.4 Evaluation of the terrestrial reference frames
(joint with IERS)
Chair: Guilhem Moreaux (France)

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
(joint with Comm 2, Comm 3)
Chair: Lambert Caron (USA)

Groups related to SC 1.4

JWG 1.4.1 Improving and homogenisation of geophysical modeling for a better consistency of the reference frames
(joint with Comm 3)
Chair: Tobias Nilsson (Sweden)

WG 1.4.2 Studying and modeling the structure of the AGNs and its evolution over time and frequency for the future CRFs
Chair: Minghui Xu (Germany)

JWG 1.4.3 Consistent realization of TRF, CRF and EOP
(joint with IAU Commission A2 and IERS)
Chair: Robert Heinkelmann (Germany)

2 Sub-Commissions, Working Groups and Study Groups

SC 1.1: Coordination of Space Techniques

Chair: Krzysztof Sośnica (Poland)

Terms of Reference

Space techniques play a fundamental role in the realization and dissemination of highly accurate and long-term stable terrestrial and celestial reference frames as well as for accurate monitoring of the Earth Orientation Parameters (EOP) linking the two fundamental frames. The current space geodetic techniques contributing to ITRF and ICRF, i.e., Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR/LLR), Global Navigation Satellite Systems (GNSS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) have particular strengths and technique-specific weaknesses.

Strengths of the techniques are exploited by combining them making use of fundamental sites co-locating more than one technique. Sub-Commission 1.1 focuses on the coordination of research related to the geodetic space techniques with emphasis on co-location aspects at fundamental geodetic observatories as well as on co-location targets in space, considering common parameters such as coordinates of stations and satellites, troposphere parameters, and clock parameters. Future terrestrial and lunar missions, such as GENESIS or Moonlight, require developing techniques and methodologies for co-location in space and a proper definition of lunar reference frames and time scales with the proper connection to the terrestrial frames and time. SC 1.1 will explore prerequisites for future terrestrial and lunar missions and introduce recommendations to ensure highest consistency between reference frames in the Earth-Moon system.

Objectives

- Coordinate research on co-location using common parameters in space;
- Coordinate research on co-location using common parameters at fundamental geodetic observatories;
- Explore the use of new techniques and technologies;
- Interface with IERS WG on Site Survey and Co-location;
- Interface with the GGOS Committee on Performance Simulations and Architectural Trade-Offs (PLATO);
- Interface with JWG 1.1.2 on Atmospheric Ties;
- Foster processing capabilities for the GENESIS mission;
- Interface between terrestrial and lunar reference and time systems with realizations in the form of the reference and time frames.

JWG 1.1.1: GENESIS

(joint with IERS, GGOS)
Chair: Johannes Böhm

Terms of Reference

GENESIS is a mission of the European Space Agency (ESA) approved for launch in 2028. It realizes all major space ties on a satellite in a polar orbit at about 6000 km altitude, connecting GNSS receivers, an SLR retroreflector, a DORIS receiver and a dedicated VLBI transmitter. GENESIS holds the potential to significantly enhance the terrestrial reference frame with more accurate ties between the techniques, and it promises to enable scientific investigations with unprecedented levels of accuracy. The objective of this WG is to explore the array of scientific opportunities presented by GENESIS, to formulate optimal observing scenarios, and to develop the methodology for a consistent integration of GENESIS data into future ITRF realizations with simulations and considering already existing space ties. This WG aims at maximizing the utilization of the mission's capabilities.

Objectives

- This WG is an open forum of the international scientific community to exchange ideas and information, and to work for the best possible implementation of GENESIS and exploitation of its opportunities.
- There is close co-operation and exchange with the GENESIS Science Team of ESA including the GENESIS Science Management Board and the GENESIS Science Exploitation Team.
- Identify possible scenarios for the utilization of GENESIS for the improvement of the terrestrial reference frame.
- Set up and implement a work plan with timeline to make the most promising scenarios possible once data is available. A detailed plan supported by simulation results will be available after two years. Observation data from GENESIS will become available with the launch of the missions, planned for 2028.
- Get an overview of possible contributions by the various groups to the analysis of GENESIS observations. Help to set up cooperation between the groups to facilitate the best realization of the reference frame with GENESIS.
- Review and investigate existing co-locations in space between GNSS, DORIS, and SLR, as well as VLBI observations to satellites.
- Formulate and raise questions to address open issues with the GENESIS mission, both on a technique-specific level and on the combination level.
- Identify and investigate new scientific opportunities, which will become possible with GENESIS.

Members

Johannes Böhm (Austria); Chair
Claudio Abbondanza (USA)
Mathis Bloßfeld (Germany)
Alexandre Couhert (France)
Rolf Dach (Switzerland)
Claudia Flohrer (Germany)
Susanne Glaser (Germany)

Rüdiger Haas (Sweden)
Bruce Haines (USA)
Urs Hugentobler (Germany)
Ozgur Karatekin (Belgium)
Frank Lemoine (USA)
Benjamin Männel (Germany)
Lucia McCallum (Australia)
Oliver Montenbruck (Germany)
Arnaud Pollet (France)
Markus Rothacher (Switzerland)
Krzysztof Sośnica (Poland)
ESA representatives

Ex-officio Members of IERS

Robert Heinkelmann (Germany)
Daniela Thaller (Germany)

Ex-officio Members of GGOS

Detlef Angermann (Germany)
José Rodríguez Pérez (Spain)

Corresponding Members

Zuheir Altamimi (France)
Yoaz Bar-Sever (USA)
Grzegorz Bury (Poland)
Bingbing Duan (Germany)
Richard Gross (USA)
Adrian Jäggi (Switzerland)
Tomasz Kur (Poland)
Axel Nothnagel (Germany)
Toshimichi Otsubo (Japan)
Felix Perosanz (France)
Manuela Seitz (Germany)
Vishwa Sing (Germany)
Benedikt Soja (Switzerland)
Peter Steigenberger (Germany)
Helene Wolf (Austria)

JWG 1.1.2: Atmospheric ties

(joint with GGOS)
Chair: Jungang Wang (Germany)

Terms of Reference

To achieve the 1 mm position and 1 mm/decade velocity requirement of the terrestrial reference frame defined by the GGOS, a rigorous combination of space geodetic techniques should be performed, utilizing as many ties as possible. In addition to the commonly used global (Earth Orientation Parameters) and local (station coordinates) ties, tropospheric parameters between co-location stations can also be combined to enhance the solution, referred to as troposphere ties. Studies have indicated that the inter-technique agreement of tropospheric parameters is optimal (e.g., around 4 mm for zenith total delay (ZTD) between GNSS and VLBI), and the benefits of employing troposphere ties in multi-technique combinations have been demonstrated, such as improved VLBI scale estimates. However, previous studies are typically based on short-term observations (e.g., during VLBI CONT campaigns), which may not adequately represent long-term reference frame determination. Additionally, studies have revealed that troposphere parameters estimated from space geodetic techniques can exhibit systematic biases, potentially stemming from different instrument types and data processing strategies. Neglecting these systematic biases when employing troposphere ties could distort the network, introducing artificial biases in station coordinates. Weighting is another critical consideration in utilizing troposphere ties, where appropriate weighting should account for the stochastic noise level of tropospheric parameters and exploit the benefits of the troposphere ties the most. It is thus essential to assess the stochastic noise of inter-technique troposphere delay agreements and influencing factors such as observation distribution. It is anticipated that appropriate handling of troposphere ties in multi-technique integrated processing will enhance the solution accuracy, such as TRF scale stability.

Objectives

The primary objective of the working group is threefold: firstly, to assess the long-term systematic and stochastic differences of tropospheric parameters between different space geodetic techniques at different co-location sites; secondly, to investigate optimal methodologies to combine tropospheric parameters in inter- and intra-technique integrated processing; and thirdly, to examine the benefits of utilizing troposphere ties in the combination of space geodetic techniques for long-term terrestrial reference frame determination.

Program of Activities

The working group will concentrate on the following activities:

- Evaluating the inter- and intra-technique agreement of troposphere parameters obtained from space geodetic techniques (GNSS, VLBI, DORIS), in-situ instruments (such as water vapor radiometer, radiosonde), and Numerical Weather Models with different spatial and temporal resolutions. Exploring the systematic biases of different techniques and identifying potential causes. For example, analyzing factors that could systematically impact GNSS troposphere delay estimates, such as receiver and antenna type, as well as data processing strategy (e.g., cut-off elevation angle, down-weighting strategy, mapping function).

- Investigating the stochastic noise level of troposphere parameter differences between different techniques and their influencing factors, including the inter-station distance, water vapor content, station location, and the spatial and temporal distribution of observations. The effect of atmosphere turbulence will also be included.
- Developing an optimal strategy for the rigorous combination of atmosphere parameters for space geodetic techniques (GNSS, VLBI, DORIS, and SLR) to leverage the contribution of troposphere ties, while minimizing the impact of systematic biases and stochastic noise.
- Demonstrating the advantages of utilizing troposphere ties in multi-technique integrated processing, encompassing the determination of both terrestrial and celestial reference frames, and EOP.
- Determining high-resolution and high-precision multi-technique combined troposphere delay and water vapor products for climate-related applications.

Members

Jungang Wang (Germany); Chair
Kyriakos Balidakis (Germany)
Mateusz Drożdżewski (Poland)
Claudia Flohrer (Germany)
Susanne Glaser (Germany)
Changyong He (China)
Robert Heinkelmann (Germany)
Iván Dario Herrera Pinzón (Switzerland)
Chaiyaporn Kitpracha (Tailand)
Tobias Nilsson (Sweden)
Krzysztof Sośnica (Poland)
Dariusz Strugarek (Poland)
Xiaoya Wang (China)
Zhilu Wu (China)
Florian Zus (Germany)

JWG 1.1.3: Lunar reference frames

(joint with IAU)
Chair: Agnès Fienga (France)

Terms of Reference

Recently, several organizations have established plans to visit the Moon for exploration and science. These led to the recognition that updated localization standards for both surface and orbital activities at the Moon are needed and should therefore be a priority for operations leading to exploration. The objective of this WG is to address the issues of the connection between Celestial, Earth and Lunar Reference Frames for the future missions in coordination with the IAG, IAU, and IERS and to formulate recommendations regarding the definition, the realization, and the dissemination of Lunar Reference Systems, across agencies and user communities. Experience acquired

with the establishment of the Earth Reference Frame (ITRF, GCRF) will serve as the foundation for this task. The work of this group will be connected with on-going Lunanet International interoperability standardization work being performed by NASA, ESA and JAXA.

Objectives

The group will work towards identifying areas or fields, including models, methodologies, and instruments necessitating enhancement to align with the requirements of forthcoming lunar surface and orbital activities. It will also assess the consistency between time reference definition as provided by other institutions and space reference frame definition. It will recommend directions for improvements and assemble specific recommendations for users and future IERS conventions.

Program of Activities

The group will:

- Coordinate with IAU and IERS for Lunar Reference System and Frames definition;
- Organize meetings during international conferences (EGU, AGU, IAU GA and symposia, ...);
- Organize online meetings in order to assess present limitations in terms of models and instrumentation with the goal of identifying directions for improvement;
- Suggest recommendations for IERS conventions, in the form of a white book.

Members

Agnès Fienga (France); Chair
Kayla J. Brinkley (USA)
Pasquale Defraigne (Belgium)
Trevor Garner (USA)
Cheryl Gramling (USA)
Robert Heinkelmann (Germany)
Luciano Iess (Italy)
Maria Karbon (Spain)
Sergei Klioner (Germany)
Erwan Mazarico (USA)
Stephan Merkowitz (USA)
Jürgen Müller (Germany)
Flora Paganelli (USA)
Dmitry Pavlov (Russia)
Nicolas Rambaux (France)
Krzysztof Sośnica (Poland)
Susan Stewart (USA)
Richard Swinden (ESA)
Patrizia Tavella (BIPM)
Javier Ventura-Traveset (ESA)

Corresponding members

Masaya Murata (Japan)
Jinsong Ping (China)

SC 1.2: Global Reference Frames

Chair: Mathis Bloßfeld (Germany)

Terms of Reference

Sub-Commission 1.2 focuses its activity on the definition and realization of the terrestrial reference system (TRS). The TRS realization, named Terrestrial Reference Frame (TRF), is fundamental to study and locate global phenomena or objects at the Earth's surface, in the ocean or in space. It is used as the basis of several operational observation system processing chains such as sea level determination from space and Earth's rotation monitoring as well as for most regional and national TRFs. In addition, especially for the precise determination of near-Earth satellite orbits, a TRF plays a fundamental role. Thus, TRF specifications in terms of origin, scale and orientation have to be optimally realized to satisfy user needs. That's why SC 1.2 shall study either fundamental questions or more practical aspects that could improve current TRF determinations. It is of outmost importance to establish a quality control for TRF realizations since precise as well as long-term stable station coordinates serve as a backbone of numerous geosciences. A first step is to compare the different global TRF solutions currently provided on a non-frequent basis by the three IERS ITRS combination centers. Thanks to technological achievements and the development in the analysis of space-geodetic observations (such as GNSS, SLR, VLBI, and DORIS observations), more than one space technique provides sufficient sensitivity to geodetic datum parameters of TRF realizations. Of special interest is the potential contribution of GNSS to the global scale realization which is usually based on SLR and VLBI only. Besides SLR, also GNSS and DORIS might reliably contribute to the origin realization in the near future. Thanks to the accumulation of space geodesy observations and progress in modeling and analysis, non-stationary Earth surface displacements are nowadays clearly evidenced. The next generation of TRF should be able to explicitly model them or should be constructed in such a way that those displacements are accurately modelled. Thereby, not only non-tidal loading models of different Earth system sub-components shall be used but also other geophysical models which are capable to picture global and regional geophysical phenomena such as, e.g., glacial isostatic adjustment (GIA) models. Nevertheless, technique-specific systematic errors still exist in space geodesy products, which impact the TRF definition, especially the scale parameter. Dedicated satellite missions with onboard multi-technique sensors could improve further our understanding of technique systematic errors thanks to solving parameters common to multiple techniques. However, a set of accurate tie vectors that relate position of various technique instruments at co-location sites will still be of outmost importance to validate those new space-ties and monitor their long-term variations.

A further step forward could be established by investigating relativistic reference frames based on a network of clocks in space linked with time transfer technologies. Such realized frame would be entirely decoupled from ground fixed stations and could be used to reference any point on the Earth's surface. The relativistic frequency shift between clocks in space and on the ground would be a direct measurement of the Earth gravity potential. This technology can be used to realize a world height system

based on a network of ground clocks. While this ultimate goal still requires intensive research works, TRF and future World Height Systems need to be studied in closer partnership in order to connect reference benchmarks, gravimeters or clocks to the TRF but also to provide consistent coordinate and height time-variations. The work of this Sub-Commission will be done in partnership with the IERS as well as with GGOS.

Objectives

The main objectives of SC 1.2 are the following:

- Definition of the global terrestrial reference frame (origin, scale and orientation, time evolution, standards, conventions, models);
- Comparison of existing global TRF solutions;
- Methods to determine local tie vectors and to relate instrument reference points to surveyed ground markers;
- Investigate new methods to determine relative motions at co-location sites;
- Evaluation of technique-specific systematic errors by focusing on errors at co-location sites;
- Enhanced forward modeling of the Earth's surface deformation;
- Modeling of the reference frame in general relativity;
- Linking global height reference frames with the terrestrial reference frame;
- Pursue studies and investigation related to multi-technique satellites (space ties) and concepts of novel dedicated missions with onboard multi-technique sensors.

Link to Services

Sub-Commission 1.2 will establish close links to relevant services for geodetic reference frames, namely the IERS, GGOS and the IAG technique services: IGS, ILRS, IVS, and IDS. A close link with the IERS Conventions Center will be also maintained, especially for chapter 4 ("Terrestrial Reference Systems and Frames") updates. In addition, SC 1.2 will work closely together with the IHRF (International Height Reference Frame) Coordination Center of the International Gravity Field Service (IGFS).

Corresponding Member

Georgios Vergos (Greece); Representative of IFGS

JWG 1.2.1: GNSS scale information for global reference frames

(joint with IGS)
Chair: Paul Rebischung (France)
Vice-Chair: Tom Herring (USA)

Terms of Reference

Since 2007, the International Terrestrial Reference System (ITRS) has been recommended by the IUGG as the preferred geodetic reference system for positioning on and around the Earth, satellite navigation and Earth Science applications. The ITRS is formally defined as a three-dimensional cartesian coordinate system co-rotating with the Earth, with its origin at the center of mass of the whole Earth system, its unit of length (scale) given by the SI meter and its orientation conventionally defined. The ITRS is realized by successive releases of the International Terrestrial Reference Frame (ITRF) which consists of precise coordinates of a global network of geodetic stations, expressed as accurately as possible in the ITRS. To satisfy particularly demanding applications such as the monitoring of sea level rise from satellite altimetry or the establishment of mass budgets from satellite gravimetry, the ITRF coordinates need to be expressed in the ITRS, in terms of origin and scale, with a millimetric accuracy over decades. However, in view of the discrepancies between the scale of the coordinates determined by the individual space geodetic techniques contributing to the ITRF, this requirement does not appear to be met yet.

The ITRF coordinates are derived from the combination of the observations of four space geodetic techniques: DORIS, GNSS, SLR, and VLBI. Only two of those techniques, SLR and VLBI, have so far contributed to the definition of the scale of the successive ITRF releases. Until the advent of the Galileo system, GNSS were indeed considered unable to provide reliable scale information, due to the combination of two factors:

- the existence, in global GNSS analyses, of a quasi-linear dependency between the average of station heights (i.e., the terrestrial scale), tropospheric zenith wet delays, satellite and station clock offsets, and the radial component of the antenna phase center offsets (z-PCOs) of GNSS satellites;
- the absence of reliable, publicly available pre-flight calibrations of GNSS satellite antennas.

This situation evolved with the public release of pre-flight antenna calibrations for the Galileo satellites, which put the IGS in a position where it could provide, for the first time, a GNSS-based estimate of the terrestrial scale. This was put into practice in the third IGS reprocessing campaign (repro3), which contributed to the latest release of the ITRF, ITRF2020.

However, the subsequent analysis of the contributions of the four techniques to ITRF2020 conducted at the Institut National de l'Information Géographique et Forestière (IGN) concluded that there was a +4.3 mm scale offset at epoch 2015.0 and a +0.11 mm/yr drift between the Galileo-based scale of the IGS repro3 solutions and the average scale of the SLR and VLBI solutions selected to define the ITRF2020 scale. A comparable offset of +4.9 mm at epoch 2010.0 (but no clear drift) was also found between the repro3 scale and that of the SLR contribution to ITRF2020 in a similar analysis conducted at the Jet Propulsion Laboratory (JPL). A third analysis conducted at the Deutsches Geodätisches Forschungsinstitut at the Technische Universität München (DGFI-TUM) concluded that there was good agreement (0.25 mm at epoch 2010.0; 0.025 mm/yr) between the repro3 scale and that of the VLBI contribution to ITRF2020, but confirmed the existence of an offset and a drift between

the repro3 scale and that of the SLR contribution to ITRF2020 (+2.2 mm at epoch 2010.0 and +0.1 mm/yr between the GNSS/VLBI average and SLR).

In this context, it appears worth investigating possible systematic errors in GNSS-based estimates of the terrestrial scale and attempting to draw a budget for these errors. This implies evaluating the accuracy of the pre-flight antenna calibrations available not only for the Galileo satellites, but now also for the GPS Block III, IIF, and IIR satellites, by, e.g., inter-comparisons across satellites, constellations, and signal frequencies. This also implies evaluating the stability of GNSS satellite z-PCOs over their lifetimes. This may also comprise comparisons between scale estimates relying on pre-flight GNSS satellite antenna calibrations with other estimates that rather rely on the dynamical constraint brought by Low Earth Orbiters (LEOs) in the joint processing of GNSS tracking data from ground stations and LEOs. This finally implies evaluating to what extent, besides errors in the GNSS satellite antenna calibrations, other types of errors in GNSS data or their analysis (e.g., inaccuracies of the ground antenna calibrations, multipath, tropospheric delay mismodeling) might bias GNSS-based scale estimates. Some of these other possible contributors may have implications for scale estimates from other geodetic systems e.g., tropospheric modeling.

Objectives

- Establish an inventory of the efforts by different groups to determine the terrestrial scale with GNSS;
- Review the consistency of GNSS-based scale and scale rate estimates across research groups, constellations and frequency combinations, as well as with estimates from other space geodetic techniques;
- Investigate potential systematic errors in GNSS-based scale and scale rate determination;
- Investigate methods for in-situ calibrations of the phase response of GNSS antenna;
- Provide recommendations and strategies to improve the scale of the IGS contribution to the next ITRF releases.

Members

Paul Rebischung (France); Chair
Tom Herring (USA); Vice-Chair
Claudio Abbondanza (USA)
Zuheir Altamimi (France)
Andria Bilich (USA)
Mathis Blossfeld (Germany)
Susanne Glaser (Germany)
Jing Guo (China)
Bruce Haines (USA)
Guorong Hu (Australia)
Benjamin Männel (Germany)
Oliver Montenbruck (Germany)
Manuela Seitz (Germany)
Peter Steigenberger (Germany)

Daniela Thaller (Germany)
Arturo Villiger (Switzerland)

JWG 1.2.2: Metrology of space geodetic infrastructure

(joint with IERS, GGOS)
Chair: Ryan Hippenstiel (USA)
Vice-Chair: Cornelia Eschelbach (Germany)

Terms of Reference

The ITRS is built upon multiple geodetic techniques: SLR, VLBI, DORIS, and GNSS. At locations where these techniques are co-located, it is vital to determine and understand the vectors between the reference points of each technique. These vectors are determined by local tie surveys conducted terrestrially with various procedures and geodetic instruments. The reference points should be collected and properly aligned to a global reference frame to produce relative and absolute coordinates. As the science of local tie surveys has developed, so has technology and the expectation of higher precision and improved protocols. It is the desire of this JWG to investigate the current and expected best practices available, along with documenting past efforts, both in the field and researched. This JWG will share methodology of existing tie surveys, continued to develop and document recommended procedures, and archive surveys completed by all agencies represented. In addition, efforts will be made to isolate systematic errors of the space geodetic techniques using surveying methods and investigate field procedures that could be completed during a tie survey to provide the operator valuable feedback on potential physical errors found onsite. One critical example of this is quantifying thermal and gravitational deformation in VLBI sensors. It is the overall goal of this JWG to encourage consistent field practice, terminology, and documentation throughout the community, with a continued eye on the future of tie surveys.

Objectives

Enhance and improve knowledge of space-geodetic infrastructure through precise local tie techniques, research on practices and error sources, and engagement with new technologies.

Program of Activities

- Investigate thermal and gravitational deformation;
- Consider importance and inclusion of DoV observations;
- Discuss overall error budget and precision (achieved/necessary) considering the above;
- Continue to enhance guidelines on procedures (and subsequent feedback for improvement);
- Archive reports, tie vectors and raw data of all agencies conducting tie surveys;
- Gather, distribute, and maintain publications on related matters;

- Coordinate with and solicit feedback from all geodetic techniques on developments;
- Participate in local tie surveys and/or testing of new methodologies;
- Attend meetings or participate in virtual/online discussions;
- Report survey results and/or research efforts towards the Objectives of the JWG;
- Develop and maintain a library of past and future reference materials.

Members (to be updated as JWG develops)

Ryan Hippenstiel (USA); Chair
Cornelia Eschelbach (Germany); Vice-Chair
Zuheir Altamimi (France)
Sten Bergstrand (France)
Steven Breidenbach (USA)
Benjamin Erickson (USA)
Charles Geoghegan (USA)
Dionne Hansen (New Zealand)
Craig Harrison (Australia)
Christopher Holst (Germany)
Ulla Kallio (Finland)
Michael Lösler (Germany)
Kevin Jordan (USA)
Saho Matsumoto (Japan)
Jack McCubbine (Australia)
Damien Pesce (France)
Anna Riddell (Australia)
Owen Smallfield (New Zealand)
Jerome Saunier (France)
Elena Martínez Sánchez, (Spain)
Daniela Thaller, (Germany)
Bart Thomas (Australia)

Corresponding Members

Xavier Collilieux (France)
Robert Heinkelmann (Germany)

JWG 1.2.3: Impact of geophysical models on reference frames

(Joint with Commission 3)
Chair: Jeff Freymueller (USA)

Terms of Reference

This working group, joint between IAG SC 1.2 and IAG SC 3.4 has the goal of assessing and improving geophysical models, to help to develop models that are sufficiently accurate that they could be used to describe non-secular motion in reference frame definition. Two broad categories of models could be considered, with the priority being

mass transport models and associated surface loading deformation. Work in the JWG is carried out on a best-effort basis and is described below in the Objectives. Meetings are primarily expected to be virtual/online. However, the goal is to have an in-person meeting at the IAG Scientific Assembly in Fall 2025. A meeting at the Fall 2024 AGU meeting is considered.

The JWG will communicate with other groups under the IAG umbrella that are working on adjacent topics: for example, recommendations about what we need from GIA models.

Objectives for Geophysical Loading Models

- Make recommendations about quantities that we want/need modelers to compute:
  - Model computations in CM frame, with degree 1 coefficients (with documented units/normalization) to allow models to be expressed in CF or other frames;
  - Geocenter time series or trend (CF minus CM);
  - Intermediate results, like the gravitationally consistent redistribution of mass to the ocean in the case of GIA and present-day mass transport models.
- Assess existing models to determine the degree of double-counting and missing mass:
  - Continental hydrology;
  - Cryosphere (the largest secular trend in hydrology, but largely missing from most continental hydrology models – but not completely missing either);
  - Non-tidal ocean mass vs gravitational redistribution of water;
  - Groundwater;
  - How do assimilation-based models (such as Gerdener et al.) compare to traditional models?
- How can we make progress toward a fully integrated global mass change model?

Objectives for Earthquake and Post-seismic Models

- Assess the state of current models.
- How do current models (i.e., ITRF PSD models) predict the future?
- Make recommendations for how to improve such models.

Program of Activities

- Propose a session for the 2025 AGU or 2026 EGU meeting.
- Convene a special session at the 2027 IUGG Assembly in Korea, focused on improving global mass transport models.
- Propose a special session for the 2026 REFAG meeting.
- Interact with JSG 3.1 (Chair: Lambert Caron):
  - JWG 1.2.3 would like to make recommendations to JSG 3.1 about what kinds of "separate" model computational values should be saved and reported because they are needed and useful for reference frame issues. One example is CF-CM, the trend (and variations if dealing with areas of low viscosity) in the geocenter due to GIA. Also, having the ocean load redistribution and its induced deformation saved and reported separately would be highly useful; and of course, 3D displacements/velocities are needed.

– JWG 1.2.3 would like to hear from JWG 3.1 about progress towards new models, and assessments of models and uncertainties.

Members (to be updated as JWG develops)

Jeff Freymueller (USA); Chair
Sophie Coulson (USA)
Maylis de la Serve (France)
Jean-Paul Boy (France)
Laura Jensen (Germany)
Anthony Mémin France)
Anna Klos (Poland)
Claudio Abbondanza (USA)
Manuela Seitz (Germany)
Laurent Métivier (France)
Karen Simon (Canada)

JWG 1.2.4: Evaluation of the terrestrial reference frames

(joint with IERS)
Chair: Guilhem Moreaux (France)
Vice-Chair: Andreja Susnik (UK)

Terms of Reference

Periodically, the ITRS combination centers (CCs) of the IERS, namely the Institut National de l'Information Géographique et Forestière (IGN, France), the Deutsches Geodätisches Forschungsinstitut at the Technische Universität München (DGFI-TUM, Germany) and the Jet Propulsion Laboratory, (JPL, USA), compute new realizations of the ITRS. The official realization is named International Terrestrial Reference Frame (ITRF) and is published by the IERS ITRS product center (PC) at IGN. DGFI-TUM and JPL compute their own ITRS realizations named DTRF and JTRF, respectively. These global TRF solutions comprise accurate station positions and are obtained by a combination of individual contributions of the four space geodetic techniques DORIS, GNSS, SLR, and VLBI. All three solutions are based on identical input data of the respective Scientific Services of the IAG, namely the IDS, IGS, ILRS, and IVS. Since each IERS ITRS CC follows its own combination strategy, each solution comprises a solution-specific array of products (e.g., station positions, velocities, post-seismic deformation models, non-tidal loading correction time series, periodic corrections). In addition to the above mentioned ITRS realizations, global technique-specific TRF solutions as well as regional densifications of the ITRF are computed by different institutions.

The ITRF is used daily by a huge number of individuals and organizations in applications such as surveying, aircraft navigation, responding to disaster emergency etc. Furthermore, the ITRF provides the fundamental basis needed for a broad variety of Earth system research applications. Examples are the determination, monitoring, and interpretation of global change phenomena on different temporal and spatial time

scales (i.e. sea-level rise and ice sheet melting), of Earth Orientation and Rotation, relativity, lunar science, as well as the calibration and evaluation of ocean and ice altimetry missions. Furthermore, it is the basis for the understanding of dynamics and modelling of satellite orbits and can be used in scientific research such as plate tectonics and crustal deformation monitoring and static and time-varying gravity field modelling. In short, the ITRF serves as the backbone in geosciences.

This JWG aims at complementing the evaluation of the ITRS realizations by the IERS ITRS PC with a special focus on the intercomparison of different global TRF solutions. The assessment aims at investigating conceptual differences of the three ITRS realizations with previous realizations based on user and application requirements important for, e.g., the precise orbit determination (POD) of low-, medium- and high-Earth-orbiting satellites and the estimation of Earth Orientation Parameters (EOPs) as well as the (mean) regional/global sea level rise.

Objectives

- Intercomparison of the combination strategies followed by the IERS ITRS CCs;
- Assessment/quantification of station position time series differences between the ITRS realizations and w.r.t. geophysical models (e.g., loading displacements);
- Promotion and development of alternative rigorous (and independent) methods for the intercomparison of global TRF solutions (e.g., POD of low-, medium- and high-Earth-orbiting satellites);
- Explore methods and procedures for the quality control of TRF solutions.

Members

Guilhem Moreaux (France); Chair
Andreja Susnik (UK); Vice-Chair
Dimitrios Ampatzidis (Greece)
Peter Clarke (UK)
Alexandre Couhert (France)
Rolf Dach (Switzerland)
Linda Geisser (Switzerland)
Frank Lemoine (USA)
Anton Reinhold (Germany)
Sergei Rudenko (Germany)
Erik Schönemann (ESA)
Patrick Schreiner (Germany)

Corresponding members

Claudio Abbondanza (USA)
Zuheir Altamimi (France)
Paul Rebischung (France)
Manuela Seitz (Germany)

Ex-officio members

Mathis Blossfeld (Germany)
Daniella Thaller (Germany); IERS CB
Robert Heinkelmann (Germany); IERS AC

JSG 3.1: Model representation and geodetic signature of solid-Earth rheology in surface loading problems

(joint with IAG Commissions 2 and 3)
Chair: Lambert Caron (USA)
Vice-Chair: Rebekka Steffen (Sweden)
Refer to the Chapter Commission 3 in this Handbook.

SC 1.3: Regional Reference Frames

Chair: Fernand Bale (Côte d'Ivoire)

Terms of Reference

Sub-Commission 1.3 deals with the definitions and realizations of regional reference frames and their connection to the global International Terrestrial Reference Frame (ITRF) and International Height Reference Frame (IHRF). It offers a home for service-like activities addressing theoretical and technical key common issues of interest to regional organizations.

Objectives

In addition to the specific objectives of each regional sub-commission, the main objectives of SC 1.3 as a whole are to:

- Coordinate the activities of the regional sub-commissions focusing on exchange of data, competences and results;
- Promote operation of permanent GNSS stations, in connection with IGS whenever appropriate, as the basis for the long-term maintenance of regional reference frames;
- Promote open access to the GNSS data from permanent stations used for the maintenance of regional reference frames and scientific applications;
- Develop specifications for the definition and realization of regional reference frames, including the vertical component;
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations;
- Encourage and assist countries, within each regional sub-commission, to re-define and modernize their national geodetic systems, compatible with the ITRF;
- Support the efforts of the United Nations Initiative on Global Geospatial Information Management (UN-GGIM) towards a sustainable Global Geodetic Reference Frame (GGRF).

Program of Activities

- Provide a forum for addressing activities, results and key issues of common interest to the regional sub-commissions;
- Develop analysis strategies and compare methods for the implementation of the regional reference frames and their expression in the ITRF, in full interaction with the IGS;
- Consider developing deformation models that will enable transformation of locations within a defined reference frame between different epochs.

SC 1.3a: Europe (EUREF)

Chair: Martin Lidberg (Sweden)
Secretary: Karin Kollo (Estonia)

Terms of Reference

Sub-Commission 1.3a, the regional Reference Frame Sub-Commission for Europe (EUREF), deals with the definition, realization and maintenance of the European Reference Frames. It is focusing on both the spatial and the vertical components in close cooperation with the pertinent IAG components (Services, Commissions and Intercommission projects). For more information, see www.euref.eu.

Objectives

- The definition, realization and maintenance of the European Geodetic Reference Systems;
- The promotion and assistance of the adoption and use of European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS) in our partner countries;
- The development and maintenance of the EUREF GNSS Permanent Network (EPN) which is the ground based GNSS infrastructure for scientific and practical applications in positioning and navigation (GGOS, IGS Real-time Service);
- The development of strategies and technologies for the realization of geodetic reference systems.

Structure, Working Groups

Sub-Commission 1.3a is composed of representatives from European IAG member countries. The Governing Board is composed of members elected by the EUREF plenary, members in charge of special tasks and ex-officio members. The following Working Groups have been set up:

- SC1.3a-WG1: European Unified Height Reference
  Chair: Joachim Schwabe (Germany)
  This WG has the following goals:
  - Complement EVRS with an official height reference surface (hybrid quasigeoid model).
  - Improve information about national height coordinate frames and their transformations to the EVRS.
  - Enhance the usability of the unified European height reference.
- SC1.3a-WG2: EPN Densification (EPN-D)
  Chair: Ambrus Kenyeres (Hungary)
  The primary goal of this WG is to realize a continental-scale, homogeneous, high-quality position and velocity product in a well-defined reference frame, with comparable quality from Greenland to Crete, from Svalbard to Gran Canary. To achieve this goal, processing results (daily or weekly SINEX files) of national or regional GNSS networks are merged using the EPN as backbone in multi-year position and velocity solutions.

- SC1.3a-WG3: Deformation models
  Chair: Martin Lidberg (Sweden)
  The goal of the WG is to develop models of crustal velocities withing EUREF area of interest, based on observed velocities at Continuously Operating GNSS stations in the EPN and EPN-D.
- SC1.3a-WG4: EPN Reprocessing
  Chair: Christof Völksen (Germany)
  The purpose of this WG is the coordination of re-processing of GNSS-observations from the EPN when major updates are implemented in scientific GNSS analysis. This typically occurs after major re-analysis by the IGS and release of new ITRFs. Current activity is the third reprocessing of the EPN, aiming for homogeneous time series and reliable velocity estimates following igs2020-standards and compatible with the ITRF2020.

Program of Activities

- Continue to develop the EPN in close cooperation with IGS, for the maintenance of the European Terrestrial Reference Frame (ETRF), as a contribution to the ITRF and as an infrastructure to support practical applications for precise positioning and referencing geoinformation;
- Extend the United European Levelling Network (UELN) in order to include as many countries as possible in the current realization of the European Vertical Reference System (EVRS), and further continue the long term maintenance of the European Vertical Reference Frame (EVRF) applying a kinematic approach, in order to take vertical crustal deformations into account;
- Closely follow and contribute to the developments regarding the International Height Reference System (IHRS) and its realizations in International Height Reference Frames (IHRF), and when appropriate establish the precise relation between IHRF and EVRF;
- Promote efforts on regional geoid models in Europe as the link between the ETRF and the EVRF;
- Support new developments in reference frame realization and applications by introducing new technologies like real-time GNSS data transfer and products, as well as Galileo for precise positioning;
- Realize a dense and homogeneous position and velocity product for Europe;
- Establish a dense velocity field model in Europe for the long-term maintenance of the European reference frame;
- Provide GNSS tropospheric estimates at the EPN stations in support of climate research;
- Contribute to the GGOS using the installed infrastructures managed by the EUREF members;
- Promote the adoption of the reference systems defined by EUREF (ETRS89 - European Terrestrial Reference System 1989 and EVRS - European Vertical Reference System) in the European countries and European-wide initiatives related to geo-referencing activities like INSPIRE;
- Cooperate with European political and scientific organizations and projects, e.g. EuroGeographics, EUMETNET, CEGRN (Central European GPS Geodynamic

Reference Network), EPOS (European Plate Observing System), UN-GGIM: Europe, etc.;
- Organize annual symposia addressing activities carried out at national and Europe-wide levels related to the global work and objectives of EUREF.

Members

The members of the Governing Board at the beginning of 2024 are as follows. New members can be elected. An up-to-date list is available at www.euref.eu.

Carine Bruyninx (Belgium)
Rolf Dach (Switzerland)
Ambrus Kenyeres (Hungary)
Karin Kollo (Estonia)
Juliette Legrand (Belgium)
Martin Lidberg (Sweden)
Tomasz Liwosz (Poland)
Benjamin Männel (Germany)
Rosa Pacione (Italy)
Martina Sacher (Germany)
Wolfgang Söhne (Germany)
Christof Völksen (Germany)
Joaquin Zurutuza (Spain)

Active honorary members

Zuheir Altamimi (France)
Alessandro Caporali (Italy)
Markku Poutanen (Finland)
João Agria Torres (Portugal)

SC 1.3b: South and Central America (SIRGAS)

Chair: José Antonio Tarrío (Chile)
Vice-Chair: Demián Gómez (USA)

Terms of Reference

Sub-Commission 1.3b (South and Central America) encompasses the activities developed by the "Geocentric Reference System for the Americas" (SIRGAS). As such, it is concerned with defining, realising and maintaining a modern geodetic reference infrastructure for South and Central America and the Caribbean. This includes a geometric reference frame consistent with ITRS/ITRF and a gravity field-related vertical reference system defined and realized globally. For more information, see https://sirgas.ipgh.org.

Objectives

- To determine, maintain and make available a geocentric reference frame (a set of stations with high-precise geocentric positions and their variation with time) as a regional densification of the global ITRF;
- To support the SIRGAS countries in establishing and maintening national geodetic reference networks as local densifications of SIRGAS in order to guarantee accessibility to the global ITRF at national and local levels;
- To establish a unified vertical reference system supporting the determination and precise combination of physical and geometric heights as well as their variations with time;
- To support the IAG Sub-Commission 2.4b (Gravity and Geoid in South America) in activities related to gravity densifications in order to improve the distribution of gravity information and to establish a new Absolute Gravity Network in South America;
- To contribute to the GGOS program by developing and implementing state-of-the-art products based on the SIRGAS observational infrastructure;
- To promote, support, and coordinate the efforts of the American and Caribbean countries to achieve these objectives.

Structure, Working Groups

The structure of the Sub-Commission 1.3b is based on the functioning SIRGAS Working Groups. They are responsible for implementing the scientific activities and practices approved by the Directing Council. There are currently three WGs:

- SC1.3b-WG1: Establishment and maintenance of the Geocentric Reference Frame for the Americas and the Caribbean
  Chair: José Antonio Tarrío (Chile)
  This WG is responsible for:
  - Coordinating the implementation and maintenance of the geocentric reference frame.
  - Coordinating its activities at the data centers and its analyses.

  - Developing the tools, applications, technical guides and training related to its own activities.
- SC1.3b-WG2: National Integration to the SIRGAS Reference Frame
  Chair: Demián Gómez (USA)
  This WG is responsible for:
  - Encouraging the integration of the pre-existing geodetic networks of the Member States to SIRGAS.
  - Developing the tools, applications, technical guides and training for implementing the SIRGAS reference frames.
- SC1.3b-WG3: Definition, establishment and maintenance of the Vertical Datum for the Americas and the Caribbean
  Chair: Gabriel do Nascimento Guimarães (Brazil)
  This WG is responsible for:
  - Defining, maintaining and updating a unified system of physical heights.
  - Coordinating the implementation of a network of stations linked to the international system for heights.
  - Developing and updating a model of a gravimetric, high-resolution geoid.
  - Establishing and maintaining an absolute gravity network.
  - Developing the tools, applications, technical guides and training related to its own activities.

  SC1.3b-WG3 is strongly linked with IAG Sub-Commission 2.4b (Gravity and Geoid in South America).

Program of Activities

Since the SIRGAS countries are improving their national reference frames by installing an increasing number of continuously operating GNSS stations, it is necessary to outline the best strategy for the combination of those frames to the continental frame. This includes:

- Promotion of the IGS and IERS standards within the SIRGAS countries to ensure the adequate installation, maintenance, and analysis of continuously operating GNSS stations;
- Establishment of a SIRGAS National Processing Centre in all the member countries;
- Refinement of the SIRGAS station hierarchy. At present, two classes are considered: core and densification stations (the establishment of other categories is under consideration);
- Promotion of the adequate usage of SIRGAS as a reference frame using capacity building activities. This comprises SIRGAS schools on reference frames, scientific processing of GNSS data, atmospheric analysis based on the SIRGAS infrastructure, etc.;
- Promotion and implementation of real-time services based on the SIRGAS infrastructure to make available the reference frame to more users;
- The kinematics of the SIRGAS frame, up to now, have been represented by linear station movements (i.e. constant velocities). This representation is not sufficiently precise due to existing seasonal variations in the station position time series and

discontinuities caused by the frequent occurrence of seismic events in the SIRGAS region.

According to this it is necessary

- To model non-linear station movements within the reference frame computation;
- To implement a methodology aiming at a precise transformation between different epochs and, in general, between pre-seismic and post-seismic reference frame realizations in particular;
- To evaluate the feasibility of computing and using near-real-time reference frames instead of those based on epoch station positions and constant velocities.

Members

SIRGAS Executive Committee

Gustavo Caubarrère (Uruguay); Chair
Salomão Soares (Brazil); Vice-Chair
José Antonio Tarrío (Chile); Chair SC1.3b-WG1
Demián Gómez (USA); Chair SC1.3b-WG2
Gabriel do Nascimento Guimarães (Brazil); Chair SC1.3b-WG3

SIRGAS Directing Council:

for an up-to-date list see https://sirgas.ipgh.org

SIRGAS Scientific Council

Denitzar Blitzkow (Brazil)
Laura Sánchez (Germany)
Hermann Drewes (Germany)
Claudio Brunini (Argentina)
María Virginia Mackern (Argentina)
Luiz Paulo Souto Fortes (Brazil)
Sílvio Rogerio Correia de Freitas (Brazil)
Melvin Jesús Hoyer Romero (Venezuela)

SC 1.3c: North America (NAREF)

Co-Chairs: Jason Bond (Canada) and Phillip McFarland (USA)

Terms of Reference

Sub-Commission 1.3c intends to provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, including Greenland (Denmark). For more information, see www.naref.org.

Objectives

In collaboration with the IAG community, its Services and the national geodetic organizations of North America, the objectives of Sub-Commission 1.3c are:

- Densification of the ITRF in North America and promotion of its use;
- Definition, maintenance and future evolution of plate-fixed geometric reference frames for North America, including the North American Datum of 1983 (NAD83) and the forthcoming North American Terrestrial Reference Frame of 2022 (NATRF2022);
- Effects of crustal motion, including post-glacial rebound and tectonic motions along, e.g., the western coast of North America and in the Caribbean;
- Coordination of efforts with neighboring SC 1.3b South and Central America (SIRGAS) to ensure strong ties between each other's reference frames;
- Outreach to the general public through focused symposia, articles, workshops and lectures, and technology transfer to other groups.

Working Groups, Program of Activities

There are currently the following Working Groups:

- SC1.3c-WG1: North American Reference Frame Densification (NAREF)
  Chair: Jason Bond (Canada)
  This WG is responsible to densify the ITRF in the North American region by organizing the computation of weekly coordinate solutions and associated accuracy information for continuously operating GNSS stations that are not part of the current IGS global network. A cumulative solution of coordinate and velocities will also be determined on a weekly basis. The working group will organize, collect, analyze and combine solutions from individual agencies, and archive and disseminate the weekly and cumulative solutions.
- SC1.3c-WG2: North American Terrestrial Reference Frame of 2022 (NATRF2022)
  Chair: Rick Bennett (USA)
  This WG is responsible to establish a high-accuracy, geocentric reference frame, including velocity models, procedures and transformations, tied to the stable part of the North American tectonic plate which would replace NAD83 and serve the broad scientific and geomatics communities by providing a consistent, mm-accuracy, stable reference with which scientific and geomatics results (e.g., positioning in tectonically active areas) can be produced and compared.

- SC1.3c-WG3: Reference Frame Transformations in North America
  Chair: Michael Dennis (USA)
  This WG is responsible to determine consistent relationships between international, regional and national reference frames in North America, to maintain (update) these relationships as needed and to provide tools for implementing these relationships.

Members

Phillip McFarland (USA); Co-Chair
Jason Bond (Canada); Chair SC1.3c-WG1; Co-Chair
Rick Bennett (USA); Chair SC1.3c-WG2
Michael Dennis (USA); Chair SC1.3c-WG3
Mike Bremner (Canada)
Mohammad Ali Goudarzi (Canada)
Mike Piraszewski (Canada)
Finn Bo Madsen (Denmark)
Dan Gillins (USA)
Dan Roman (USA)
Jarir Saleh (USA)
Dru Smith (USA)
Michael Craymer (Canada)
Mike Bevis (USA)
Geoff Blewitt (USA)
Jeff Freymueller (USA)
Tom Herring (USA)
Corné Kreemer (USA)
Richard Snay (USA)

SC 1.3d: Africa (AFREF)

Chair: Elifuraha Saria (Tanzania)

Terms of Reference

Sub-Commission 1.3d (Africa) is concerned with the definition and realization of a unified continental reference frame (AFREF) for Africa, which will be consistent and homogeneous with the global ITRF.

Objectives

In collaboration with the IAG community and its Services, regional organizations, and the National and Regional Mapping Organizations of Africa, the objectives of Sub-Commission 1.3d are:

- Coordinate the activities of the regional organizations focusing on exchange of data, competences and results;
- Promote operation of permanent GNSS stations, in connection with IGS whenever appropriate, as the basis for the long-term maintenance of regional reference frames;
- Promote open access to the GNSS data from permanent GNSS stations used for the maintenance of regional reference frames and scientific applications;
- Develop specifications for the definition and realization of regional reference frames, including the vertical component;
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations;
- Encourage and assist countries, within each regional organization, to re-define and modernize their national geodetic systems, compatible with the ITRF;
- Support the efforts of the United Nations Initiative on Global Geospatial Information Management (UN-GGIM) towards a sustainable Global Geodetic Reference Frame (GGRF).

Program of Activities

- Provide a forum for addressing activities, results and key issues of common interest to the regional organizations;
- Develop analysis strategies and compare methods for the implementation of the regional reference frames and their expression in the ITRF, in full interaction with the IGS;
- Consider developing tectonic deformation models that will enable coordinate transformation of locations within a defined reference frame between different epochs.

SC 1.3e: Asia-Pacific (APREF)

Chair: Basara Miyahara (Japan)

Terms of Reference

Sub-Commission 1.3e aims to improve regional cooperation that supports the realization and densification of the ITRF. This activity will be carried out in close collaboration with the Geodetic Reference Framework for Sustainable Development Working Group of the United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP). For more unformation, see https://un-ggim-ap.org/wg/working-group-1-geodetic-reference-frame.

Objectives

- Densification of the ITRF and promotion of its use in the Asia Pacific region;
- To encourage the sharing of GNSS data from Continuously Operating Reference Stations (CORS) in the region;
- To develop a better understanding of crustal motion in the region;
- To promote the collocation of different measurement techniques, such as GNSS, VLBI, SLR, DORIS and tide gauges, and the determination and maintenance of precise local tie vectors among these geodetic techniques at these sites;
- To provide capacity development opportunities to developing countries through symposia, workshops, seminars, training courses, and technology transfer activities.

Program of Activities

The activities of this Sub-Commission will principally be those of the Asia-Pacific Reference Frame (APREF) project. This is a joint project between IAG SC 1.3e and the geodetic working group of UN-GGIM-AP and consists of a Central Bureau, Network operators, Data centers and Analysis centers. The Central Bureau is at Geoscience Australia and functions as the "day-to-day" APREF coordinating body. Specifically, the Central Bureau ensures that APREF products are made available to the global geodetic community.

Furthermore, they are the Combination Centers responsible for analyzing, combining and validating the individual solutions of the contributing Analysis Centers, and for expressing the combined solution in the ITRF.

The resulting APREF data and products have an open access data policy via the internet following the practice of the IGS. They consist of daily GNSS RINEX data, station log-files, weekly coordinate estimates in SINEX format, and APREF network and time-series plots. For more details, see https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame.

Members

The members of the SC 1.3e are national geodetic representatives from the UN-GGIM-AP member nations and APREF participating organizations.

1. UN-GGIM-AP WG1 (Geodetic Reference Frame)
   Basara Miyahara (Japan); Chair
   Guorong Hu (Australia); Vice-Chair
   Yamin Dang (China)
   Asakaia Tabua (Fiji)
   Upendra Nath Mishra (India)
   Sidik Tri Wibowo (Indonesia)
   Seyed Abdoreza Saadat Mirghadim (Iran)
   Ahmad Sanusi bin Che Cob (Malaysia)
   Dalkhaa Munkhtsetseg (Mongolia)
   Nic Donnelly (New Zealand)
   Jongsin Lee (South Korea)
2. APREF Analysis Group
   Guorong Hu (Australia)
   Alex Woods (Australia)
   Yunbin Yuan (China)
   Basara Miyahara (Japan)

SC 1.3f: Antarctica

Chair: Martin Horwath (Germany)

Terms of Reference

Sub-Commission 1.3f focuses on the realization and densification of a unified reference frame for Antarctica, which will be consistent with the global ITRF. The Sub-Commission shares objectives and activities of the Scientific Committee on Antarctic Research (SCAR), namely of the SCAR Expert Group Geodetic Infrastructure of Antarctica (GIANT). The SC 1.3f closely links IAG and SCAR activities by embedding identical activities (with identical persons where indicated) into the two complementary organizational structures.

Objectives

- Maintenance and densification of the precise geodetic reference network in Antarctica by permanent observations and GNSS campaigns;
- Realization of a unified vertical datum including GNSS ties of tide gauges;
- Providing unified reference for further GNSS applications like airborne gravimetry, ground truthing for satellite missions, geodynamics and glaciology;
- Develop technologies for remote geodetic observatories;
- Stimulate and coordinate international collaboration on the above fields, under the unique political conditions of Antarctic research given by the Antarctic Treaty, in order to make optimum use of logistics and infrastructure.

Program of Activities

- Organization of GNSS campaigns in Antarctica;
- Extend activities for the operation of remote permanent GNSS stations;
- Maintenance of the data archive (SCAR GNSS data base) to collect Antarctic GNSS data and provide them to the scientific community;
- Data analysis and determination of the Antarctic GNSS network as a regional densification of ITRF;
- Provide homogeneous site velocities for e.g. glacial iso-static adjustment determination;
- Support airborne surveys and satellite missions with precise terrestrial reference;
- Collaborate with IAG Sub-Commission 3.4 (Cryospheric Deformation) and the SCAR Scientific Research Programme Solid Earth Response and Influence on Cryosphere Evolution (SERCE) and subsequent programmes, respectively;
- Organize special workshops on the consistent analysis of GNSS data and realization of ITRF;
- Organize meetings/sessions at conferences like IAG, IUGG, SCAR Open Science Conference.

Members

Martin Horwath, (Germany); Chair
Yuichi Aoyama (Japan)
Manuel Berrocoso (Spain)
Alessandro Capra (Italy)
Dave Collett (New Zealand)
Rene Forsberg (Denmark)
Thomas James (Canada)
Aspurah Kamburov (Bulgaria)
Hannu Koivula (Finland)
Matt King (Australia)
Kenichi Matsuoka (Norway)
Alexey Matveev (Russia)
Gennadi Milinevsky (Ukraine)
Elizabeth Petrie (United Kingdom)
Goncalo Prates (Portugal)
Mirko Scheinert (Germany)
Norbertino Suarez (Uruguay)
Terry Wilson (USA)
Andres Zakrajsek (Argentina)

SC 1.4: Interaction of Celestial and Terrestrial Reference Frames

Chair: Maria Karbon (Spain)

Terms of Reference

Sub-Commission 1.4 focuses its activity on the understanding of the interplay of the reference frames and their auxiliary components; be it at their inception, their dependencies and differences w.r.t. previous iterations or their evolution over time. The final aim is to enable the achievement of the requirements for future releases.

The International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF) and the link between them, expressed by the Earth Orientation Parameters (EOP), are key products of geodesy and astrometry. The demands on all components of this triad are increasing, as the mm/μas level of accuracy is the present goal of the astronomical and geodetic community.

The current method for the ITRS realization is based on a multi-stage processing of observations made with different spatial geodetic techniques, i.e. VLBI, SLR, GNSS and DORIS. The final ITRF is derived from the combination of all four techniques, but not all contribute equally. Most realizations are dominated by GNSS, due to its unrivaled station network and data volume. VLBI and SLR are predominately used for the determination of the scale, and the latter also defines the origin. The current ITRF2020 is based on a combination of the full time series of the station positions and EOP of the four techniques, and the station positions are augmented by PSD (post-seismic deformation) parametric models and seasonal (annual and semi-annual) signals. However, the increased demand on accuracy forces improved station motion modeling and continuous updates.

The ICRS realization on the other hand, is based solely on VLBI. The current ICRF3 features source positions only, predominantly in the X band frequency (8 GHz). In addition, two independent catalogs observed at K (22 GHz) and Ka band (32 GHz) are included as well. The three individual monolithic solutions are aligned to the X band catalog through a match of common sources for the transfer of the datum. The ESA satellite mission Gaia measures the positions of star images relative within its field of view. Hence, the resulting coordinate system of positions and proper motions has to be aligned with the ICRS via quasars that are also visible in the optical frequency range and have an ICRF3 counterpart. Thus, all four frames are determined independently and then aligned to each other through individual sets of datum sources.

The tie between ITRF and ICRF is established through an arbitrary set of reference VLBI stations. At the same time VLBI relies on the ITRF origin as established by SLR, and simultaneously contributes to its scale together with SLR. All techniques contribute to the positions and velocities of the ITRF stations. At the same time, all reference frames inherit the orientation from their preceding realization by applying NNR constraint based on various subsets of network stations or radio sources. Thus, each new frame inherits the orientation uncertainty of all its predecessors and adds its own to it.

The definition of the EOP is based on the transformation between the ICRS and ITRS. However, while a reference frame may remain unaltered for years until a new version is released, EOP are subject to constant change and depend on continuous

updates. Further, many applications need accurate predictions. Nonetheless, the EOP must remain consistent with the most recent reference frames. Similar to the ITRF, the individual space geodetic techniques deliver different EOP components with different accuracy, which are then combined in a multi-step process. This combination is linked to the ITRF and ICRF mainly only by the determination process of the EOP within the individual techniques.

Another reference frame that needs to be considered, is the emerging International Terrestial Gravity Reference System and Frame (ITGRF). It is, like the International Height Reference Frame (IHRF), linked to the ITRF via absolute gravity observations at co-located sites. The consistency between these systems needs to be established and ensured over variouse temporal and spacial domains. As it stands, the realization of a global vertical reference system supporting geometric and physical heights is still in its infancy.

Last but not least, the nacent Lunar Reference Frame has to be taken into consideration as well, as updated localization standards for both surface and orbital activities at the Moon are needed for future exlporation missions.

Objectives

The entanglements between ITRF, ICRF and EOP mentioned above lead to convoluted dependencies and complex interactions between them, which need to be carefully investigated and understood to reach the GGOS goals.
While some improvements may be reached by

- reviewing the theory,
- augmenting the models involved,
- refining and unifying the processing strategies,

other limitations are imposed by

- the technological limitations of the observing systems,
- the systematic errors inherent to them.

All these points will be addressed within the respective Working Groups, and due the interdependency of these topics a close collaboration and information exchange is encouraged. This incitement is extended to other IAG Commissions and beyond.

JWG 1.4.1: Improving and homogenisation of geophysical modeling for a better consistency of the reference frames

(joint with Comm 3)
Chair: Tobias Nilsson (Sweden)

Terms of Reference

In the data analysis done for a new reference frame realisation (e.g., the ITRF or the ICRF), a multitude of models are used to correct for geophysical effects, for example atmospheric refraction, tides, and geophysical loading. Since the models used in the

data analysis for the ITRF and the ICRF are not necessarily identical, this will lead to inconsistencies between the frames. These inconsistencies will also affect the EOP. The aim of the working group is to investigate the geophysical models used in the data analyses to find out their quality, as well how they impact the reference frames and the EOP. The work will mainly focus on the TRF and CRF, but emerging reference frames like the ITGRF, IHRF and the reference frame for the moon will also be considered.

Objectives

- Investigate the quality of different geophysical models;
- Develop methods for comparing TRF, CRF and EOP realisations and assessing the consistency between them;
- Perform different studies (theoretical, simulations, and analysis of real data) aimed at determining the impact of different geophysical models on the TRF and CRF and their consistency;
- Assess the consistency between the geophysical models used for the ITRF and the ICRF with those used for the ITGRF, the IHRF, and the lunar refence frame;
- Give recommendations to the IAG technique Services on what models to use in the data analysis and on the importance of using consistent models.

WG 1.4.2: Studying and modeling the structure of the AGNs and its evolution over time and frequency for the future CRFs

Chair: Minghui Xu (Germany)

Terms of Reference

The aim of this working group is to characterize, monitor, model, and interpret the structure of the AGNs in order to improve the position accuracy for the next generation CRFs and thus provide a more stable CRF for geodesy. This working group will lead a pilot project to develop a road map to make structure maps, align them over frequency and time in the presence of core shift, and calibrate the visibilities based on them. The final products from this project are group and/or phase delays that are free of the effects of source structure and refer to the positions of the selected feature of the AGNs.

Objectives

- Construct the structure models (aligned images) from VLBI observations, e.g., the VGOS observations and the astrometric VLBI observations from VLBA and compare the different algorithms/methods for deriving images;
- Define the key parameters for the future CRFs and explore different approaches, such as the radio feature defining the reference position, jet direction, and Gaussian parameters of the structure;
- Study the role of the jet directions in VLBI data analysis and the frame ties between multiple radio wavelengths and optical wavelengths for the best frame ties;

- Monitor the structure evolution over time and frequency in geodetic VLBI observations;
- Explore the usage of geodetic VLBI observations for astrophysics by providing aligned images and core-shift measurements on a weekly basis;
- Create a knowledge-transfer result-validation loop in the three disciplines of geodesy, astrometry, and astrophysics on the ground of the new generation of geodetic VLBI system.

JWG 1.4.3: Consistent realization of TRF, CRF and EOP

(joint with IAU Commission A2 and IERS)
Chair: Robert Heinkelmann (Germany)
Vice-Chair: Manuela Seitz (Germany)

Terms of Reference

Many applications, e.g. in geodesy, astronomy, or navigation, rely on the consistency between terrestrial (TRF) and celestial (CRF) reference frames and Earth Orientation Parameters (EOP). The EOP connect the CRF and TRF in terms of their orientation and rotation differences. The EOP can only be considered as physically meaningful when determined consistently with the reference frames. The quality requirements for the applications including societal contributions were quantified through the GGOS as 1 mm accuracy and 0.1 mm/yr stability, i.e. about 33 μas and 3.3 μas/yr in terms of EOP. For Earth system science based on EOP the consistency is a crucial characteristic. Today, the quality requirements for reference frames and EOP are not met.

Data and model inconsistency. Currently, TRF and CRF are determined independently of each other. Individual Working Groups (CRF) or Combination Centers (TRF) compute the frames through reprocessing/combination efforts every five to ten years. The releases of the terrestrial and celestial frames do not happen at the same time. In this way, the frames are computed based on different input data and on different analysis models in case of updates of the conventional models. Following independent approaches, the consistency of a new release of one of the frames can only be quantified and thus ensured to the last release of the respective other frame. If the frames are not fully consistent, the EOP based on these frames cannot be consistent.

Multi-technique vs. single technique analysis. DORIS, GNSS, SLR and VLBI observations are combined with local tie vectors at co-location sites for the TRF computation, whereas the CRF is directly connected to the TRF through VLBI alone. This situation does not change when applying alternative data analysis procedures. Nevertheless, as VLBI networks are sparse in comparison to multi-technique networks, it has been shown that the terrestrial part of the Earth orientation significantly improves through the combination with satellite-based data. The celestial parts of Earth orientation, dUT1 (UT1 $\sim$ ERA) and CPO, determined by VLBI observations only – and possibly by LLR data –, can in turn improve due to correlations between the EOP within the VLBI data analysis. CRF realizations in other wavelengths are aligned to the X/S VLBI CRF and thus do not contribute to the CRF orientation for ICRF3. Nevertheless, they permit an independent validation. Apart from the rotation and

spin, catalogues based on Gaia (optical) data releases can provide independent insight into deformations and other technique-dependent systematic errors and thus present another independent validation for the VLBI-based CRF.

Prediction problem. The reference frames and the EOP are customarily applied in prediction mode, e.g. for geodetic and astrometric data analyses. Accordingly, values have to be given beyond the data time-span considered for the reference frame realization. As long as no significant non-linearity occurs, the global coordinates can be used very well for predicting the position into the future. For most applications, predicted EOP have to be available as well. These predicted EOP require consistency to the frames and to the reprocessed EOP at the same time. It is impossible to fulfill both requirements when new reference frame releases become available.

Objectives

Addressing the above-mentioned issues, the working group will:

- compute multi-technique CRF-TRF solutions together with EOP in one step, which will serve as a basis to quantify the consistency of the current conventional reference frames and EOP as well as the consistency of reprocessed and predicted EOP;
- investigate the impact of different analysis options, model choices and combination strategies on the consistency between TRF, CRF and EOP;
- study the differences between multi-technique and VLBI-only solutions;
- study the differences between VLBI solutions at different radio wavelengths;
- study the differences between Gaia (optical) and VLBI (radio) reference frames;
- study the effects on the results, when different data time spans are considered;
- compare the practically achievable consistency with the quality requirements theoretically addressed by the GGOS;
- derive conclusions about future observing systems or analysis procedures in case the quality requirements cannot be met with the current infrastructure and approaches.

Members

Robert Heinkelmann (Germany); Chair
Manuela Seiz (Germany); Vice-Chair
Sabine Bachmann (Germany)
Liliane Biskupek (Germany)
Christian Bizouard (France)
Xavier Collilieux (France)
Aletha de Witt (South Africa)
David Gordon (USA)
Christopher Jacobs (USA); IAU CA1
Maria Karbon (Spain)
Hana Krasna (Austria)
Sebastien Lambert (France)
Karine Le Bail (Sweden)

David Mayer (Austria)
Tobias Nilsson (Sweden)
Krzysztof Sośnica (Poland)
Nickolas Stamatakos (USA)
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Corresponding members

Alberto Escapa (Spain); IAU CA2
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Florian Seitz (Germany)
Daniela Thaller (Germany); Director IERS CB
Malkin Zinovy (Russia); IAU CA2

Commission 2- Gravity Field

https://doi.org/10.82507/iag-gh2024_com2

President: Srinivas Bettadpur (USA)
Vice President: Tao Jiang (China)

Commission 2 website - www.com2.iag-aig.org

1 Terms of Reference

The accurate determination of the gravity field and its temporal variations is one of the three fundamental pillars of modern geodesy (next to geometry/kinematics and Earth rotation). This is essential for applications in positioning and navigation, civil and aerospace engineering, metrology, geophysics, geodynamics, oceanography, hydrology, cryospheric sciences and other disciplines related to the Earth's climate and environment. IAG Commission 2 was established at the IUGG in Sapporo in summer 2003 for promoting, supporting, and stimulating the advancement of knowledge, technology, and international cooperation in the geodetic domain associated with the Earth's gravity field.

Since most of the scientific themes are of long-term interest, large parts of the structure of Commission 2 are continued on the same basis as in the previous period 2020-2023. Main drivers for the activities of the present period 2023-2027 are related to the IAG resolution adopted at the XXVIII IUGG General Assembly 2023 in Berlin, concerning the International Terrestrial Gravity Reference System (ITGRS).

Commission 2, at the start of the new period, consists of six Sub-Commissions (SC), plus Study Groups (SG) Joint Working Groups (JWG) and Joint Study Groups (JSG), all of them jointly with other Commissions and/or services. The Sub-Commissions cover the following scientific topics:

- Terrestrial (land, marine, airborne) gravimetry and relative/absolute gravity networks;
- Geoid, Physical Height Systems and Vertical Datum Unification;
- Satellite gravity missions;
- Regional geoid determination;
- Satellite altimetry;
- Gravity inversion and mass transport in the Earth system.

Commission 2 has strong links to other commissions, GGOS, IGFS, ICCT and other components of IAG. Connections to these components are created through JWG and JSG that provide a cross-disciplinary stimulus for work in several topics of interest to the commission, and the joint organization of meetings.

The main tasks of Commission 2 in the period 2023-2027 are among others:

- Establishment of a Global Absolute Gravity Reference System (GAGRS) to replace the International Gravity Standardization Net 1971 (IGSN71), which no

longer fulfills the requirements and accuracy of a modern gravity reference; especially to include time-dependent gravity variations;
- Supporting the realization of an International Height Reference System (IHRS);
- Supporting the realization of a Global Geodetic Reference System (GGRS);
- Analysis of current and future satellite data (CHAMP, GRACE, GOCE, GRACE-FO) and the release of improved global gravity field models (satellite-only models and in combination with terrestrial data and satellite altimetry);
- Promoting future gravity mission constellations for assuring the continued monitoring of global gravity and mass transport processes in the Earth system;
- Assuring the future of the comparison campaigns of absolute gravimeters;
- Investigating modern relativistic methods and geodetic metrology with special focus on gravity field and height determination;
- Fostering regional gravity and geoid determination and integration of regional models into a global reference;
- Understanding of physics and dynamics of the Earth sub-systems and mass transport processes in the Earth system;
- Providing contributions to operationalization of mass transport modelling and stimulation of new applications;
- Fostering communication with user communities;
- Assisting the IGFS and its components in improving their visibility and their services;
- Assisting the regional sub-commissions in establishing contacts and in acquiring data.

1.1 Objectives

The main objectives of Commission 2 are as listed in the IAG Bylaws:

- Terrestrial, marine and airborne gravimetry
- Satellite gravity field observations
- Gravity field modeling
- Time-variable gravity field
- Geoid and height determination
- Satellite orbit modeling and determination
- Satellite altimetry for gravity field modeling

1.2 Program of Activities

The Gravity Field Commission fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing Symposia, either independently or at major conferences in geodesy. The activities of its sub-entities, as described below, constitute the activities of the Commission, which will be coordinated and summarized in annual reports to the IAG Bureau.

The principal symposia that will be organized jointly by Commission 2 and the IGFS in the next period will be held in September 2024 in Thessaloniki and in 2026 (location TBD). The other two symposia where a Commission 2 meeting will be held

are the IAG Scientific Assembly 2025 in Rimini, Italy and the IUGG General Assembly 2027 in Incheon, South Korea.

The status of Commission 2, with links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the web site: https://com2.iag-aig.org/.

1.3 Structure

Sub-Commissions

SC 2.1 Terrestrial gravimetry for the needs of geosciences and metrology
Chair: Przemysław Dykowski (Poland)
SC 2.2 Geoid, Physical Height Systems and vertical datum unification
Chair: Georgios S. Vergos (Greece)
SC 2.3 Gravity Missions
Chair: David Wiese (USA)
SC 2.4 Gravity and Geoid
Chair: Hussein Abd Elmotaal (Egypt)
SC 2.4a Gravity and Geoid in Europe
Chair: TBD
SC 2.4b Gravity and Geoid in South America
Chair: Gabriel Guimarães (Brazil)
SC 2.4c Gravity and Geoid in North and Central America
Chair: Jianliang Huang (Canada)
SC 2.4d Gravity and Geoid in Africa
Chair: Hussein Abd Elmotaal (Egypt)
SC 2.4e Gravity and Geoid in Asia-Pacific
Chair: Cheinway Hwang (China-Taipei)
SC 2.5 Satellite Altimetry
Chair: Xiaoli Deng (Australia)
SC 2.6 Gravity Inversion and Mass Transport in the Earth System
Chair: Wei Feng (China)

Study Groups

SG 2.1.1 Developments in near Earth gravity measurements on moving platforms
Chair: Derek van Westrum (USA)
SG 2.5.1 High-resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies (HRA)
Chair: Luciana Fenoglio-Marc (Germany)
SG 2.5.2 Synergistic Applications of Satellite Altimetry with Other Satellite Sensors and Physical Models (SASA)
Chair: Hyongki Lee (USA)
SG 2.5.3 High Resolution Mean Sea Surface (MSS)
Chair: David Sandwell (USA)
SG 2.5.4 The International Altimeter Service (IAS) Planning Group
Chair: Xiaoli Deng (Australia)

SG 2.6.1 Geodetic observations and physical interpretations in the Tibetan Plateau
Chair: Wenbin Shen (China)

Joint Working Groups

JWG 2.1.1 Development of the International Terrestrial Gravity Reference Frame
(joint with IGFS, BGI, IGETS)
Chair: Hartmut Wziontek (Germany)

JWG 2.2.1 Comprehensive gravity data integration for the sub-cm geoid/quasi-geoid modelling
(joint with IGFS, ISG)
Chair: Ismael Foroughi (Canada)

JWG 2.3.1 Spatial Leakage Mitigation in Satellite Gravimetry
(joint with ICCC)
Chair: Eva Boergens (Germany)

Joint Study Groups

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
(joint with Comm 1 and Comm 3)
Chair: Lambert Caron (USA)

1.4 Steering Committee

- President Commission 2: Srinivas Bettadpur (USA)
- Vice President Comm. 2: Tao Jiang (China)
- Past President: Adrian Jäggi (Switzerland)
- Chair Sub-Comm. 2.1: Przemysław Dykowski (Poland)
- Chair Sub-Comm. 2.2: Georgios S. Vergos (Greece)
- Chair Sub-Comm. 2.3: David Wiese (USA)
- Chair Sub-Comm. 2.4: Hussein Abd Elmotaal (Egypt)
- Chair Sub-Comm. 2.5: Xiaoli Deng (Australia)
- Chair Sub-Comm. 2.6: Wei Feng (China)
- Representative of IGFS: Georgios S. Vergos (Greece)
- Representative of ICGEM: E Sinem Ince (Germany)
- Representative of ICCC : Balaji Devaraju (India)
- Member-at-Large: Rebecca McGirr (Australia)
- Member-at-Large: Andrea Santacruz Jaramillo (Brazil)
- Representative of Early Career Scientists (non-voting): Athina Peidou (USA)

1.5 Overview of Working Groups and Study Groups

Groups related to SC 2.1

SG 2.1.1 Developments in near Earth gravity measurements on moving platforms
Chair: Derek van Westrum (USA)

JWG 2.1.1 Development of the International Terrestrial Gravity Reference Frame
(joint with IGFS, BGI, IGETS)
Chair: Hartmut Wziontek (Germany)

Groups related to SC 2.2

JWG 2.2.1 Comprehensive gravity data integration for the sub-cm geoid/quasi-geoid modelling
(joint with IGFS, ISG)
Chair: Ismael Foroughi (Canada)

Groups related to SC 2.3

JWG 2.3.1 Spatial Leakage Mitigation in Satellite Gravimetry
(joint with ICCC)
Chair: Eva Boergens (Germany)

Groups related to SC 2.5

SG 2.5.1 High-resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies (HRA)
Chair: Luciana Fenoglio-Marc (Germany)

SG 2.5.2 Synergistic Applications of Satellite Altimetry with Other Satellite Sensors and Physical Models (SASA)
Chair: Hyongki Lee (USA)

SG 2.5.3 High Resolution Mean Sea Surface (MSS)
Chair: David Sandwell (USA)

SG 2.5.4 The International Altimeter Service (IAS) Planning Group
Chair: Xiaoli Deng (Australia)

Groups related to SC 2.6

SG 2.6.1 Geodetic observations and physical interpretations in the Tibetan Plateau
Chair: Wenbin Shen (China)

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
(joint with Comm 1 and Comm 3)
Chair: Lambert Caron (USA)

2 Sub-Commissions, Working Groups and Study Groups

SC 2.1: Terrestrial gravimetry for the needs of geosciences and metrology

Chair: Przemysław Dykowski (Poland)
Vice-Chair: Ezequiel Antokoletz (Argentina/Germany)

Terms of Reference

Geodesists, geophysicists as well as the metrological community utilize gravity datasets from a wide variety of sources: local relative gravity campaigns, pointwise absolute gravity observations, gravity variations in time at fixed locations, and regional scale observations from marine and airborne platforms. These observations need to be consistent with each other, consistent with satellite-based results, and have well defined accuracy/uncertainty determinations. SC 2.1 aims to bring together scientists from all over the globe that are interested in the instruments, techniques, and analysis of terrestrial, marine and airborne gravity measurements.

Objectives

The Sub-Commission 2.1 will:

- Provide the scientific community with the means to assess the accuracy of their collected gravity datasets with respect to the international gravity reference standards maintained through absolute gravity observations and the organization of regular international absolute gravimeter comparisons. These efforts are done in close cooperation with the metrology community: the BIPM Consultative Committee on Mass and Related Quantities, its Working Group on Gravimetry (CCM-WGG), and other Regional Metrology Organizations as well as all interested scientific institutions. This relationship allows for direct traceability of gravity data to international standards between the geoscience and metrology communities.
- Support the dissemination of the results of these activities through an international absolute gravity database, which in turn, will support the ongoing realization of a new and improved International Terrestrial Gravity Reference Frame (ITGRF), as a realization of the International Terrestrial Gravity Reference System (ITGRS) defined by the IAG in its Resolution adopted during the IUGG General Assembly 2023 (https://www.iag-aig.org/doc/651bd7f2e3cbf.pdf).
- Support sharing expertise and experience in performing gravity surveys on moving platforms (Marine, Airborne) allowing for the collection of the highest possible quality gravity data using the most up-to-date techniques and, at the same time, allowing the assessment of achieved accuracies.
- Promote research and development into new instruments and techniques by stimulating communication, cooperation as well as knowledge dissemination between scientific groups worldwide. The Sub-Commission will encourage regional meetings and dedicated workshops to face specific problems when and where appropriate.

Program of Activities

This Sub-Commission will:

- Appoint the Steering Committee consisted of experienced members related to the activities of SC2.1 and the contact persons for European, East Asia, Western Pacific, South America and North America Gravity Networks.
- Host the SG2.1.1 "Developments in near Earth gravity measurements on moving platforms".
- Support IAG Commission 2 Symposia such as GGHS as well as any gravity-related meetings.
- Support of the ITGRF with a database for absolute gravity observations and the documentation of results from the comparisons of absolute gravimeters.
- Support the activities of the Working Group Q.1: Quantum gravimetry in space and on ground of the IAG Project – Novel Sensors and Quantum Technology for Geodesy (QuGe).

Steering Committee

Przemysław Dykowski (Poland); Chair
Ezequiel Antokoletz (Argentina/Germany); Vice-Chair
John Crowley (Canada)
Jack McCubbine (Australia)
Shuqing Wu (China)
Derek van Westrum (USA)
Sylvian Bonvalot (France)
Hartmut Wziontek (Germany)
Mirjam Biker-Koivula (Finland)
David Avalos (Mexico)
Iuri Bjorkstrom (Brasil)
Thapelo Mametja (South Africa)
Takahito Kazama (Japan)
Leni Sophia Heliani (Indonesia)

JWG 2.1.1: Development of the International Terrestrial Gravity Reference Frame

(joint with IGFS, BGI, IGETS)
Chair: Hartmut Wziontek (Germany)
Vice-Chair: Sylvain Bonvalot (France)

Terms of Reference

One task of IAG's Commission 2 is the establishment of the International Terrestrial Gravity Reference System and Frame (ITGRF). These activities are motived by the IAG Resolutions No. 2 of 2015 (IUGG General Assembly Prague), No. 4 of 2019 (IUGG General Assembly Montreal) and No. 1 of 2023 (IUGG General Assembly Berlin). The

SC 2.1 promotes consistency and compatibility of gravity and gravity gradient datasets and assessment of their accuracy. The International Gravity Field Service (IGFS) coordinates the servicing of the geodetic and geophysical community with gravity field related data, software and information. The infrastructure of IGETS, specifically stations operating superconducting gravimeters, provides a basis for reference stations of the ITGRF. The ITGRF as a modern and precise absolute gravity reference frame will not only contribute to the establishment of the Global Geodetic Reference Frame (GGRF) of the UN, but will also serve as a long-term and precise gravity reference for the IAG GGOS.

Objectives

- Within SC 2.1, activities on the ITGRF will be continued. The ITGRF is the realization of the International Terrestrial Gravity Reference System (ITGRS). According to IAG Resolution No. 1 of 2023, the ITGRS is defined by the observation of the instantaneous acceleration of free fall, the traceability of these observations to the International System of Units (SI), and a set of conventional corrections for the time independent components of gravity effects. The ITGRF is based on observations with absolute gravimeters (AG) which are monitored at reference stations, and during comparisons. The ITGRF further recommends a set of conventional models for the correction of temporal gravity changes. Finally, the ITGRF demands a compatible infrastructure accessible to end-users, according to IAG Resolution No. 4 of 2019.
- The JWG focuses on establishing such infrastructure in cooperation with IGFS, GGOS, international and national institutions, agencies, and governmental bodies. This infrastructure should consist of reference stations on the national level for the monitoring of AGs. On the international level, comparison stations will provide the facilities to check the compatibility of AGs, and core stations will link to space geodetic techniques (ITRF) and the International Height Reference Frame (IHRF).
- The absolute gravity database "AGrav" which is a permanent component of the International Gravimetric Bureau (BGI) services will be developed to a central inventory to document all ITGRF stations and related AG observations.
- A close cooperation with the International Geodynamics and Earth Tide Service (IGETS) supports the continuous monitoring at the gravity reference stations. The collaboration with the Working Group on Gravimetry of the Consultative Committee on Mass and Related Quantities (CCM-WGG) at BIPM establishes a link to metrology and supports the traceability of the AG observations.
- The activities should be further aligned with those on the implementation of the IHRF.

Members

Hartmut Wziontek (Germany); Chair
Sylvain Bonvalot (France); Vice-Chair
Mauro Andrade de Sousa (Brazil)
Ezequiel Antokoletz (Germany)

Mirjam Bilker Koivula (Finland)
John Crowley (Canada)
Przemysław Dykowski (Poland)
Andreas Engfeldt (Sweden)
Alessandro Germak (Italy)
Jaakko Mäkinen (Finland)
Urs Marti (Switzerland)
Jack McCubbine (Australia)
Vojtech Palinkas (Czech Republic)
Victoria Smith (UK)
Ludger Timmen (Germany)
Claudia Tocho (Argentina)
Christian Ullrich (Austria)
Derek van Westrum (USA)
Shuqing Wu (China)
Koji Matsuo (Japan)
Arturo Villar García (Spain)

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Jean-Paul Boy (France)
Ana Cristina O. Cancoro de Matos (Brazil)
In-Mook Choi (Korea)
Neda Darbeheshti (Australia)
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Camilo Matiz (Colombia)
Leidy Johanna Moisés Sepúlveda (Colombia)
Per-Anders Olsson (Sweden)
Tomasz Olszak (Poland)
Andrea Prato (Italy)
Rene Reudink (Netherlands)
Laura Sanchez (Germany)
Heping Sun (China)
V.M. Tiwari (India)

SG 2.1.1: Developments in near Earth gravity measurements on moving platforms

Chair: Derek van Westrum (USA)
Vice-Chair: Neda Darbeheshti (Australia)

Terms of Reference

Developments in gravity and gravity gradiometry measurements from (non-satellite) moving platforms continue at a rapid pace. Alongside conventional spring-based systems, sensors now include micro-electromechanical systems (MEMS), inertial measurement units (IMUs), and quantum absolute instruments. In addition to ships and fixed-wing aircraft, mobile platforms now include a wide range of drones (airborne, seaborne, and underwater). Proposals are even underway for optical clock deployments on moving platforms.

SG 2.1.1 focuses on tracking all aspects of these developments: sensors, platforms and their integration, analysis techniques, survey projects, and data applications.

Objectives

- Communication between the gravity science community and the institutes, research groups, and companies that are developing novel instruments and deployments.
- Coordination of scientific efforts and best practices regarding the collection and analysis of mobile platform gravity data.
- Promotion and coordination of mobile gravity datasets for the establishment of regional gravity networks and other applications.
- Organization of scientific workshops and meetings to discuss techniques and methods of mobile gravity measurements.

Members

Derek van Westrum (USA); Chair
Neda Darbeheshti (Australia); Vice-Chair
Jack McCubbine (Australia)
Tao Jiang (China)
Tim Jensen (Denmark)
Christoph Forste (Germany)
Masahiro Nakashima (Japan)
Koji Matsuo (Japan)

SC 2.2: Geoid, Physical Height Systems and vertical datum unification

Chair: Georgios S. Vergos (Greece)
Vice-Chair: Rossen S. Grebenitcharsky (Saudi Arabia)

Terms of Reference

A global height reference frame with high accuracy and stability is required to determine the global changes of the Earth. A major step towards this goal was taken by the IAG resolution (No. 1) for the definition and realization of an International Height Reference System (IHRS), adopted at the IUGG 2015 meeting in Prague and the IAG resolution (No. 3) for the establishment of the International Height Reference Frame (IHRF), adopted at the IUGG 2019 meeting in Montreal. Given the work carried out for the general methodological scheme for geoid and potential determination, the data prerequisites and practical studies, it has become apparent that the IHRS should be globally realized with common standards in terms of the processing strategy.

Given the versatility (in terms of the topographic and geomorphological characteristics) of realized IHRF sites, data availability and data quality issues, the achieved accuracy in the realization of potential values is still far from the wanted ± 0.1 m2s-2 (equivalent to ± 1 cm) error. Moreover, the use of all available data sources, e.g., GNSS-derived heights, satellite altimetry, topography/bathymetry, local gravity (terrestrial, airborne and marine) as well as the latest global geopotential models, should be properly studied to model the high-frequency part of the gravity field spectrum. Such combination of heterogenous data has been deemed as mandatory in order to reduce the omission error as well as to properly model the contribution of topography. Furthermore, the absence of local gravity data posses an additional problem in local geoid and potential determination, which in that case should rely solely on the best available GGM and topographic effects.

Traditional levelling might also be integrated on a regional or local scale, as they form the natural means to realize physical heights and provide the link to tide-gauge data that usually realize local vertical datums. The unification of local/national vertical reference frames to regional ones and their link to the IHRF is of main importance, employing local geoid realizations and datum definitions. Finally, given that the current realization of the IHRF refers to a (quasi)static one, the temporal variations of the geoid, physical heights and the potential are of paramount importance to be in-line with the IHRF conventions.

The IAG SC 2.2 aims at bringing together scientists concerned with methodological questions in geoid and potential determination, who in different ways contribute to reach the above-mentioned goal of a global height system realization and unification as well as its temporal variations. It includes topics (state of art methodologies for processing, analyzing, utilizing data, unifying datums, etc.) ranging from regional gravimetric geoid determination to the realization and implementation of IHRS in view of the existing regional/local/national height system realizations and 3D vertical datum (geoid) definitions.

Objectives

The SC 2.2 promotes and supports scientific research related to methodological questions in geopotential, geoid and height determination, both from the theoretical and practical perspectives. The former refers in particular on methodological questions and practical numerical applications contributing to the realization of IHRS with the required sub-centimeter accuracy, the combination of local/regional vertical reference frames and their unification to the IHRF and the estimation of geoid, physical heights and the potential temporal variations. This includes for instance:

- Realization of the International Height Reference System (support to the "International Height Reference Frame Computation Center – IHRF CC").
- Height system unification at regional scales and unification to the IHRF.
- Studies on W_0 determination.
- Studies on data requirements, data quality, distribution and sampling rate to reduce the omission error to the sub-centimeter level in different parts of the world.
- Contributions of alternate data sources, such as altimetry sea surface heights, absolute SAR, InSAR and GNSS geometric heights to geopotential modeling and geoid determination at reference benchmarks.
- Investigation of the theoretical framework required to compute the sub-centimeter geoid with the support of JWG 2.2.1 and various ICCT SG and WG on the geoid modelling and height systems.
- Investigation of the error budget of potential determination and vertical reference frames unification.
- Investigation and benchmarking of alternative regional geoid determination methods and software.
- Studies on theoretical and numerical problems related to the solution of the geodetic boundary value problems (GBVPs) in geoid determination.
- Studies on time variations of the gravity field and heights due to Glacial Isostatic Adjustment (GIA) and land subsidence.
- Development of relativistic methods for potential difference determination using precise atomic clocks (support of Working Group X.3).
- Investigating the role of traditional levelling in future regional/local height system realizations combined with all available data linked to Earth's geopotential determination.
- Investigating the utilizations of already defined national and regional geoid models together with new types of Geodetic Earth Observations (GEOs) and based on theoretical and practical developments linked to mixed GBVPs.
- Investigating temporal geoid, physical height and potential variations from current gravity field missions (GRACE/GRACE-FO), higher-resolution hydrological land surface models and glacial surface mass balance models as well as the impact of future mission concepts.

Program of Activities

- Organizing meetings and conferences.
- Organization of local/regional workshops for the promotion of IHRF related studies.

- Inviting the establishment of Special Study Groups on relevant topics.
- Reporting activities of SC2.2 to the Commission 2.
- Communication/interfacing between different groups/fields relevant to the realization of IHRS.
- Conceptual and methodological support to working groups for national & regional vertical datums and reference frames definitions as realizations of IRHS.

Steering Committee

Georgios S. Vergos (Greece); Chair
Rossen S. Grebenitcharsky; Vice-Chair
Riccardo Barzaghi (Italy)
Thomas Gruber (Germany)
Claudia Tocho (Argentina)
Jianliang Huang (Canada)
Xiapoeng Li (USA)
Laura Sanchez (Germany)

JWG 2.2.1: Comprehensive gravity data integration for the sub-cm geoid/quasi-geoid modelling

(joint with IGFS, ISG)
Chair: Ismael Foroughi (Canada)
Vice-Chair: Tao Jiang (China)

Terms of Reference

The evergrowing availability of new types of gravity field observations, including those from land-level surveys (terrestrial, marine, and airborne) and satellite gravity missions, alongside height information, such as DEMs, satellite altimetry and/or spirit levelling data, necessitates their efficient integration for precise (sub-centimetre) regional geoid/quasi-geoid modelling. The variety of gravity field observations, influenced by their positioning in 3-D space, sensor type, or surveying method, underscores the need for a comprehensive investigation in order to reduce the effect of data errors in solving geodetic boundary-value problems. Additionally, computations of topographic corrections to observed gravity data as well as to solved quantities, which are integral to regional gravity field modelling to meet theoretical requirements to form boundary-value conditions and/or interpolate scattered observations, require thorough examination in the context of various data combination. The efficient spectral and/or spatial combination of gravity observation types along with topographic corrections to estimate a sub-centimetre geoid/quasi-geoid is still the open issue and the main goal of this working group.

Objectives

This working group aims to:

- For land-level gravity observation types:
  - Develop a cleaning process for terrestrial gravity observations
  - Find the optimal combination of scattered marine gravity observations with offshore global gravity models derived from data of satellite altimetry missions
  - Investigate various filtering methods to efficiently use both scalar- and vector-valued airborne gravity observations.
- Investigate different combination methods to integrate scalar- and vector-valued gravity observations.
- Study the contribution of satellite-only or combined global gravitational models, for their efficient integration with high-frequency gravity observations provided by land-level sensors.
- Examine how different ways of combining data affect the accuracy of geoid/quasi-geoid models, considering:
  - errors caused by interpolating (gridding) terrestrial/marine gravity data
  - errors caused by filtering airborne gravity data
  - errors originating from global gravitational models (omission and commission errors)
  - errors in topographic corrections due to errors in DEMs.
- Explore the potential use of GNSS/levelling observations for optimizing the combination of various types of gravity observations.
- Investigate optimal techniques for evaluation of the full (spatial) or band-limited topographic corrections to each type of gravity observations
  - Including the effect of using spatially-varying or mean topographic mass density.
- Investigate the complexity of gravity field observations, and its effect on their interpolation and downward continuation.
- Use a very high degree/order synthetic global gravitational model, e.g., up to 21600, to test different combination techniques, and omission and commission errors.
- Share experimental data and software tools dedicated to gravity data integration and evaluation of topographic corrections on gravity data and computed quasi-/geoid in a repository.
- Investigate the potential benefits of Machine Learning and Artificial Intelligence for gravity data interpolation and integration.
- Provide a comprehensive report on gravity data combination strategies and their applications for regional gravity field modelling.
- Present interim and final outcomes at international conferences.

Members

Ismael Foroughi (Canada); Chair
Jack McCubbine (Australia)
Pavel Novák (Czech Republic)
Georgios S. Vergos (Greece)
Robert Kingdon (Canada)
Sten Claessens (Australia)

Riccardo Barzaghi (Italy)
René Forsberg (Denmark)
Mehdi Goli (Iran)
Jonas Ågren (Sweden)
Bihter Erol (Türkiye)
Xiaopeng Li (USA)
Roland Klees (Netherlands)
Ana Crisitina Oliveira Concoro de Matos (Brazil)
Jianliang Huang (Canada)
Vegard Ophaug (Norway)
Gabriel Guimarães (Brazil)
Cornelis Slobbe (Netherlands)
Mirko Reguzzoni (Italy)
Hussein Abd-Elmotaal (Egypt)
Ropesh Goyal (India)
Tao Jiang (China)
Josef Niedermaier(Germany)
Sabah Ramouz (Iran)
Stephen Ferguson (Canada)
Patroba Achola Odera (South Africa)
Matej Varga (Switzerland)
Christian Gerlach (Germany)
Robert Tenzer (China-Hong Kong)

SC 2.3: Gravity Missions

Chair: David Wiese (USA)
Vice-Chair: João de Teixeira da Encarnacao (Netherlands)

Terms of Reference

The successful launches of the German CHAMP (2000), the US/German GRACE (2002), the ESA GOCE (2009) and US/German GRACE-FO (2018) missions have led to a revolution in global gravity field mapping using space-borne observation techniques. These missions have utilized an array of measurement concepts and technologies, including high-low satellite-to-satellite tracking (SST) using the GNSS constellation, low-low SST based on microwave and laser ranging technologies, satellite gravity gradiometry (SGG), as well as high-precision space-borne accelerometry, to provide direct measurements of the global mass distribution and transport within the Earth system. The GRACE (2002-2017) and GRACE-FO (2018-present) missions have combined to provide a 21-year (and still growing) record of Earth system mass change and have served as the catalyst for several new planned gravity missions, including the US/German GRACE-Continuity (GRACE-C; planned launch in late 2020s), and ESA's Next Generation Gravity Mission NGGM; planned launch in early 2030s), to both continue and improve upon this vital climate data record. GOCE provided high- accuracy and high-resolution static gravity field models. In combination with complementary gravity field information from terrestrial data and satellite altimetry, including the newly launched SWOT mission, an even higher spatial resolution static gravity field model can be achieved. These satellite missions provide valuable contributions to a diversity of geoscientific application fields, such as geodesy, hydrology, oceanography, glaciology, solid Earth physics, and climate research.

Objectives

The focus of SC 2.3 will be to promote and stimulate the following activities:

- providing the scientific environment for the development of the next generation of static and temporal gravity field solutions based on observations from the satellite gravity missions CHAMP, GRACE, GOCE, and GRACE-FO, as well as optimum combination with complementary data types (SLR, terrestrial and air-borne data, satellite altimetry, GNSS tracking, etc.),
- developing alternative methods and new approaches for global gravity field processing with special emphasis on functional and stochastic models and optimum data combination,
- fostering the exchange of knowledge and data among processing entities,
- communication and interfacing with gravity field model user communities (climatology, oceanography/altimetry, glaciology, solid Earth physics, geodesy, hydrology, etc.) as well as relevant IAG organizations such as the GGOS Committee on Satellite and Space Missions and the GGOS Bureau of Products and Standards,
- supporting the implementation of currently planned satellite gravity missions,

- identification, investigation, and definition of enabling technologies for future gravity field missions such as observation types, technologies or mission architectures, and
- triggering new gravity field mission proposals and supporting their implementation.

Program of Activities

The Sub-Commission will establish, if necessary, Working Groups on relevant topics. The Steering Committee will work closely with members and other IAG Commissions and Sub-Commissions to obtain mutual goals. The SC 2.3 will also promote and jointly sponsor special sessions at IAG Symposia and other workshops and conferences.

JWG 2.3.1: Spatial Leakage Mitigation in Satellite Gravimetry

(joint with ICCC)
Chair: Eva Boergens (Germany)
Vice-Chair: Bramha Dutt Vishwakarma (India)

Terms of Reference

An inherent and well-known problem of satellite gravimetry is the limited spatial resolution of the sensors observing the functionals of the Earth's gravity field. The problem is particularly present for mass change applications from GRACE and GRACE-FO. That is due to the limited amount of sensor data available to calculate monthly gravity fields, the signal attenuation due to the distance between the sensor (the satellites) and observable, and the typically applied global mathematical basis functions. The limited spatial resolution leads to apparent mass loss or gain in regions by mass signals from neighbouring regions and is called the spatial leakage effect. Although future gravity missions are planned to increase the spatial resolution with additional satellite pairs in inclined orbits (e.g. ESA's MAGIC), the spatial leakage effect will only be reduced.

Over the last 20 years of the GRACE and GRACE-FO mission lifetime, numerous methods have been proposed by various research groups to mitigate the disadvantageous effects of leakage. Some of these approaches focus on specific regions, while others provide a global mitigation scheme.

The approaches can be grouped into the following categories:

- Estimates obtained from Earth system models of the most prominent surface mass processes;
- Forward-modelling approaches, where the geometry of surface mass change is assumed a-priori and parameters are estimated to fit the gravity field data (in a least-squares sense);
- Data-driven approaches that only rely on the geodetic data themselves;
- Regional integration approaches that use apriori covariance information on the surface mass change signal and accordingly optimize the weight function (or sensitivity kernel) used for the regional integration;
- Methodologies based on (non-geodetic) satellite remote sensing data.

Further, spatial leakage is treated very differently for individual surface mass change applications and across international research institutions. In some cases, leakage is readily corrected before providing mass anomalies to non-geodetic users. In other cases, only some leakage approximation is provided to inform users about this systematic error source. Furthermore, leakage is sometimes not even treated at all.

Thus, consolidating spatial leakage approaches across the geodetic community will guide geodetic and non-geodetic users and increase the accessibility of satellite mass anomaly data to the latter group.

Objectives

- Collect existing leakage approximation and mitigation methods;
- Develop a common and independent validation approach;
- Recommend best practices in communicating spatial leakage to non-geodetic users of surface mass change data derived from satellite gravimetry. Planned timeline with deliverables The planned time frame of the working group is four years.
- Year 1:
  - Collection and review of existing leakage mitigation methods (A review paper);
  - Definition of community-accepted validation criteria and requirements for validation data set (Tech report or a white paper);
  - Apply for a grant/fellowship-scheme for a PhD student.
- Year 2:
  - Generation of validation data set (Paper to a data journal).
- Year 3:
  - Execution and evaluation of validation experiments.
- Year 4:
  - Analysis of the validation experiments (Research paper);
  - Recommendation to the user community (Tech report or a white paper).

Members

Eva Boergens (Germany); Chair
Bramha Dutt Vishwakarma (India); Vice-Chair
Christoph Dahle (Germany)
Balaji Devaraju (India)
Thorben Döhne (Germany)
Wei Feng (China)
Frank Flechtner (Germany)
Andreas Güntner (Germany)
Adrian Jäggi (Swizerland)
Felix Landerer (USA)
Bryant Loomis (USA)
Mahdiyeh Razeghi (Australia)
Ernst Schrama (Netherlands)
Michael Zemp (Swizerland)

SC 2.4: Gravity and Geoid

Chair: Hussein Abd Elmotaal (Egypt)
Vice-Chair: none

Terms of Reference and Objectives

Sub-Commission 2.4 is concerned with the following areas of investigation:

- Regional gravity and geoid sub-commissions: data sets, involved institutions, comparison of methods and results, data exchange, comparison with global models, connection of regional models.
- Gravimetric geoid modelling techniques and methods, available software, new alternative geoid determination techniques.
- GNSS/levelling geoid determination: methods, comparisons, treating and interpretation of residuals, common treatment of gravity and GNSS/levelling for geoid determination.
- Geoid applications: GNSS heights, sea surface topography, integration of geoid models in GNSS receivers, vertical datums.
- Other topics: topographic effects, downward and upward continuation of terrestrial, airborne, satellite data specifically as applied to geoid modelling.

Program of Activities

Sub-Commission 2.4 is going to initiate and coordinate regional gravity and geoid sub-commissions. It will encourage and support the data exchange between agencies and will assist local, regional and national authorities in their projects of gravity field determination. It will help in organizing courses and symposia for gravity field determination.

SC 2.4a: Gravity and Geoid in Europe

Chair: TBD
Vice-Chair: TBD

Terms of Reference

The primary objective of the Sub-Commission is the development of improved regional geoid and quasigeoid models for Europe, which can be used for applications in geodesy, oceanography, geophysics and engineering, e.g., height determination with GNSS techniques, vertical datum definition and unification, dynamic ocean topography estimation, geophysical modelling, and navigation. Another emerging field is related to the development of new optical clocks in physics with relative uncertainties at the level of 10^{-18}, as in accordance with the laws of general relativity, such clocks are sensitive to the gravity potential at the level of 0.1 m^2/s^2, equivalent to 1 cm in height.

The geoid and quasigeoid modelling will be based mainly on terrestrial gravity and terrain data in combination with state-of-the-art global geopotential models. In this

context, upgraded terrestrial data sets as well as the utilization of GRACE and GOCE based global geopotential models led to significant improvements. The evaluation of the latest European gravimetric quasigeoid models by GNSS and levelling data indicates an accuracy potential of 1 – 2 cm on a national basis, and 2 – 4 cm at continental scales, provided that high quality and resolution input data are available within the area of interest. Further improvements can be expected from the inclusion of upgraded gravity field data sets, especially in areas with hitherto insufficient input data.

Program of Activities

- Utilization of state-of-the-art global geopotential models.
- Identification and acquisition of new terrestrial data sets, including gravity, terrain, and GPS/levelling data.
- Merging and validation of all data sets.
- Investigation of refined mathematical modelling techniques and numerical tests.
- Computation of new geoid and quasigeoid models.
- Evaluation of the results by GNSS/levelling data.
- Study of applications, such as vertical datum definition and unification, dynamic ocean topography estimation, ground truth for optical clocks, etc.

SC 2.4b: Gravity and Geoid in South America

Chair: Gabriel Guimarães (Brazil)
Vice-Chair: Ayelen Pereira (Argentina)

Terms of Reference

This Sub-Commission was established as an attempt to coordinate efforts to establish a new Absolute Gravity Network in South America, to carry out gravity densification surveys, to derive a geoid model for the continent as a height reference and to support local organizations in the computation of detailed geoid models in different countries.

Besides, a strong effort is being carried out in several countries in order to improve the distribution of gravity information, to organize the gravity measurements in the continent and to validate the available gravity measurements.

Objectives

The main objectives of the project are:

- To re-measure existent absolute gravity stations and to encourage the establishment of new stations.
- To validate fundamental gravity network from different countries in order to establish a single and common gravity network for South America.
- To adjust national gravity networks and to link them together.
- To obtain and to maintain files with data necessary for the geoid computation like gravity anomalies, digital terrain models, geopotential models and satellite observations (GPS) on the levelling network of different countries.

- To provide a link between the different countries and the IGFS in order to assure access to proper software and geopotential models for local geoid computation.
- To compute a global geoid model for South and Central America using the available data. To encourage countries to cooperate by releasing data for this purpose.
- To encourage and eventually support local organizations in different countries endeavoring to increase the gravity data coverage, to improve the existing digital terrain models, to carry out GPS observations on the levelling network and to compute a high resolution geoid.
- To organize and/or encourage the organization of workshops, symposia or seminars on gravity and geoid determination in South America.
- To test and to use future geopotential models derived from the modern missions (GRACE and GOCE) as well as any new combined model.
- To support the IAG Sub-Commission 1.3b (Reference Frame for South and Central America, SIRGAS) in the activities related to the unification of the existing vertical datums.
- Establish close connections with SC2.4c (Gravity and Geoid in North and Central America) to have a good overlap of data coverage in Central America and the Caribbean.

SC 2.4c: Gravity and Geoid in North and Central America

Chair: Jianliang Huang (Canada)
Vice-Chair: David Avalos (Mexico)

Terms of Reference and Objectives

The primary objective of this Sub-Commission is the development of a regional gravity field and geoid model covering the region of North America and Central America by 2025 in order to achieve a common vertical datum. The region involved will encompass Iceland, Greenland, Canada, the U.S.A. (including Alaska and Hawaii), Mexico, countries forming Central America, the Caribbean Sea and the northern parts of South America. This model will serve as the official realization of the vertical datum for countries that want to adopt it.

The intention is to ensure that a suitable North American Geoid is developed to serve as a common datum for everyone in the region. All countries in the region would be served by having access to a common model for translating oceanographic effects to terrestrial datums for various scientific, commercial, engineering and disaster preparedness applications. Likewise, it shall serve as the basis for the forthcoming International Great Lakes Datum in 2025 (IGLD 2020).

The achievement of a geoid model for North and Central America will be accomplished by coordinating activities among agencies and universities with interest in geoid theory, gravity, gravity collection, gravity field change, geophysical modelling, digital elevation models (DEM), digital density models (DDM), altimetry, dynamic ocean topography, levelling and vertical datums. Of particular interest will be relating geoid and ocean topography models to ocean topography and tidal benchmarks, taking advantage of the recent satellite altimetry and geopotential field products.

The determination of a geoid model for North and Central America is not limited to a single agency, which will collect all necessary data from all countries. The Sub-Commission encourages theoretical diversity in the determination of a geoid model among the agencies. Each agency takes responsibility or works in collaboration with neighboring countries in the development of a geoid model for their respective country with an overlap (as large as possible) over adjacent countries. Each solution will be compared, the discrepancies will be analyzed, and the conclusions will be used to improve on the next model.

Program of Activities

The SC 2.4c will support geoid activities in countries where geoid expertise is limited by encouraging more advanced members to contribute their own expertise and software. The SC 2.4c will encourage training and education initiative of its delegates (e.g., ISG geoid school, graduate studies and technical cooperation projects). Starting in 2024 the SC 2.4c will organize regular meetings with representatives of Central American and Caribbean countries to promote an increase of expertise as well as to create a wide network of specialists. The chair (or a delegate representative) of the Sub-Commission will meet with the equivalent European and South American projects to discuss overlap regions and to work towards agreements to exchange data. The delegates of SC 2.4c will keep close contact with all related Study Groups of the IAG. The Sub-Commission is open to all geodetic agencies and universities across North and Central America with an interest in the development of a geoid model for the region. The meetings of the SC 2.4c are open to everyone with interests in geodesy, geophysics, oceanography and other related topics. The delegates will communicate primarily using e-mail. In addition, starting in 2023, Canada (CGS), USA (NGS) and Mexico (INEGI) have been organizing audio/video conferences every four weeks to discuss activity plans and present results. The Sub-Commission also plans to organize annual meetings if enough delegates can be present. Preferably, these meetings will be held during international conferences. Minutes of meetings will be prepared and sent to all delegates of the SC 2.4c.

Members

Jianliang Huang (Canada); Chair
David Avalos (Mexico); Vice-Chair
Rene Forsberg (Denmark)
Xiaopeng Li (USA)
Dan Roman (USA)
Laramie Potts (USA)
Yan Min Wang (USA)
John Crowley (Canada)
Ismael Foroughi (Canada)
Guido Gonzalez (Mexico)
Vinicio Robles (Guatemala)
Anthony Watts (Cayman Islands)
Alvaro Alvarez (Costa Rica)

Wilmer Medrano (Nicaragua)
Christopher Ballesteros (Panama)

SC 2.4d: Gravity and Geoid in Africa

Chair: Hussein Abd Elmotaal (Egypt)
Vice-Chair: Benahmed Daho (Algeria)

Terms of Reference

The main goal of the African Gravity and Geoid Sub-Commission is to determine the most complete and precise geoid model for Africa that can be obtained from the available data sets. Secondary goals are to foster cooperation between African geodesists and to provide high-level training in geoid computation to African geodesists.

Objectives, Program of Activities

The objectives and activities of the Sub-Commission are summarized as follows:

- Identifying and acquiring data sets - gravity anomalies, DTMs, GPS/levelling, seismic Moho.
- Training of African geodesists in geoid computation.
- Merging and validating gravity data sets.
- Computing African geoid models.
- Evaluating the computed geoid models using GPS/levelling data.
- Updating the geoid models using new data/strategies to obtain better geoid accuracy (dynamic process).

SC 2.4e: Gravity and Geoid in Asia-Pacific

Chair: Cheinway Hwang (China-Taipei)
Vice-Chair: Wenbin Shen (China)

Context

The Asia-Pacific region, encompassing approximately 40-50 countries, has seen significant investments in the development of improved geoid models. Recent advancements in gravimetric technologies and satellite altimetry have substantially increased the accuracies and densities of land and marine gravity measurements. The use of satellite remote sensing and LiDAR data for the creation of digital elevation models (DEMs) has been integral to geoid modeling. The increasing frequency of GNSS/leveling observation campaigns across the region is instrumental in collecting data essential for the assessment and quality controls of geoid models. These collective efforts are pivotal in refining geoid models throughout the Asia Pacific.

Terms of Reference and Objectives

As a continuation of its predecessor, this Sub-Commission is dedicated to advancing the science and practice of geoid modeling in the Asia Pacific region. This objective is achieved by fostering the collection of gravity data, enhancing geoid processing and evaluation techniques, and broadening the application of geoid knowledge within the Asia-Pacific. A special focus will be placed on densifying gravity measurements using the latest gravity measurement technologies. The SC 2.4e will facilitate workshops for the exchange of data, methodologies, and best practices in geoid modeling and assessment.

Program of Activities

- Gravity and Related Data
  - Facilitate the sharing of available gravity data and DEMs, especially along common borders.
  - Collaborate on terrestrial gravity surveys in border regions.
  - Advocate for regional airborne/shipborne gravity surveys.
  - Develop methodologies to derive improved coastal gravity anomalies from satellite altimeter measurements, including those from the scanning altimeter SWOT.
- Gravimetric Geoid and Hybrid Geoid Quality Control
  - Share GNSS/leveling and vertical deflection data for enhanced geoid quality control.
  - Encourage and coordinate regional GNSS/leveling and vertical deflection campaigns.
  - Work towards the unification of regional vertical datums using geoid models.
- Education & Research
  - Organize conferences, meetings, and workshops to advance the modeling and evaluation of geoid models, and promote their applications in height modernization and vertical datum unification.
  - Propose technical sessions at scientific and professional conferences.
  - Identify and address matters of mutual concern and interest within the field.

Members

Cheinway Hwang (China-Taipei); Chair
Wenbin Shen (China); Vice-chair
Sten Claessens (Australia)
Robert Tenzer (China-Hong Kong)
Rupesh Goyal (India)
Brian Bramanto (Indonesia)
Arisauna Maulidyan Pahlevi (Indonesia)
Koji Matsuo (Japan)
Jay Hyoun Kwon (Korea)
Ami Hassan Md Din (Malaysia)
Muhammad Faiz Bin Pa'suya (Malaysia)

D. Munkhtsetseg (Mongolia)
B. Javzandulam (Mongolia)
Rachelle Winefield (New Zealand)
Sushmita Timilsina (Nepal)
Jak Sarmiento (Philippines)
Ronnie Gatchalian (Philippines)
Puttipol Dumrongchai (Thailand)

SC 2.5: Satellite Altimetry

Chair: Xiaoli Deng (Australia)
Vice-Chair: C.K. Shum (USA)

Terms of Reference

Satellite altimetry missions (e.g., Geosat, TOPEX/Poseidon, ERS-1/2, Envisat and Jason-1/2/3) have been providing vital measurements of global ocean surface topography since 1991. The latest altimetry missions (e.g., HY2a/2b, Ka-band altimetry SARAL/Altika, SAR and SARIn altimetry Cry-oSat-2 and Sentinel-3A/B, and laser altimetry ICEsat-2) are providing higher resolution observations. The upcoming Jason-CS/Sentinel-6 mission includes two identical satellites scheduled to launch in 2020 (satellite A) and 2025 (satellite B), which will continue measuring the sea level for at least a decade. The future Surface Water and Ocean Topography (SWOT) satellite mission equipped with radar interferometry, due to launch in 2021, will substantially improve measurements of sea surface heights and surface water hydrology at finer scales; this has not been possible before. In addition, the in situ GNSS reflectometry (GNSS-R) and the NASA CYGNSS 8-satellite constellation have been providing water/sea level, land cover, water/snow extents, wave and wind measurements.

Altimetry observations cover the global oceans, cryosphere, sea-ice, ice-covered oceans and inland water bodies, providing invaluable geodetic and climatic information for studying the Earth and ocean dynamics (e.g., sea level, ocean wave and wind speed, ocean surface topography, tides, soil moisture, snow depth, ice sheet, ice caps, mountain glacier, inland water and solid Earth deformation), and geophysical features (e.g., marine gravity field, mean sea surface and bathymetry).

The growing altimetry datasets are driving technological leaps forward for satellite geodesy and oceanography. At the same time, they will bridge an observational gap on a spatial-temporal domain critical for solving interdisciplinary problems of considerable societal benefit. The purpose of SC 2.5 is to promote innovative research using historic and future altimeter observations to study local, regional, and global geophysical processes, with emphasis on emerging cross-disciplinary applications using satellite altimetry, and in combination with other in situ data sets and techniques including hydrography data, GNSS-R, CYGNSS, SAR/InSAR and GRACE/GOCE.

Objectives

The Sub-Commission 2.5 will:

- Establish a close link with the International Altimeter Service (IAS) and data product providers, in order to (1) establish scientific forums to discuss new results, (2) bring new algorithms from expert research into data production, and (3) encourage development of data products that more directly facilitate cross-disciplinary applications using satellite altimetry.
- Promote innovative applications of satellite altimetry, including evaluations and cross-disciplinary applications of future satellite altimetry.

- Continue developing techniques to improve altimeter data quality, aiming towards the development of new data products across the coastal zones including the coastal ocean, estuaries and inland water bodies.
- Focus on capabilities of the very high spatial resolution from SAR and SARAL altimeters, as well as upcoming SWOT, for precisely modelling the marine gravity field, mean sea surface, bathymetry and ocean mean dynamic topography, as well as temporal variations induced by solid Earth processes and the global terrestrial water cycle.
- Promote cross-disciplinary research on the shapes and temporal variations of land/ice/ocean surfaces, such as studies of long-term ocean variability, regional and global sea level changes, mountain glaciers/ice-sheet ablations/accumulations, permafrost degradation, coastal and ice-shelf ocean tides, vertical displacements at major tectonic-active zone, land subsidence and other geophysical processes.

Steering Committee

Xiaoli Deng (Australia); Chair
C.K. Shum (USA); Vice-Chair
Ole Andersen (Denmark)
Lifeng Bao (China)
Jérôme Benveniste (Italy)
Denise Dettmering (Germany)
Fukai Peng (China)
Luciana Fenoglio-Marc (Germany)
Cheinway Hwang (China-Taipei)
Hyongki Lee (USA)
Eric Leuliette (USA)
Taoyong Jin (China)
Chungyen Kuo (China-Taipei)
Jürgen Kusche (Germany)
Karina Nielsen (Denmark)
David Sandwell (USA)
Walter Smith (USA)
Stefano Vignudelli (Italy)

Program of Activities

This Sub-Commission will:

- Organize independent workshops or special sessions in major meetings to promote altimetric applications in interdisciplinary earth sciences, and to increase the visibility of IAG in altimetric science.
- Provide independent forums for potentially improved altimetry data processing and data product access, to encourage innovative and interdisciplinary scientific research and applications of satellite altimetry.
- Prepare and organize the IAS, currently established as a "Pilot Service", so that it fulfills the requirements to become a regular IAG Service in the future. This main initiative and activity is described in detail below.

International Altimetry Service (IAS) - Pilot Service

Chair: Xiaoli Deng (Australia)
Vice-Chairs: C.K. Shum (USA), Jérôme Benveniste (Italy), Stefano Vignudelli (Italy)

Executive summary of the opportunity
The IAS Pilot Service, began on 22 July 2023. It was established in preparation for the IAS as a Service of the IAG in the future.

The IAS is to fill the knowledge "gaps" between space agencies and scientific/other users of satellite altimetry data and data products, with the goal of conducting non-duplicated efforts to advance validated alternate altimetry data processing algorithms/analytics towards new data products.

Satellite altimetry has evolved into a unique and operational geodetic remote sensing measurement system with multi-missions and multi-satellite constellations generating an unprecedented climate data record since 1993, for three decades and in the decades to come. Satellite altimetry has fostered seminal research in interdisciplinary Earth sciences, including general ocean circulation, sea-level science, sea-state, global gravity field models (EGMs), bathymetry and marine geophysics, ocean tides, ice reservoir mass change, polar, coastal and oceanography, hydrology and water cycles, low altitude total electronic contents, land and ice digital surface models, near-surface soil moisture, and land surface deformation. Satellite altimetry is deemed to be operational and sustained, contributing to many societal needs, including climate monitoring, meteorological and ocean circulation forecasting, vertical datum realization, maritime safety, ocean pollution tracking services, flood and water resources management, energy and many others.

The significant opportunities below potentially could afford, more than ever, a need for the establishment of the IAS under the IAG. These opportunities include, but are not limited to, the following:

- Satellite pulse-limited and SAR radar altimetry has been declared mature and operational, with priorities of generating near-real data products for assimilative coastal ocean and wind/wave forecasting, lake meteorological forecasting, and to potentially support disaster response and management.
- High quality satellite radar/laser altimetry missions have been generating global climate and geophysical data. The currently flying (12 satellites) and planned (6 satellites) altimetry missions are abundant in the decades to come. The extension of the multi-altimetry climate record and its application require collaborations between multiple space agencies, NGOs, and potentially industries, for calibration and validation of multiple onboard instrumentations, and the associated orbital, media, and geophysical corrections, to assess potential inter-mission instrument biases, their drifts, and overall consistency of the interdisciplinary data products, including multi-decadal surface elevation evolutions of ice-sheets, mountain glaciers/ice caps, ice-shelves, sea-/lake-ice, lake/dam water and river levels, and solid Earth deformations.
- Multi-mission and multi-decadal altimetry data records in repeat and geodetic orbital phases contribute significantly to the success of global high-resolution estimates of Earth Gravity Models (EGMs), mean sea surface (MSS), and dynamic

ocean topography (DOT) models. The new suite of altimetry mission data will continue to improve the next EGM and seafloor bathymetry modelling, and foster innovative geophysical studies.

- Altimetry measurement technology has evolved from pulse-limited Ku-/C-/S-Band altimeters to the Ka-Band at the higher sampling rate (1–40 Hz), to the along-track higher resolution SAR and Interferometric altimetry (SARIn) with tunable sampling rates up to 160 Hz and higher with the Fully-Focused SAR (FFSAR) processing onboard Sentinel-3/-6, to the multi-beam photon-counting laser altimetry (ATLAS) onboard ICESat-2, to the wide-swath Ka-band radar interferometry (KaRIn) onboard SWOT, and to the planned IRIS (Interferometric radar altimeter for Ice and Snow) Ku/Ka band altimeter onboard CRISTAL, as well as the current and future bistatic radar Signal of Opportunity (SoOP, L-, P-band) altimetry/radiometry/scatterometry missions (e.g., CyGNSS, Spire, Triton, HydroGNSS, PRETTY; P-band: SNoOPI). The L-band GNSS-R bistatic forward scattering radar signals have been advancing studies of cyclone science and land processes. It is anticipated that the advances in instrument technology will produce finer-scale data products with high accuracy to address interdisciplinary scientific questions and new applications.

Some or majority of the above rationale were articulated to promote the establishment of the IAS over a decade ago. The IAS Planning Group initiated this proposal in 2019 IUGG, Montreal. Based on lessons learnt, a renewed strategy, new innovative technologies, and availability of increased numbers of contemporary satellite altimetry constellations, establishing the IAS Pilot Service as an IAG-ordained Service is thus timely essential.

Background, past actions:

- July 9, 2019: The proposal of re-establishing the IAS was initiated at the IAG Executive Committee meeting in IUGG, Montreal.
- Apr 27, 2022: The ToR of SC2.5.4 - The IAS Planning Group was discussed at the IAG Executive Committee meeting.
- Dec 27, 2022: The revised ToR of SC2.5.4 - The IAS Planning Group was approved at the IAG Executive Committee meeting.
- Apr 27, 2023: The revised ToR of the IAS proposal was discussed at the IAG Executive Committee meeting.
- July 20, 2023: The IAS Pilot Service was approved at the IAG Executive Committee meeting in IUGG, Berlin.
- December 10, 2023: IAS Pilot Service status presented at the IAG Executive Committee meeting.

Vision and Purpose

Objectives: The IAS Pilot Service is to bring collaborations together to anticipate and solve geodetic and climate research problems using our satellite altimetry expertise. The broad objective is to provide a service with information about altimetry data, geodetic and climate models, research and operational applications based on satellite altimetry technology innovations. Mechanism of operations will be under IAG structure, with an elected International Governing Board and coordinated peer-reviewed projects.

The IAS Pilot Service is to provide a platform for open access to information on satellite altimetry and data distributions for scientific, educational and operational applications. It shall serve users with little experience in satellite altimetry and scientific users with evaluating data, generating new products, models and algorithms. The IAS Pilot Service will:

- establish deliberate bylaws, policy, and rules, and via Call for Participations (CoP) towards establishing IAG Service-Style Coordinating Board, Analysis and Data Centres, and others.
- convene and establish formal dialogs with scientists and key technical curators of existing altimetry data product services to assess the rationales on establishing the IAS Pilot Service that would be mutually beneficial, to IAG IAS, and to their sponsoring agencies.
- provide a collection of links to altimetry data products, auxiliary information, basic knowledge, models, software tools and physical collections for the benefit of all geodetic/public users.
- provide platform for discussion organized in themes with moderators.
- provide products that are generated using altimetry data archived in the international space agencies, such as AVISO, EUMESAT, JPL, RADS, etc., by IAS analysis and associate centers and members.
- provide users with product descriptions and advice on altimetry data archived in the international space agencies based on IAS members' altimetry expertise.
- provide web services for geodetic and public use that allows access to IAS products, models, results, altimetry-based knowledge and tools.
- provide training courses for scientific users during IAG and IUGG general assemblies.
- organise regular symposia addressing activities carried out at global and regional scales related to the work and objectives of IAS.
- ensure future generations are informed in science, technology and applications of altimetry.

Key projects: The IAS Pilot Service (and future IAS) will provide a service to address the key research question: "how new and existing altimetry observations can be used to ensure high-impact solutions of benefit to the geodetic community". The key here is to provide one place for all information about altimetry data and generated results/models. It will also provide a platform to post questions and answers, which open to a community of registered members and open to everyone but monitored by a moderator.

Critical to IAS Pilot Service activities are six clusters (or working groups) based on existing and new study/working groups. Here each cluster is not an isolated mutually exclusive silo, but complements the activities of other clusters (Fig. 1). Clusters can be included in or parallel to IAS Data and Analysis Centres. Each Cluster includes duties such as collecting data and ancillary from space agencies, performing data analysis and validation, providing online availability, and transmittal to and equalization with other Clusters. The set of Clusters provides for open access to IAS data and products by IAS participants and all external users. Clusters are approved by the IAS Pilot Service GB following demonstration of qualifications and commitment.

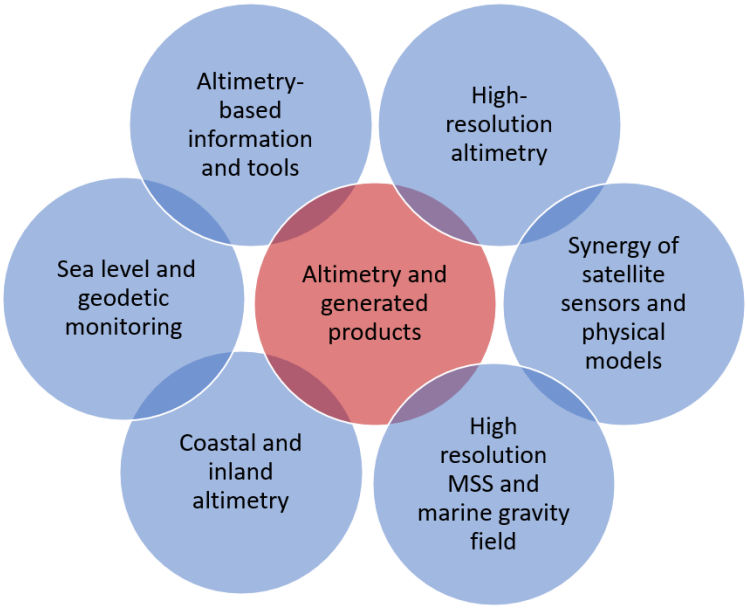

Fig. 1. Key clusters of the IAS.

Clusters will provide altimetry data and generated results that have been and will be studied by:

1. Sea level and geodetic monitoring
   It provides data and results that support studies using altimetry, in situ/SNR and spaceborne GNSS-R altimetry/radiometry for monitoring long-term ocean variability, regional and global sea level changes, inland water bodies, vertical displacements at major tectonic-active zone, land subsidence and other geophysical processes.
2. Altimetry-based information and tools
   Chair: Jürgen Kusche (Germany)
   It provides altimetry-based knowledge, data, tools and resources for supporting

activities for inter-comparisons of processing algorithms and evaluations of data products, as well as new applications of future and other satellite sensors (e.g., wind/wave fields or ocean/atmosphere coupling application). It will enhance collaborations among scientific users from different IAG commissions, directly facilitating innovative applications and cross-disciplinary applications of satellite altimetry.

3. Coastal and inland altimetry
   Chair: Fukai Peng (China);Vice-Chair: Stefano Vignudelli (Italy)
   It provides auxiliary data and algorithms to produce new products across the coastal zone including coastal ocean, land-sea surface, estuaries and inland water bodies for applications in studies of the extremes, long-term climate change and environmental development.
4. High-resolution altimetry
   Chair: Luciana Fenoglio-Marc (Germany); Vice-Chair: Ole Baltazar Andersen (Denmark)
   This group focuses on high resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies. It investigates the development allowed by high-resolution altimetry in 1-D and SWOT 2-D fields. It will enhance processing of high-resolution altimetry along-track in SAR mode and comparison of available techniques, and studies in open and coastal oceans, polar oceans and inland waters.
5. Synergy of satellite sensors and physical models
   Chair: Hyongki Lee (USA); Vice-Chair: Chungyen Kuo (China-Taipei)
   This group promotes innovative usage of altimetry data synergistically integrated with data obtained from other satellite sensors (e.g., GNSS-R) and physical models in order to advance scientific studies and real-world applications. It studies geophysical processes from merging multi-mission radar altimetry and laser altimetry (ICESat, ICESat-2), other geodetic data and SWOT interferometric altimetry.
6. High resolution MSS and marine gravity field
   Chair: David Sandwell (USA); Vice-Chairs: Ole Andersen (Denmark) and Philippe Schaeffer (France)
   This cluster provides a long-term reference sea surface for the physical oceanographic and geodetic communities as well as for CAL/VAL of new altimeter missions, and distributes the consensus mean sea surface (MSS) model(s) to the physical oceanography, geodetic, offshore industry, and altimetry communities. It focuses on the development of a MSS for the SWOT mission to provide calibration and validation early in its mission, and on the refinement of the global high-resolution marine gravity field and seafloor bathymetric models.

Products: The IAS Pilot Service collects, archives and distributes altimetry observational datasets of high quality to satisfy the objectives of a wide range of scientific and other high-end applications and experimentation. These data sets are used by the IAS to generate the following products:

- High level data products of long-term ocean variability, sea level and inland water level variations, and land subsidence
- High accuracy sea surface heights in coastal zones
- MSS, marine gravity field and bathymetry models

- High-resolution and high-resolution data products
- Tools and algorithms of new applications of future and other satellite sensors.

Examples of existing products produced by IAS Pilot Service members include:

- ESA Global/Coastal Sea Level/Lakes CCI (https://climate.esa.int/en/projects/sea-level/about/)
- ESA Coastal Altimetry (https://www.coastalaltimetry.org)
- NASA/NOAA PODDAC (https://podaac.jpl.nasa.gov/) Sea Level Portal (https://sealevel.nasa.gov)
- NOAA Real-time Altimetry (https://www.star.nesdis.noaa.gov/socd/lsa/NearRealTime/)
- Aviso/Aviso+ (https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/gridded-sea-level-anomalies-mean-and-climatology.html#c7273)
- University of Houston Jason/Sentinel-3/6 Altimetry Stand-Alone Tool for Earth Research (JASTER_Amirhossein_Feb2024_Final,Sentinel3_Altimetry_Tool_Sep_2023_V2,andSentinel6_Altimetry_Tool_Oct_2023_V2)
- TUM-DGFI Open Altimeter Database (OpenADB, https://openadb.dgfi.tum.de/en/)
- TUM-DGFI Database for hydrological time series of inland waters (DAHITI, https://dahiti.dgfi.tum.de/en/)
- Scripps global marine gravity field from satellite altimetry (https://topex.ucsd.edu/marine_grav/mar_grav.html)
- Scripps global seafloor topography from satellite altimetry (https://topex.ucsd.edu/WWW_html/mar_topo.html)
- DTU Space mean sea surface, ocean tide and marine gravity models (https://data.dtu.dk)
- Improved coastal altimeter data, retrackers and algorithms by altimetry groups at University of Bonn (Germany), University of Newcastle (Australia), DGFI TUM (Germany), and Tongji University (China), and others.

Engaging with other space agencies as partners: Engagement is already a strong focus of IAS members. IAS will provide a focus that differentiates this service from the "data service" made available by the space agency or each single institute. The goal is to foster and ease the access to each existing platform in a structured way. The expected outcome is to optimise the information-based service already existing and to fill eventual gaps and fix discrepancies. For this interaction with agencies, institutes and other providers is fundamental. A regular seminar series and workshops targeted at key services will be implemented to increase cooperation between the partners.

IAS has members from a diverse background in geodesy, geophysics, oceanography, remote sensing disciplines. IAS also has members who sit in altimetry science teams and mission advisory groups, as well as in scientific committees of altimetry communities (e.g., OSTST and coastal altimetry). Members from different IAG commissions and cross-associations provide an opportunity for multi-disciplinary collaborations.

Organization structure

The IAS Pilot Service is to be implemented as a multi-institutional effort. The Joint-Central Bureaus will be set up at The Ohio State University in USA and The University of Newcastle in Australia (for Asia and Pacific regions). The organization consists of the following components:

- *Associated members*, persons affiliated with contributing organizations that are the electorate body of the IAS Governing Board spend majority of their time on work contributes to the IAS.
- *Governing/Coordinating Board (GB)*, the international body which sets policy and direction for the IAS. Positions are either elected or appointed. The GB is also responsible for the management of IAS restructuring and service activities.
- *Central Bureau (CB)*, functions as the "day-to-day" IAS coordinating body and ensures that IAS Service is made available to the global geodetic community. The CB is responsible for compliance to IAS standards, monitors service operations and quality assurance of products, maintains documentation, organizes meetings and workshops, and coordinates and publishes reports.
- *Data and Analysis Centres*, analyse the altimetry data to form submissions to IAS products such as sea surface heights, lake/river water surface heights, mean sea surface etc., and provide open access to IAS data and products, and interact with data products provided by space agencies. The centres are committed to submit products for combination into IAS products using designated standards and conventions to meet IAS requirements.
- *Clusters*, act as working groups via pilot projects with particular focus on components, products, and infrastructural elements within Clusters. Members take responsibility for providing contributions to Cluster's products and make their expertise available to the Cluster. The GB has power to establish and terminate the Cluster, as well as appoints the chairs of Clusters.
- *Executive Committee*, comprises of the IAS Chairs and cluster leaders/Chairs, oversees the overall performance and direction of the IAS, ensures the efficient and sustainable pursuit of IAS' objectives.
- *Advisory Board*, comprises external members from space agencies and universities which provides advice on data product strategy.

Group Members

At present, the activities for the IAS Pilot Service are carried out by the team of the SG 2.5.4 IAS Planning Group, chaired by Xiaoli Deng (Australia). It consists of 32 confirmed members from 11 countries. The IAS Pilot Service is welcoming new members, expecially Early Career Scientists. The members should have aspirations and scientific interest to actively undertake various IAS activities. They may be members of altimetry mission science teams, mission advisory groups, organised interdisciplinary altimetry communities, and stakeholders of new concepts of satellite altimetry and their applications.

SG 2.5.1: High-resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies (HRA)

Chair: Luciana Fenoglio-Marc (Germany)
Vice-Chair: Ole Andersen (Denmark)

Terms of Reference

The mapping of the surface water elevation (SWE) at high resolution in space and time has been a goal of geodetic, oceanic and hydrologic scientific communities. Satellite altimetry global observations of high spatial and temporal resolution are required to understand the climate-related oceanic and hydrologic dynamics, which involve small-scale processes and their interaction with larger-scale dynamics. In the ocean, small-scale processes are related to meso- and sub-mesoscale ocean eddies, to internal tides and internal waves, to the cross-shelf interaction between coastal regions, open ocean dynamics and ecosystem. The dynamical processes in coastal oceans and estuaries are responsible for the along-shore distribution of nutrients and pollutions. On land, the small-scale processes relate to river dynamics and river discharge of water and nutrients from land into oceans, to extreme hydrological events and to climate change in inland waters. In the cryosphere, small-scale processes relate to dynamics of land ice and sea ice change. High-resolution altimetry (HRA) also provides improvement of bathymetry and geoid at small scales.

New technologies, like Ka-band in pulse-limited altimetry and Delay Doppler (DD), with one or two antennas in Synthetic Aperture Radar (SAR) and SAR-interferometric (SARin) modes, with unfocused and fully focused (FF-) SAR processing for CroySat-2, Sentinel-3 and Sentinel-6 missions, provide today the highest accuracy and along-track resolution. Moreover, the Surface Water and Ocean Topography Mission (SWOT) is offering a unique contribution by providing observational evidence of currently unobserved wavelengths between 100 km and 15 km.

In light of the above rationale, HRA is proposed to investigate the development allowed by high-resolution altimetry in 1-D and 2-D fields. Mechanism of operations will be under IAG structure, with an elected International Governing Board and coordinated peer-reviewed projects.

Objectives

HRA is a scientific and independent entity organized by the international scientific community. HRA will host and support peer-reviewed community proposed "projects" intending to:

- Provide a forum for scientific exchange on enhanced usage of past and future altimetry data to improve the understanding of small-scale signals.
- Support discussions on innovative interdisciplinary scientific research and applications.
- Provide training courses for scientific users during IAG and IUGG general assemblies.

An initial list of possible "projects", may include, but is not limited to the following:

- Enhanced processing of high-resolution altimetry along-track in SAR mode and comparison of available techniques (e.g., FF-SAR, LRMC, Unfocused SAR and Reduced SAR).
- Understanding of the SWOT signal outputs and realistic errors, and conducting calibration/validation of the observations.
- High resolution altimetry in open seas to study eddy dynamics and related vertical processed with exchanges of heat and carbon between the ocean and the atmosphere. The assimilation in high-resolution ocean models is recommended.
- High resolution altimetry in coastal zones and estuaries to study dynamics of exchanges in the river estuary and open ocean continuum. The assimilation in high-resolution hydrodynamic models is recommended.
- High resolution altimetry in rivers to study river dynamics and river discharge. The assimilation in hydrodynamic model is recommended.
- High resolution altimetry in lakes and wetland to study water mass change on land.
- High resolution altimetry on polar regions to study ice mass change and sea ice variation, ocean-cryosphere and solid Earth-cryosphere interactions.
- High resolution altimetry for determination of bathymetry and geoid.
- Innovative merging of products for interdisciplinary science and applications.
- Support activities for inter-comparisons of processing algorithms and evaluations of data products.

Members

Luciana Fenoglio-Marc (Germany); Chair
Ole Andersen (Denmark); Vice-Chair
Lifeng Bao (China)
Xiaoli Deng (Australia)
Denise Dettmering (Germany)
Taoyong Jin (China)
Cheinway Hwang (China-Taipei)
Armin Agha Karimi (Australia)
Chungyen Kuo (China-Taipei)
Jürgen Kusche (Germany)
Hyongki Lee (USA)
Eric Leuliette (USA)
Karina Nielsen (Denmark)
Fukai Peng (China)
David Sandwell (USA)
Walter Smith (USA)
C.K. Shum (USA)
Xiaoli Su (USA)
Christopher Watson (Australia)

SG 2.5.2: Synergistic Applications of Satellite Altimetry with Other Satellite Sensors and Physical Models (SASA)

Chair: Hyongki Lee (USA)
Vice-Chair: Chungyen Kuo (China-Taipei)

Terms of Reference

With advances in waveform retracking and new technologies, such as altimeters operating in Synthetic Aperture Radar (SAR, or Delay-Doppler) and SAR-interferometric (SARin) modes, satellite radar altimetry is a mature geodetic technique successfully providing surface elevation changes over, not only oceans, but also inland water bodies, ice-sheets/glaciers and topographic lands. In particular, satellite altimetry has been used to augment existing monitoring network or to derive new estimates with data from other satellite sensors or a physical model, especially over terrestrial surfaces. By adopting daily water levels created by integrating altimetry data and a hydrological model, daily-inundated areas can be generated with a data decomposition technique such as empirical orthogonal function analysis for finding correlation between altimetry-derived water levels and satellite imagery-derived inundated areas. The fusion of satellite laser altimetry (e.g., ICESat-2), optical imageries and models can be used to derive shallow water bathymetry (depth <40 m) and to reconstruct topography of a tidal flats, producing a seamless ocean-land topography. Altimetry in synergy with GRACE and GRACE-FO has also played a major role in monitoring mass changes of the ice sheets and glaciers of the world.

Another class of sensors, which is potentially able to sense high temporal frequency signals, is the spaceborne Global Navigation Satellite System Reflectometry (GNSS-R). It measures the Earth surface from different constellations for sensors already in place (e.g., GNSS). The NASA CYGNSS and the UK TechDemoSat-1 satellites both carry the GNSS-R receiver. The application of GNSS-R for altimetry offers a unique opportunity to monitor the ice sheets, sea ice, land cover, soil moisture, polar and coastal oceans.

It is therefore important to promote innovative usage of altimetry data synergistically integrated with data obtained from other satellite sensors (e.g., optical/SAR imaging sensors, laser altimetry, GRACE/GRACE-FO and GNSS-R) and physical models in order to advance scientific studies and real world applications.

Objectives

To support synergistic applications of altimetry data with data from other satellite sensors and physical models, SASA intends to:

- Support collaborations among scientific users of altimetry and other satellite sensors – working groups from different sub-commissions.
- Merge altimetry-derived water levels with imaging sensor-derived river widths/inundated areas, in situ data, model outputs and GRACE/GRACE-FO data for river discharge estimation, reservoir monitoring and inundation mapping.

- Integrate altimetry data with hydrologic models to reduce uncertainties in model-derived streamflow;
- Use altimetry-derived water level based on flow correlation for evaluation of hydrological model for ungauged basins.
- Study geophysical processes, merging multi-mission radar altimetry and laser altimetry (ICESat, ICESat-2), other geodetic data and SWOT interferometric altimetry in the future.
- Combine altimetry with GRACE and GRACE-FO data to estimate ice-sheet/glacier firn density, and to isolate contributions from Glacial Isostatic Adjustment (GIA).
- Map land ice and mountain glacier elevations using multiple radar altimetry missions.
- Use in situ/SNR and spaceborne GNSS-R altimetry/radiometry for monitoring coastal sea levels, inland water bodies, soil moisture, snow elevation changes and land/water classifications.

Members

Hyongki Lee (USA); Chair
Chungyen Kuo (China-Taipei); Vice-Chair
Lifeng Bao (China)
Xiaoli Deng (Australia)
Denise Dettmering (Germany)
Taoyong Jin (China)
Cheinway Hwang (China-Taipei)
Armin Agha Karimi (Australia)
Jürgen Kusche (Germany)
Eric Leuliette (USA)
Karina Nielsen (Denmark)
Fukai Peng (China)
David Sandwell (USA)
Walter Smith (USA)
C.K. Shum (USA)
Xiaoli Su (USA)
Christopher Watson (Australia)

SG 2.5.3: High Resolution Mean Sea Surface (MSS)

Chair: David Sandwell (USA)
Vice-Chairs: Ole Andersen (Denmark), Philippe Schaeffer (France)

Terms of Reference

Satellite radar altimeter measurements of sea surface heights have been continuously collected since the early 1990's for two main purposes. The physical oceanography (PO) community has nearly 30 years of measurements along the 10-day repeat ground tracks of TOPEX/Poseidon, Jason-1/2/3, and Sentinel-6 missions. In addition, there has been a similar 30-years of data collected along the 35-day repeat ground tracks

of ERS-1/2, Envisat and SARAL, and 3–5 years of 27-day repeat ground tracks of Sentinel-3A/-3B interleave orbits. These two tracks have been used to monitor global and regional sea level rise and provide a highly accurate framework for time variations in the mean sea surface (MSS) (https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mss.html,https://www.space.dtu.dk/english/research/scientific_data_and_models/global_mean_sea_surface).

Higher spatially sampled altimetry data have been also collected along orbits having much longer repeat times greater than 180 days from Geosat, ERS-1, Cryosat-2, SARAL/Altika, and Jason-1/2 (extension of life). While these data have poor temporal resolution, the high spatial resolution provides new information on the marine gravity field (https://topex.ucsd.edu/grav_outreach/).

These two kinds of altimetric missions are fundamentally complementary. Exact Repeat Missions (ERM) allow to access to an accurate determination of the steady state of the ocean, and Geodetic Missions (GM) provide the knowledge of the shortest topographic structures to a few kilometer. In addition, new altimeter technologies such as the Surface Water and Ocean Topography (SWOT) mission collect data at both high spatial and high temporal resolution. Our study group is developing a MSS to provide a validation surface for these new measurements.

This group listed below has been collaborating for the past three years on the development of this MSS by comparing largely independent developments. There are a number of important challenges including: the definition of the averaging time for the MSS; the methods of combining the short wavelength information from the high spatial density measurements with the sparse framework provided by the PO missions; and extending the MSS into the Arctic where the spatial and temporal coverage is less than optimal due to sea ice cover.

Objectives

To provide a long-term reference sea surface for the physical oceanographic and geodetic communities as well as for CAL/VAL of new altimeter missions, the MSS study group intends to:

- Support discussions and collaborations in the international scientific community on the development of a high resolution MSS.
- Develop a consensus global MSS by combining the long-term framework from exact repeat altimeter missions including: TOPEX/Jason, Envisat/SARAL and Sentinel-3 with the high spatial resolution data provided by Geosat, Cryosat-2, SARAL and Jason-1/2/3 (extension of life).
- Hold regular meetings to compare and contrast MSS models developed at CLS, DTU and SIO.
- Distribute the consensus MSS model(s) to the physical oceanography, geodetic, offshore industry and altimetry communities.
- Focus, in particular, on the development of a MSS for the upcoming SWOT mission to provide calibration and validation early in its mission.

Members

David Sandwell (USA); Chair

Ole Andersen (Denmark); Vice-Chair
Philippe Schaeffer (France); Vice-Chair
Adili Abulaitijiang (Germany)
Xiaoli Deng (Australia)
Bruce Haines (USA)
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Jinbo Wang (USA)
Daocheng Yu (China)
Shengjun Zhang (China)
Mao Zhou (China)

SG 2.5.4: The International Altimeter Service (IAS) Planning Group

Chair: Xiaoli Deng (Australia)
Vice-Chairs: C K Shum (USA), Jérôme Benveniste (Italy), Stefano Vignudelli (Italy)

Terms of Reference

Satellite altimetry has demonstrated seminal research in interdisciplinary Earth sciences, including general ocean circulation, sea-level science, sea-state, global gravity field models (EGMs), bathymetry and marine geophysics, ocean tides, ice reservoir mass change, polar and coastal and oceanography, hydrology and water cycles, low altitude total electronic contents, land and ice digital surface models, near-surface soil moisture, and land surface deformation. The major geodetic and geophysical contribution of satellite altimetry has been and will be the refinement of the global high-resolution gravity field and seafloor bathymetric models.

At present and since late 1970's, multiple national and international space, defense, oceanic, atmospheric and meteorological agencies, Universities, industries, and other organizations have collectively launched satellite radar and laser altimetry missions. These constellations of altimeter missions enable the generation of multi-decadal, continuous, and uniform geophysical and climate data records at unprecedented spatiotemporal resolution and accuracy. Innovative instrumentation advanced from pulse-limited to Delay-Doppler or SAR, to wide-swath (SWOT mission), to multi-beam photo counting laser altimetry (ATLAS), and to the more recent exploitation of SoOP (Signals of Opportunity) satellite sources in bistatic radar enabled satellite altimetry, including L-band GNSS-Reflectometry enabled altimetry. Current pulse-limited and SAR altimetry missions are operational, with other contemporary scientific missions poised to be operational.

The currently flying and planned altimetry missions are abundant in the decades to come. To extend the multi-altimetry climate record, it necessitates collaborations

beyond a single space agency for calibration and validation of multiple altimetry instrument, and orbits, media and geophysical corrections, to assess potential inter-mission instrument biases, their drifts, and overall consistency of the interdisciplinary data products, including multi-decadal elevation evolutions of ice-sheets, mountain glaciers/ice caps, ice-shelves, and sea-/Lake-ice, Lake water and river levels, and solid Earth displacements.

The IAS Planning Group proposed the establishment of an IAS in 2019 IUGG, Montreal, and the IAS Pilot Service was accepted as an IAG-ordained service in July 2023. It would be overachieving the goal of this IAS planning group to recommend a strategical plan and to continue deliberating the feasibility of eventual establishment of the IAS under IAG.

Objectives

As a dedicated IAS planning group, it intends to:

- Convene annual workshops and conducts dialogs with scientists and key technical curators of existing altimeter data product services, to assess the rationales on establishing a potential IAS would be mutually beneficial to them and to their sponsoring agencies.
- Continue to confirm a list of key members at the end of the IAS Planning Group activity period, towards a potential next phase of IAS activities.
- Seek and disseminate ideas from the Planning Group, IAS Pilot Service and the community to identify potential new and useful altimetry data products, with the associated data retrieval and visualization tools.
- Pursue new potential altimetry mission data product processing and validation collaborations with, for example, Chinese satellite altimeter missions, such as HY2A historic data re-processing, and processing strategies for HY2B/2C/2D in the future; as well as potential GNSS-R altimetry data products from existing and future LEOs (CyGNSS, Triton, HydroGNSS, PRETTY, and possible commercial LEOs, including Spire constellation).
- Improve IAS objectives through experience of IAS Pilot Service, a renewed strategy, new innovative technologies, and availability of increased numbers of contemporary satellite altimetry constellations.
- Seek a consensus among the IAS Planning Group members on the feasibility assessment to establish the IAS during the next phase.

Members

The group has 32 confirmed international members from diverse disciplines in geodesy, geophysics, oceanography, hydrology, cryosphere, solid Earth and climate science. They may be members of altimetry mission science teams, mission advisory groups, organised interdisciplinary altimetry communities (e.g., IAG Commissions and Sub-Commissions, OSTST, coastal altimetry, CCI/MEaSUREs projects), and stakeholders of new concepts of satellite altimetry and their applications, including altimetry from signals of opportunities. Chair: Xiaoli Deng (Australia)
Vice-Chairs: C K Shum (USA), Jérôme Benveniste (Italy), Stefano Vignudelli (Italy)

Xiaoli Deng (Australia); Chair
C K Shum (USA); Vice-Chair
Jérôme Benveniste (Italy); Vice-Chair
Stefano Vignudelli (Italy); Vice-Chair
Mohammad Al-Khaldi (USA)
Ole Andersen (Denmark)
Lifeng Bao (China)
Jean François Crétaux (France)
Denise Dettmering (Germany)
Luciana Fenoglio-Marc (Germany)
James Garrison (USA)
Cheinway Hwang (China-Taipei)
Sinem Ince (Germany)
Yongjun Jia (China)
Yuanyuan Jia (USA)
Taoyong Jin (China)
Chungyen Kuo (China-Taipei)
Jürgen Kusche (Germany)
Hyongki Lee (USA)
Weiqiang Li (Spain)
Xiaopeng Li (USA)
Hossein Nahavandchi (Norway)
Marc Naeije (Netherlands)
Jason Otero Torres (USA)
Fukai Peng (China)
Marco Restano (Italy)
Richard Salman (USA)
David Sandwell (USA)
Christian Schwatke (Germany)
Yohanes Budi Sulistioadi (Indonesia)
Pieter Visser (Netherlands)
Xiaoyun Wan (China)

SC 2.6: Gravity Inversion and Mass Transport in the Earth System

Chair: Wei Feng (China)
Vice-Chair: Roelof Rietbroek (Netherlands)

Terms of Reference

Spatial and temporal variations of gravity are related to the dynamics of the Earth's interior, land surface, oceans, cryosphere, and atmosphere. The geoid maps equilibrium dynamic processes in the ocean and in the Earth's mantle and crust, and large-scale coherent changes in gravity result from mass transports in atmosphere, hydrosphere, cryosphere, and the ocean, and across these. The gravity field, derived from terrestrial and space gravimetry (SLR, CHAMP, GRACE, GOCE, GRACE-FO, NGGM, ...) with unprecedented accuracy and resolution, provides a unique opportunity to investigate gravity- solid earth coupling, the structure of the globe from the inner core to the crust, and mass transports such as those associated within the global water cycle. Gravimetry also contributes to a better understanding of the interactions in the Earth system, and to its response to climate change and the anthropogenic fingerprint.

Objectives

- To further the understanding of the physics and dynamics of the Earth's interior, land surface, cryosphere, oceans and atmosphere using gravity and other geodetic and geophysical measurement techniques.
- To promote the study of solid Earth mass (re-)distribution from gravity and gravity gradient tensor variations, e.g. crust thickness, isostatic Moho undulation, mass loadings, basin formation, thermal effects on density, deformations, as well as interactions with the Earth's interior.
- To advance the investigation of mass transports in the Earth system, and, in particular, to contribute to the understanding of the global water cycle, of the storage of water in cryosphere and hydrosphere, of the fluxes across these subsystems and the atmosphere, and of sea level.
- To contribute to the operationalization of mass transport monitoring, e.g. for water resource monitoring.
- To aid in reconciling multiple geodetic observations at various spatio-temporal scales for mass transport monitoring and interpretation.
- To stimulate new techniques and potential applications of gravimetry and mass transport monitoring, e.g. quantum gravimeter, optical clock, new satellite gravimetry concept.
- To communicate with gravity-related communities in oceanography, hydrology, cryosphere, solid Earth, geodesy, etc.

Program of Activities

The SC 2.6 will establish Working Groups (WG) on relevant topics. The Steering Committee will work closely with members and other IAG Commissions and Sub-

Commissions to obtain mutual goals. Also it will promote and jointly sponsor special sessions at IAG Symposia and other workshop/conferences.

SG 2.6.1: Geodetic observations and physical interpretations in the Tibetan Plateau

Chair: Wenbin Shen (China)
Vice-Chair: Cheinway Hwang (China-Taipei)

Terms of Reference

Mass transport and (re-)distribution of the Tibetan Plateau is a research hotspot in the field of geoscience, relevant to global climate, glaciers, lakes, permafrost and deep geodynamics. The mountain building processes and their dynamic mechanisms of the Tibetan Plateau are still unclear and remain a key topic of research in geosciences. As multiple-type of data continue rapidly to grow on the Tibetan Plateau, advanced techniques in signal processing are needed to effectively extract targeted signals. Cross-correlations between different data types are important keys to discover the connections between the data, and to understand the causes and the consequences of the phenomena of interest.

This working group will concentrate on but not limit to the studies of hydrological change, crustal deformation, regional gravity field and its variation, mass migration and Moho variation, geodynamic and cryospheric processes and climate change of the Tibetan Plateau, based on various observations from space-borne and terrestrial sensors, such as GNSS, GRACE, GRACE-FO, satellite altimetry, InSAR, and ground gravity. Relevant investigations and studies will significantly promote the understanding and revealing of the uplift processes and dynamic mechanisms of mass transport in the Tibetan Plateau.

Objectives

- Hydrological change over river basins, lake level variation, permafrost, vertical deformation, mountain glacier change, atmospheric circulation of the Tibetan Plateau, and their interpretations from altimeter, GNSS, GRACE, GRACE-FO, and gravimeters;
- Geopotential and orthometric height determinations and unification of world height datum systems;
- Long-term monitoring of surface processes from satellite altimeters such as ICESat, TOPEX, Jason-1, -2, and -3, ERS-1, -2, ENVISAT, SWOT and Sentinel series;
- Results of satellite and terrestrial-based gravimetric observations;
- Results of GNSS observations, GNSS meteorology, and ionosphere;
- Geophysical interpretations and consequences of gravity, GNSS, satellite altimetry, and seismic observations;
- SAR and LiDAR detections of surface deformation, especially over the Tibetan Plateau;
- Crust structure and density refinement especially in the Tibetan region using multi-datasets.

Members

Wenbin Shen (China); Chair
Cheinway Hwang (China-Taipei); Vice-Chair
Benjamin Fong Chao (China-Taipei)
Tonie van Dam (Luxembourg)
Xiaoli Deng (Australia)
Hao Ding (China)
Xiaoli Ding (China-Hong Kong, China)
Jeffrey T. Freymueller (USA)
Mi Jiang (China)
Yuanjin Pan (China)
Jim Ray (USA)
Xiaodong Song (USA)
CK Shum (USA)
Heping Sun (China)
Wenke Sun (China)
Robert Tenzer (China-Hong Kong, China)
Leonid Zotov (Russia)

JSG 3.1: Model representation and geodetic signature of solid-Earth rheology in surface loading problems

(joint with IAG Commissions 1 and 3)
Chair: Lambert Caron (USA)
Vice-Chair: Rebekka Steffen (Sweden)
Refer to the Chapter Commission 3 in this Handbook.

Commission 3 - Earth Rotation and Geodynamics

https://doi.org/10.82507/iag-gh2024_com3

President: Rebekka Steffen (Sweden)
Vice President: José M. Ferrándiz (Spain)

Commission 3 website - www.com3.iag-aig.org

1 Terms of Reference

The Earth is a dynamic planet that can be explored through the analysis of geodetic data. Both space-based and terrestrial geodetic techniques, owing to their high accuracy, precision, and reliable georeferencing capabilities, offer invaluable observations for investigating a wide array of geophysical (geodynamic) processes. Spatial variations in the Earth's global static and temporal gravity field as well as global and local deformation (displacement) of the Earth's surface are used to learn more about the Earth's internal structure and dynamics. Phenomena associated with the Earth's rotation and orientation in space, such as polar motion, Universal Time (UT), Length of Day (LOD), precession/nutation, and (oceanic) pole tides, reveal insights into the dynamic behaviour of our planet. Precise measurements of these phenomena are pivotal for establishing the transformation between terrestrial and celestial reference frames. Commission 3 studies the entire range of physical processes associated with the movement and deformation of the Earth in response to both external and internal forces.

Modern geodesy effectively facilitates research and data analysis concerning variations in Earth's rotation, gravitational field, and geocenter motion, stemming from mass redistribution and exchange among the Earth's fluid sub-systems, including the atmosphere, oceans, continental hydrosphere, cryosphere, mantle, and core. This encompasses also geophysical phenomena related to tidal processes such as solid Earth and ocean loading tides as well as crustal and mantle deformation associated with tectonic motions, earthquakes, volcanic eruptions, hydrological events, isostatic adjustment, etc. Relevant quantities, such as angular momenta, associated torques, gravitational field coefficients and geocenter shifts, are observed using global-scale measurements and are compared to theoretical studies along with the application of advanced models, some of which have already been constrained using geodetic measurements.

Geodynamic modelling tools serve as foundation for comprehending geodetic observations and advancing our understanding of the dynamic Earth. Insights gained from these modelling studies can, in turn, assist in correcting geodetic time series, which are essential for tasks such as estimating reference frames, distinguishing between various changes in polar motion, and detecting other mass changes.

Geodesy plays a crucial role in monitoring and analyzing natural hazards. Through geodetic observations, researchers can study the geometry and temporal changes of volcanic systems, while playing a crucial role in monitoring and assessing hazards

during volcanic unrest and eruptions. Moreover, geodetic data contribute significantly to the study of various phases of the seismic cycle, enabling the recording of static and dynamic displacements during large earthquakes, as well as the slow postseismic and interseismic deformation. Thus, the monitoring of seismic hazards and associated risks is greatly enhanced by geodetic observations. Additionally, geodetic observations serve as an essential tool for studying mass changes between and within the cryosphere and the hydrosphere. Mass changes of ice sheets contribute significantly to sea-level change, which can be mapped through the integration of geodetic observations with geodynamic models. The purpose of Commission 3 is to promote, disseminate, and where necessary, facilitate the coordination of research within this wide area.

Sub-Commission 3.1 (Earth Tides and Geodynamics) addresses both direct and indirect tidal phenomena, as well as non-tidal loading, that influence the positioning of fiducial sites. Correcting for these effects is essential to ensure accurate spatial referencing, which is critical for observing and accurately monitoring changes of the Earth's surface at global, regional and local scales. Consequently, tidal and surficial loading research significantly contributes to global geodynamics and climate change studies by providing key constraints to geophysical models.

Sub-Commission 3.2 (Volcano Geodesy) addresses the growing volume and quality of volcano-geodetic data, which has created a need for new approaches to data analysis, interpretation, and modelling. These approaches are crucial for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano-monitoring results.

Sub-Commission 3.3 (Earth Rotation and Geophysical Fluids) addresses the space-time variation of atmospheric pressure and winds, seafloor pressure, ocean currents, and flows in the Earth's liquid core. It also considers the surface loads associated with the hydrological cycle, and Earth's (mainly elastic) responses to these mass redistributions and particle flows.

Sub-Commission 3.4 (Cryospheric Deformation) addresses present-day deformations of the solid Earth induced by past and present changes in the mass balance of the Earth's glaciers and ice sheets. This includes improving the understanding of cryospheric deformation from local to global scales, both through observational measurements, and the use of these observations as constraint in the ongoing development of geophysical models.

Sub-Commission 3.5 (Seismogeodesy) addresses studies of plate boundary deformation zones and the integration of geodetic and seismological observations in seismically active regions to better understand the behaviour of faults. This involves enhancing and/or developing infrastructures dedicated to broadband observations from the time scale of seismic waves to decades-long displacement and promoting the joint seismological-geodetic analysis of these observations.

Commission 3 interacts with the GGOS, other Commissions, Inter-Commission Committees and Services of the IAG as well as with external organizations such as the IAU (International Astronomical Union, see https://www.iau.org/), IASPEI (International Association of Seismology and Physics of the Earth's Interior, see http://www.iaspei.org/), IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior, see https://www.iavceivolcano.org/), IACS (International Association of Cryospheric Sciences, see https://cryosphericsciences.org/), and the IUGG

Commission on the Study of the Earth's Deep Interior (SEDI) (https://hope.simons-rock.edu/~bergman/sedi/).

1.1 Objectives

Commission 3 will:

- promote cooperation and collaboration on the theory, modelling and observation of Earth rotation and geodynamics;
- support research on how geodesy contributes to studying natural hazards by maintaining interdisciplinary groups on volcanic deformations (with IAVCEI), present-day ice mass changes (with IACS), and phases of the seismic cycle (with IASPEI);
- identify uncertainties in geodetic time series introduced by local to regional background processes (e.g., due to glacial isostatic adjustment models and hydrological models);
- approach as close as possible the new models of Earth Orientation Parameters (EOPs) and other related parameters to the dynamically time-varying, actual Earth, to be adaptable to future updating of reference frames and standards;
- foster the development of increasingly consistent and accurate geodetic multi-technique solutions;
- encourage the exchange of ideas and data as well as the comparison of methods and results with the goal of improving accuracy, content, methods, theories, and understanding of Earth rotation and geodynamics;
- serve the geophysical community by facilitating interactions with organizations that provide the data needed to study Earth rotation and geodynamics.

1.2 Program of Activities

Commission 3 fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing symposia, either independently or at major conferences in geodesy or geophysics. Some events will focus narrowly on the interests of the Sub-Commissions and other entities listed above, while others will have a broader commission-wide focus.

Commission 3 will involve under-represented groups into IAG activities.

1.3 Structure

Sub-Commissions

SC 3.1 Earth Tides and Geodynamics
Chair: Séverine Rosat (France)
SC 3.2 Volcano Geodesy (joint with IAVCEI)
Chair: Susanna Ebmeier (United Kingdom)
SC 3.3 Earth Rotation and Geophysical Fluids
Chair: Sigrid Böhm (Austria)
SC 3.4 Cryospheric Deformation (joint with IACS)
Chair: Karen Simon (Canada)

SC 3.5 Seismogeodesy (joint with IASPEI)
Chair: Jean-Mathieu Nocquet (France)

Working Groups

WG 3.1 Hydrologic signature in geodetic observations
Chair: Carla Braitenberg (Italy)

Joint Working Groups

JWG 3.1 Consistent improvement of the Earth's rotation theory
(Joint with IAU)
Chair: José M. Ferrándiz (Spain)

In addition, Commission 3 jointly contributes to JWG established by other IAG components:

JWG 1.2.3 Impact of geophysical models on reference frames (led by Comm 1),
JWG 1.4.1 Improving and homogenisation of geophysical modeling for a better consistency of the reference frames (led by Comm 1),
JWG C.1 Climate Variability and Climate Change in EOP (led by ICCC),
JWG C.2 Polar geodesy for understanding climate change (led by ICCC),
JWG M.2 GNSS-Acoustic technologies and experiments (led by ICCM),
JWG M.3 Seafloor pressure- an essential variable for monitoring vertical deformation as well as ocean dynamics (led by ICCM),
JWG M.6 How marine geodesy can better contribute to coastal hazards assessment and mitigation (led by ICCM),
JWG Prediction of Earth Orientation Parameters (PEOP) - following the WG on the 2nd EOP Prediction Comparison Campaign (led by IERS).

For descriptions of these groups, refer to the chapters of their lead components in this Handbook.

Joint Study Groups

JSG 3.1 Model representation and geodetic signature of solid-Earth rheology in surface loading problems
(Joint with Comm 1, Comm 2)
Chair: Lambert Caron (USA)

In addition, Commission 3 jointly contributes to JSG established by other IAG components:

JSG T.41 Geodetic quality/integrity modelling, monitoring and design (led by ICCT),
JSG T.42 Theoretical developments and applications of combined methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics (led by ICCT),
JSG T.45 Dynamic gravity modelling of given distributions (led by ICCT),

JSG T.46 Deformation, rotation and gravity field modeling for Earth and space (led by ICCT),
JSG T.48 Theoretical Foundations of Machine and Deep Learning in Geodesy (led by ICCT),
GGOS.AI4G.JSG 3 AI for EOP Prediction (led by GGOS),
GGOS.AI4G.JSG 4 AI for Geodetic Deformation Monitoring (led by GGOS).

For descriptions of these groups, refer to the chapters of their lead components in this Handbook.

1.4 Steering Committee

- President Commission 3: Rebekka Steffen (Sweden)
- Vice President Comm. 3: José M. Ferrándiz (Spain)
- Chair Sub-Comm. 3.1: Séverine Rosat (France)
- Chair Sub-Comm. 3.2: Susanna Ebmeier (United Kingdom)
- Chair Sub-Comm. 3.3: Sigrid Böhm (Austria)
- Chair Sub-Comm. 3.4: Karen Simon (Canada)
- Chair Sub-Comm. 3.5: Jean-Mathieu Nocquet (France)
- Representative of IERS: Tonie van Dam (USA)
- Representative of IGFS: Pavel Novák (Czech Republic)
- Representative of IGETS: Ezequiel Antokoletz (Germany)
- Member-at-Large: Chikondi Chisenga (Malawi)
- Member-at-Large: Laura Fernández (Argentina)

Non-voting members

- Representative of GGOS: Laura Sánchez (Germany)
- Representative of IAU: Alberto Escapa (Spain)
- Representative of SEDI: Jérémy Rekier (Belgium)
- Representative of Early Career Scientists: Anna Riddell (Australia)

2 Sub-Commissions, Working Groups and Study Groups

SC 3.1: Earth Tides and Geodynamics

Chair: Séverine Rosat (France)
Vice-Chair: Xiaoming Cui (China)

Terms of Reference

SC 3.1 addresses the entire range of tidal phenomena, non-tidal loading and dynamics of the Earth, both at the theoretical as well as at the observational level. The Earth tide affects many types of high precision instrumentation, be it measurements of position, deformation, potential field or acceleration. The tidal phenomena influence both terrestrial and satellite-borne acquisitions. The tidal potential is a driving force that is accurately calculated. The tidal response observable as deformation and variations in Earth orientation and rotation parameters, gives information on Earth's rheology. Instruments sensitive enough to detect the tidal signal, record a large range of periodic and aperiodic phenomena such as ocean and atmospheric tidal loading, ocean, atmospheric and hydrospheric non-tidal effects, mass redistributions and deformation related to the earthquake cycle and even to gravitational waves, as well as plate tectonics and intraplate deformation. The periods range from seismic normal modes over to the Earth tides and the Chandler Wobble and beyond, ending at the long periods of nutation-precession. Thus, the time scales range from seconds to decennia, and for the spatial scales from local, continental to global dimensions. As tidal friction is affecting Earth's rotation, all the physical properties of the Earth contribute to the explanation of this phenomenon. Therefore, research on tidal deformation due to changes of the tidal potential as well as ocean and atmospheric loading is a prerequisite to constrain Earth's rheological properties. Further, direct and indirect tidal phenomena affect the position of fiducial sites and have to be corrected to provide accurate spatial referencing. Such referencing is needed for the observation and monitoring of changes of the Earth's surface at global, regional and local scales. Therefore, there is a considerable contribution of tidal research to global geodynamics and climate change by providing important constraints to geophysical models.

Modern instrumental developments for which tidal phenomena are relevant are gravimeters and gradiometers based on superconductivity, atom interferometry, microelectromechanical-system (MEMS) gravimeters, Inertial Measurement Units, gravitational wave antennas, satellite gravimetry and atomic clocks. Improvements in gravimetric instrumentation lead to the use of gravimetry as a tool to detect underground mass changes, as naturally occurring hydrologic draughts or fluids injected into the underground for the purpose of temporary storage for instance. The Earth is a complex dynamic system interacting with its fluid surficial layers. The Earth is studied in terms of its global gravity field and its temporal variations, as well as its surface deformation in order to characterize the Earth's internal structure and dynamics. In the next few years, instrumental developments in portable absolute gravimeters are expected, and further innovations can be envisaged from the atomic interferometry technology.

SC 3.1 will follow the instrumental developments and infer innovative applications. These geophysical observations together with other geodetic observations and geological information provide the means to better understand the structure, dynamics and evolution of the Earth system. The existence of a network of superconducting gravimeters (SGs) allows continuous monitoring of the gravity signal at selected stations with a precision of better than 10^{-10} m/s^2. The range of applications of SG measurements has become very wide and applicable not only to Earth tides investigations, but also to support studies on Earth's seismic cycle and hydrological mass estimates. The SG network has had scientifically close relation to the SC 3.1 and IGETS (International Geodynamics and Earth Tide Service), which distributes the data. Therefore, the Chair of SC 3.1 is responsible for the close cooperation with the IGETS to provide effective service-with science coupling.

Objectives

Objectives of SC 3.1 include:

- to study and implement new observational techniques and improve existing ones, including clinometric and extensometric techniques;
- to demonstrate the importance of long term geodetic stations;
- to predict the signals observable with space geodetic techniques based on high precision terrestrial long term time series;
- to advance tidal data analyses and prediction methods;
- to enhance the models on the interaction among solid Earth, ocean, and atmospheric tides;
- to research the effects of the atmosphere and hydrology on gravity and other geodetic observations;
- to study the response of the Earth at tidal and non-tidal forcing frequencies;
- to study the interplay between tides and Earth rotation;
- to study the effects of ocean loading and global water distribution;
- to study the seismic cycle in terms of deformation and normal modes;
- to establish and coordinate working groups on specific topics of interest and relevancy to the understanding of our planet;
- to develop, coordinate and promote international conferences, programs and workshops on data acquisition, analysis and interpretation related to the research fields mentioned above;
- to contribute to the definition and realization of the International Terrestrial Reference Frame via advanced geodynamic models at global, regional and local scales;
- to promote the systematic calibration and intercomparison of absolute and relative gravimeters (FG5, atomic gravimeter, SGs, MEMS as well as traditional spring instruments);
- to study planetary tides and dynamics;
- to promote interdisciplinary research in Earth and planetology;
- to support the GGOS in the field of:
  - the integral effect on Earth rotation of all angular momentum exchanges inside the Earth, between land, ice, hydrosphere and atmosphere, and between the Earth, Sun, Moon, and planets,

- the geometric shape of the Earth's surface (solid Earth, ice and oceans), globally or regionally, and its temporal variations, whether they are horizontal or vertical, secular, periodical or sudden,
- the Earth's gravity field-stationary and time variable mass balance, fluxes and circulation.

Program of Activities

- Organization of International Symposium on Geodynamics and Earth Tide (G-ET Symposium held every four years) as well as other thematic conferences together with other Commission 3 SCs if possible.
- Awarding of (an) outstanding scientist(s) with the Paul Melchior Medal, formerly known as the Earth Tides Commission Medal.
- Organization of special sessions at international meetings.
- Organization of the comprehensive SC meeting together with the IGETS.
- Publishing the outcome of the research, either as stand-alone publications or as proceedings or special issues of scientific journals.
- Cooperating with other Joint Study Groups (JSG), Joint Working Groups (JWG) or Inter-Commission Projects (ICP) and Committees (ICC).
- Cooperate with GGOS, as mentioned above.

SC 3.2: Volcano Geodesy (joint with IAVCEI)

Chair: Susanna Ebmeier (UK)
Vice-Chair: Matthew Head (USA)

Terms of Reference

Geodesy is an important tool for exploring the geometry and temporal evolution of magma plumbing systems, as well as for monitoring and hazards assessment during volcanic unrest and eruption. Geodetic techniques include measurements of both deformation (to determine the magnitude, location, and geometry of subsurface sources of pressure change) and gravity (to assess subsurface mass variations).

Recent decades have seen an explosion in the quality and quantity of volcano geodetic data, especially from satellite instruments, which has created a need for new approaches to data analysis, interpretation, and modelling (Powell Centre Report, see www.usgs.gov/publications/optimizing-satellite-resources-global-assessment-and-mitigation-volcanic-hazards). Geodetic data can have different temporal and spatial resolutions, as well as different origins (ground-, air-, and space-based), and they are best utilized in conjunction with other non-geodetic datasets, like seismicity and gas emissions. New tools are therefore needed for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano monitoring results. This is critical for volcano monitoring, and especially important where both multi-sensor constellation imagery and ground-based imagery is available, e.g., through volcanic sites in GEO's Geohazard Supersites (https://earthobservations.org/) and Natural Laboratories initiative GEO-GSNL (https://geo-gsnl.org) or through the CEOS (Committee

on Earth Observations Satellites) Volcano Demonstrator (https://ceos.org/ourwork/workinggroups/disasters/volcanoes/) and related initiatives.

The IAG-IAVCEI Commission on Volcano Geodesy (https://volcgeodesy.iavceivolcano.org/) aims to support the diverse international research community, foster collaborations, and ultimately promote a better understanding of magmatic processes and volcanic hazards through the use of geodetic techniques and modelling.

Objectives

Objectives of SC 3.2 include:

- foster communication within the volcano geodesy community, particularly between senior and early-career researchers, between scientists from different countries, and between volcano observatories;
- support coordinated geodetic response to volcanic unrest and eruptions around the world, including the acquisition of, and access to, satellite data through collaboration with GEO, CEOS and individual members;
- encourage high-level geodetic capability at the world's volcanoes through the sharing of best practices; development, testing, and distribution of open-source analysis and modelling tools; standardization of techniques for the measurement and interpretation of geodetic changes; exploitation of new technologies; and capacity-building activities;
- support the establishment and maintenance of databases for volcano geodetic observations, as well as the interoperability between these and other sources of geological, geochemical, and geophysical data related to volcanoes;
- promote volcano geodesy as a tool with broad implications and diverse applications in research, monitoring, and crisis response by serving as a bridge between geodesy and other branches of volcanology; connecting geodesists within the academic community, volcano observatories, space agencies, industry, government institutions, and other organizations; and advocating for the commitment of appropriate resources;
- encourage and enable collaborations between geodesy and other disciplines, given that interdisciplinary approaches to volcano research and hazards assessment offer the best prospects for improving overall understanding of volcanic processes and their impacts;
- implementation and dissemination of new standard approaches, protocols and best practices;
- promotion of common initiatives and projects with other IAG and IAVCEI entities.

Program of Activities

- Organize a scientific conference to define big scientific questions that could be addressed with Volcano Geodesy.
- Organize a scientific workshop with the goals of training early-career volcano geodesists, sharing current research, and comparing codes on a standardized synthetic data set.

- Establish an accessible means of communicating regular updates (e.g., news, recent academic and observatory publications, conference sessions, job opportunities) to the volcano geodesy community, and promote the visibility of ongoing projects.
- Organize a quarterly virtual seminar for ongoing research in volcano geodesy, with at least one slot reserved for early-career/student volcano geodesists.

SC 3.3: Earth Rotation and Geophysical Fluids

Chair: Sigrid Böhm (Austria)
Vice-Chair: Christopher Dieck (USA)

Terms of Reference

Mass transport in the atmosphere-hydrosphere-mantle-core system, or the "global geophysical fluids", causes observable geodynamic effects on broad time scales. Although relatively small, these global geodynamic effects have been measured by space geodetic techniques to increasing, unprecedented accuracy, opening important new avenues of research that will lead to a better understanding of global mass transport processes and of the Earth's dynamic response. Angular momenta and the related torques, gravitational field coefficients, and geocenter shifts for all geophysical fluids are the relevant quantities. They are observed using global-scale measurements and are studied theoretically as well as by applying state-of-the-art models; some of these models are already constrained by geodetic measurements. Increasingly more efforts are also being made internationally to constitute future projections of mass transports in the geophysical fluid systems. These enable the investigation of global change impacts on Earth rotation variability, particularly considering possible consequences of human interaction with Earth's fluid systems.

Objectives

The objective of SC 3.3 is to serve the scientific community by supporting research and data analysis devoted to variations in Earth rotation, the gravitational field, and the geocenter caused by mass redistribution within and mass exchange among the Earth's fluid sub-systems, i.e., the atmosphere, ocean, continental hydrosphere, cryosphere, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle. The SC contributes to accomplishing the GGOS vision of "Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time" with the quantification of the following parameters for the past, present, and future:

- angular momentum exchange and mass transfer;
- deformation due to mass transfer between solid Earth, atmosphere, and hydrosphere including ice.

Program of Activities

- To promote the exchange of ideas and results as well as of analysis and modelling strategies, sessions at international conferences and topical workshops will be organized.
- In addition, SC 3.3 interacts with the sister organizations and Services, particularly with the IERS components providing Earth rotation and geophysical fluids data (atmosphere, hydrology, ocean, combination).
- SC 3.3 will have close contacts to the GGOS activities, in particular to the activities of the GGOS Committee "Contribution to Earth System Modelling".
- The SC will foster the exchange and collaboration with the IAG Inter-Commission Committee on Geodesy for Climate Research (ICCC), for example to evaluate the potential of Earth system data from climate simulations for Earth rotation research.

SC 3.4: Cryospheric Deformation (joint with IACS)

Chair (IAG): Karen Simon (Canada)
Chair (IACS): Matthias Willen (Germany)
Vice-Chair: Carsten Ludwigsen (Denmark)

Terms of Reference

Past and present changes in the mass balance of the Earth's glaciers and ice sheets induce present-day deformation of the solid Earth on a wide range of spatial and temporal scales, from the very local to global and from immediate elastic deformations to millennial viscoelastic glacial isostatic adjustment (GIA) to past ice ages. This present-day deformation of the solid Earth is thus a window into glacial history and provides insights into the solid-Earth rheology, enabled by sophisticated GIA modeling. The geodetic observation of this deformation regarding changes in Earth's geometry, gravity field, and orientation is essential in validating or constraining GIA models. This holds true for direct information on the history of sea level and glaciation.

Present-day ice mass changes induce an immediate elastic deformation of the Earth, while the integrated history of mass changes induces an additional viscoelastic deformation. Traditionally, these responses have been considered separately, which is a good approximation for long-ago load changes and regions of high mantle viscosity. In regions of low upper-mantle viscosity (e. g. West Antarctica, Antarctic Peninsula, Patagonia, Iceland), the present-day and recent-past load changes must be modeled together as the rapid viscoelastic relaxation is substantial and not easily separated from the immediate elastic response. In all cases, present-day geometric measurements (e.g., bedrock motion rates) measure the sum of elastic and viscoelastic deformations, and these components cannot be separated without additional models or observations. Present-day gravity changes are useful because they have a different sensitivity to the elastic and viscoelastic components. During recent years, extensive efforts have been made in the GIA modeling community to represent the spatial heterogeneity of the solid-earth rheology in the models (3-D models) and to account for the different temporal response scales by implementing more sophisticated rheology models (e.g.,

extended Burgers material models). The careful inter-comparison and validation of these models, including consideration of the microphysical basis for transient models of deformation (creep processes), will help us unravel and understand the causes of the model differences.

Furthermore, the consideration of GIA-induced feedback effects in ice-sheet modeling (coupled GIA-ice sheet modeling) is increasingly being considered, for example, to better understand (de)stabilization effects due to bedrock motion and to be able to take them into account in projections. This applies in particular to the ice sheets in West Antarctica and Greenland, which have been identified as climate tipping elements.

This SC has a long history as part of IAG. Since 2022 this is a joint sub-commission with IACS. Within IAG, SC 3.4 historically has focused on resolving technical measurement issues. With this cross-Association sub-commission, we will continue to enhance the benefits obtained during the previous term through collaboration and sharing of data with the glaciological community.

Objectives

Objectives of SC 3.4 include:

- Connecting researchers working on cryospheric deformation by
  - Organizing 1-2 international workshop(s) that will continue the very successful series organized by this Sub-Commission over the last several years;
  - Co-organizing sessions at meetings of the AGU (American Geophysical Union, see https://www.agu.org/) and EGU (European Geosciences Union, see https://www.egu.eu/);
  - Organizing and continuation of online seminar series;
- Investigate the impact of reference frame differences (mainly origin) between GIA models and geodetic reference frames;
- Stimulate and support the inter-comparison, benchmarking, and validation of 1-D and especially 3-D Earth rheological models;
- Stimulate and encourage sharing model outputs, observational data, and distribution of open source software tools for modeling cryospheric deformation, and promote the inclusion of ice sheet-solid earth interactions in past and future ice sheet model runs;
- Stimulate discussion and promote the application of (future) Earth Observation techniques to research questions related to cryospheric deformation.

In terms of workshops and the online seminar series, we will seek partners to enhance cross-disciplinary aspects of the workshops (e.g., PALSEA-Next, see https://pastglobalchanges.org/science/wg/palsea/intro and SCAR INSTANT Theme 2, see https://www.scar-instant.org/index.php).

Program of Activities

- A session on GIA entitled "Glacial isostatic adjustment: observation, modelling, analysis, and interaction" will be co-convened at the EGU General Assembly in 2024.

- Co-organize an international workshop focusing on cryospheric deformation and GIA modeling and observables somewhere in Canada in the spring of 2025 (Sidney, British Columbia; 1st of June). This workshop will likely be a 4-day event and is a continuation of the successful series of workshops co-organized by the Sub-Commission and hosted in Reykjavik, Iceland in 2017, and Ottawa, Canada in 2019. We will continue to seek coordination with cross-disciplinary groups such as IAG, IACS, and PALSEA.
- If scheduling and means allow, co-organize a second workshop in 2027. We consider "assessing cryospheric deformations across time-scales" to be of particular interest as a possible focus topic for this workshop.
- Organize an online seminar series on key topics associated with cryospheric deformation. Even though the community continues to come together in face-to-face meetings after the Covid pandemic, we would like to initiate the opportunity for the community to regularly exchange scientific findings. Each seminar will focus on a single key topic and give a speaker the opportunity to present on a topic for around 20 to 30 minutes followed by a general discussion. We plan to start this series in 2024 and have 4-5 seminars throughout the year. This series continues the concept of the popular virtual seminar series which began in 2021 and had a second edition in 2022.
- We plan to create a worldwide overview of research activities regarding cryospheric deformation and thus a central point of reference. For example on the IAG website, we would like to provide the community with a comprehensive overview. This includes, for example, the listing of global and regional GIA modeling results and their sources, validation data sets of different observation methods, etc. This should also provide an overview of which research groups are working on which regions/questions. The maintenance of this information is the responsibility of SC 3.4 and will be continued and further developed in the future by those responsible for SC 3.4. We anticipate that this will make it easier for Early Career Scientist start working on this research topic. In particular, we intend to stipulate with this initiative that research results are made accessible. This initiative is to be coordinated with the community at the planned Workshop 2025.
- Develop an online archive of 1D and 3D Earth rheological models to enhance dissemination and inter-comparison of these models. The specific development of this archiving initiative will be a subject during the workshop in 2025.
- Organize an effort to benchmark 3D GIA modeling approaches, similar to the benchmarking exercise done a few years ago for 1D codes.
- Organize a working group to analyze frame differences (especially frame origin) between GIA models and ITRF (International Terrestrial Reference Frame). It should be possible to transform global GIA model predictions into any reference frame, including Center of mass of Earth System and Center of Figure. We want to encourage future modeling efforts to compute the needed frame transformations.

SC 3.5: Seismogeodesy (joint with IASPEI)

Chair: Jean-Mathieu Nocquet (France)
Vice-Chair: Masayuki Kano (Japan)

Terms of Reference

Space and terrestrial geodetic techniques provide key observations to investigate a broad range of geophysical processes, thanks to their high accuracy, time and spatial resolution, and reliable georeferencing. Thanks to the technological evolution witnessed in the past decades, crustal movements of few millimeters can be now detected and monitored over time, opening new prospects for the study of Earth deformation.

Seismogeodesy is an evolving discipline within earthquake-related research, seamlessly integrating seismology and geodesy to comprehensively monitor Earth's deformation across a broad range of timescales, spanning from hundreds of Hertz to several decades. Seismogeodesy includes the study of the phases of the earthquake cycle by quantifying the modes of accumulation and release of stress and strain before (inter-seismic phase), during (co-seismic phase), and after (post-seismic phase) seismic events. Among the current challenges, seismogeodesy aims at documenting transient aseismic slip at faults through their geodetic and seismological signatures to understand their dynamics and their significance in the earthquake cycle.

The foundation for fully exploiting the potential of the growing set of geodetic and seismological measurements is the development of a multidisciplinary approach. The joint IAG-IASPEI SC on Seismogeodesy aims to facilitate the cooperation between the geodetic and the seismological communities to improve our current understanding of the different seismic and aseismic processes. The works of the SC focus on both theoretical aspects and observational challenges. Particular effort is dedicated to identifying gaps of knowledge and opportunity for progress, particularly in the field of hazard assessment and early warning systems.

Objectives

Objectives of SC 3.5 include:

- to actively encourage the cooperation between all geoscientists studying the plate boundary deformation zones, by promoting the exploitation of synergies between different fields;
- to promote open science through open data policy, publicly available codes and algorithms;
- to reinforce joint and integrated geodetic and seismological monitoring of seismically active areas by increasing and/or developing infrastructures dedicated to broadband observations; from the seismic wave band to the permanent displacement;
- to be a reference group for the integration of the most advanced geodetic and geophysical techniques by developing consistent methodologies for data reduction, analysis, integration, and interpretation;

- to act as a forum for discussion and scientific support for international geoscientists investigating the kinematics and mechanics of the plate boundary deformation zone;
- to promote the use of standard procedures for geodetic data acquisition, quality evaluation, and processing, particularly GNSS data and InSAR (Interferometric Synthetic-Aperture Radar) data;
- to promote earthquake geodesy, the study of seismically active regions with large earthquake potential, and geodetic application to early warning system of earthquakes and tsunamis for hazard mitigation;
- to promote the role of geodesy in tectonic studies for understanding the relationship between short term versus long term deformation, documenting deformation of all phases of the seismic cycle, including steady and transient deformation, aseismic versus seismic slip on faults.

Program of Activities

- Building on the experience of the WEGENER (Working Group of European Geoscientists for the Establishment of Networks for Earth-science Research) initiative, to continue as a framework for geodetic cooperation in the study of the plate boundary zones.
- To develop scientific programs in earthquake geodesy for subduction zones and possible occurrence of giant earthquakes and associated tsunamis.
- To foster the use of space-borne, airborne, marine and hybrid techniques such as GNSS, LIDAR (Light detection and ranging), seafloor GNSS-Acoustic and pressure gauges.
- To support the development of new satellite mission aiming at providing new information of the Earth deformation through radar, optical, and gravity.
- To promote the emergence of new technologies to monitor both seismic and aseismic deformation such as optic fibers.
- To encourage effective integrated observational and analysis strategies for these techniques to reliably identify and monitor crustal movements and gravity variations over all time scales.
- To facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geo-processes.
- To organize periodic workshops and meetings with special emphasis on interdisciplinary research and interpretation and modeling issues.
- To organize special sessions at international meetings.
- To publish the outcome of the research, either as stand-alone publications or as proceedings or special issues of scientific journals.

WG 3.1: Hydrologic signature in geodetic observations

Chair: Carla Braitenberg (Italy)
Vice-Chair: Grace Carlson (USA)

Terms of Reference

Terrestrial and space geodetic observations have proven to be suitable for integrating studies of a multitude of time-varying processes. Hydrologic fluxes and volume changes can generate geodetic signals distributed in time from impulsive through seasonal to long term variations and in space at local to regional scales. Geodetic platforms such as satellite gravimetry and GNSS have improved our ability to track large-scale movements of water and are becoming increasingly essential in our ability to measure changes in freshwater storage due to extreme hydroclimate events such as droughts and floods, anthropogenic processes such as groundwater pumping, and climate change. However, these signals are overprinted and often difficult to disentangle from other signals of interest such as, for example, long-term tectonic signals. Therefore, isolating hydro-geodetic signals is important both for our ability to manage freshwater stores as well as to monitor other geophysical processes. To address this challenge, the working group aims to define best practices to identify hydrologic signatures in geodetic observations. Our objective is to support research and data analysis that allows us to gain a better understanding for the scales at which geodetic observations are sensitive to hydrologic processes, how these processes appear in geodetic observations, and how, if necessary, to eliminate these signals depending on the observation system and scale of interest.

Objectives

- Define the physical mechanisms that generate hydrologic signals in geodetic observations.
- Define best practices for forward modeling hydrologic effects that may be present in geodetic observations.
- Identify spatiotemporal scales at which geodetic observation may be sensitive to different hydrologic processes.
- Identify pitfalls to prevent the wrong identification of signals as for instance earthquake precursors or differentiating signals of man-made from natural fluid fluxes.

Program of Activities

- Organize a cycle of seminars to promote the exchange of ideas between hydrologists and geodesists.
- Organize a workshop for geodesists studying non-hydrology related signals to convey best practices for removing these signals from their observations.
- Publish a report detailing recommendations for isolating hydrologic signals in different geodetic datasets.
- Contribute publications and to scientific conferences such as meetings of the AGU and EGU.

Members

Carla Braitenberg (Italy); Chair
Grace Carlson (USA); Vice-Chair
Maite Benavent (Spain)
Wei Feng (China)
Manuela Girotto (USA)
Anna Klos (Poland)
Laurent Longuevergne (France)
Christian Massari (Italy)
Cristiano Mendel Martins (Brazil)
Tommaso Pivetta (Italy)
Umberto Riccardi (Italy)
Jose Arnoso Sampedro (Spain)

JWG 3.1: Consistent improvement of the Earth's rotation theory

(joint with IAU)
Chair: José M. Ferrándiz (Spain)
Vice-Chair: Cheng-li Huang (China)

Terms of Reference

To complete the development of the "2019 IAG Resolution 5" (https://iag-aig.org/doc/GH2020/209_IAG\%20Resolutions.pdf) and the "2021 IAU Resolution B2" (https://www.iau.org/static/archives/announcements/pdf/ann21040b.pdf) on Improvement of the Earth's Rotation Theories and Models, which mandates:

- To encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential Earth Orientation Parameter (EOP);
- That the definition of all the EOP, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG-IAU and their components;
- That the new models should be closer to the dynamically time-varying, actual Earth, and adaptable as much as possible to future updating of the reference frames and standards.

At present the development of the said Resolutions has arrived at the obtaining of some sets of semiempirical corrections to the IAU2000/IAU2006 nutation and precession models that allow a significant reduction of the inaccuracies of those theories, measured in terms of the variance of CPO (Celestial Pole Cffsets) time series, as well as at additional reductions associated to the improvement of FCN (Free Core Nutation) models. Theoretical advances have addressed the treatment of more realistic Earth models and some specific effects on the Earth rotation but have not been integrated yet in frameworks consistent both internally and with the procedures used in observational data analysis.

Objectives

- Solving an inconsistency issue at the foundation, so that the dynamical equations ruling the evolution of all EOP be consistent and referred to the same reference systems and frames - or alternatively to different frames but specifying the transformations among them.
- An improved and more accurate solution to the precession and forced nutations, consistent with state-of-the-art models of the tide-rising potential and the known geophysical forcing, and updatable to upcoming improvements of the auxiliary models in parallel to the procedures followed in data analysis.
- Continue advancing the modelling of the free core nutation.
- Furthering the understanding and implications of the relations between nutation and polar motion, in the light of the current capabilities to determine subdiurnal polar motion.
- An additional side benefit sought is to boost the interest and expertise of young researchers in Earth rotation theory and thus help the necessary generational replacement.

Program of Activities

Tasks are cast into two groups for the clarity's sake. Members and correspondents must participate in an interactive and coordinated way.

1. Core of Theory (chaired by Alberto Escapa)
   - Revision of the reference system and frames used in theoretical developments to ensure they are or can be made consistent with the reference frames used in observation processing, and that all EOP are referred to the same frames;
   - Extend the basic Earth model to get it closer to state of the art models and relaxing tight hypothesis on structure invariance (e.g., triaxial, updated tidal models for solid earth and oceans, possibility of accounting better for motion components of angular moment, time-varying gravity and realistic J2 variation, possibility of allowing for relative motions of the main layers. . .);
   - Update the tidal potential raised by external bodies;
   - Assess deeply the impact of relativity;
   - Recompute consistently second order effects and derive a solution for precession-nutation, accurate at the observation (or GGOS) level;
   - Revisit the problem of separation of nutations and polar motion, in particular at the sub-diurnal level.
2. Observations (chaired by Maria Karbon):
   - Ensure that hypothesis, equations and models used in the data analysis packages are consistent with those in theory and compliant with the IAU-IAG-IUGG resolutions;
   - Providing guidance and help to the potential update and revision of definitions;
   - Check the new theory and fit it to observations.

Members and corresponding members

1. Core of Theory
   Alberto Escapa (Spain); Chair
   Christian Bizouard (France)
   Tomás Baenas (Spain)
   Ben F. Chao (China-Taipei)
   Jolanta Nastula (Poland)
   Henryk Dobslaw (Germany)
   Pengshuo Duan (China)
   Wei Chen (China)
   Juan Getino (Spain); corresponding member
   Harald Schuh, Germany); corresponding member
   Richard S. Gross (USA); corresponding member
   David Salstein (USA); corresponding member
   Mian Zhang (China); corresponding member
   Xueqing Xu (China); corresponding member
   Wenbin Shen (China); corresponding member
   Nicolas Rambaux (France); corresponding member
   Jean Paul Boy (France); corresponding member
2. Observations
   Maria Karbon (Spain); Chair
   Santiago Belda (Spain)
   Sigrid Böhm (Austria)
   Kaho Hashimoto (Japan)
   Sebastien Lambert (France)
   Zinovy Malkin (Russia)
   Saho Matsumoto (Japan)
   Tobias Nilsson (Sweden)
   Lizheng Lian (China)
   Oleg Titov (Australia)
   Axel Nothnagel (Austria); corresponding member
   Hao Ding (China); corresponding member
   Yuanwei Wu (China); corresponding member
   Jiacheng Liu (China); corresponding member
   Laura Fernández (Argentina); corresponding member

JSG 3.1: Model representation and geodetic signature of solid-Earth rheology in surface loading problems

(joint with Commission 1 and Commission 2)
Chair: Lambert Caron (USA)
Vice-Chair: Rebekka Steffen (Sweden)

Terms of Reference

The redistribution of mass at the Earth surface in the cryosphere, hydrosphere and ocean and the associated solid-Earth response create perturbations in the sea level, gravity field, bedrock topography, crustal stress field, geocenter motion, and rotation of the Earth. The geodetic signatures of these effects can be characterized in terms of amplitude, wavelength, and time-dependence. Our understanding of the underlying mechanisms controlling these characteristics currently relies on the model representation of the rheology of the Earth mantle and lithosphere, which is inferred by comparisons of model output to the observations.

Over the last decade, the community has put together several benchmarks and model inter-comparisons using numerical approaches to surface loading problems (including Glacial Isostatic Adjustement – GIA) for the case of an incompressible Maxwell Earth. However, an incompressible Maxwell Earth can no longer explain all geodetic signals observed by modern data missions and networks, and more advanced rheologies are increasingly becoming the norm across the community.

This study group tasks itself with organizing the community to extend such benchmarking and intercomparison efforts to the current state-of-the-art in mantle rheology modeling. We shall document the computation of compressible material and rheologies featuring transient relaxation for spherically symmetric Earth models. We will also assist ongoing efforts in benchmarking models with lateral viscosity variations. This effort aims to standardize the theory, computation, and error calibration in surface loading models for geodetic and geodynamic applications. We aim at expressing model results in a form that is applicable to common geodetic observational frameworks, in particular space gravimetry, GNSS, tide gauges, rotational data, and reference frames.

We seek to identify critical assessments that can be performed to constrain the relationships more tightly between effective mantle rheology for use in geodynamics and GIA models that are compatible with new advances in seismic tomography, rock laboratory experiments, post-seismic deformation and tidal dissipation. Consequently, this Study Group is joined between Commission 1 on Reference Frames, Commission 2 on Gravity Field and Commission 3 on Earth Rotation and Geodynamics with promising cooperation with SEDI (https://hope.simons-rock.edu/~bergman/sedi/).

Objectives

- Reviewing the established approaches to model surface loading problems, for spectral, grid-based and element-based modeling.
- Assessing the accuracy of and spread between existing modeling frameworks for standardized compressible and transient rheologies.
- Establishing and documenting standard tests and results that enable the community to calibrate current and future efforts to model surface loading problems.
- Encouraging open science and international collaboration for surface loading and geodetic science.

Program of Activities

- Creation of two benchmarks for modeling surface loading problems, the first one focusing on compressible Maxwell rheology and the second on linear transient rheology.
- Contribution to international meetings and conferences (e. g., by AGU and EGU).
- Co-organization of a session at the IUGG meeting in Incheon, South Korea, in 2027.
- Common publications by JSG members.
- Management of a website with updates on the development of the JSG and ensuring benchmark results remain perennially in open access for the community.

Members

Lambert Caron (USA); Chair
Rebekka Steffen (Sweden); Vice-Chair
Pingping Huang (UK)
Volker Klemann (Germany)
Harriet Lau (USA)
Tanghua Li (Singapore)
Andrew Lloyd (USA)
Anthony Purcell (Australia)
Daniele Melini (Italy)
Holger Steffen (Sweden)
Wouter van der Wal (Netherlands)
Doug Wiens (USA)

Commission 4 - Positioning and Applications

https://doi.org/10.82507/iag-gh2024_com4

President: Paweł Wielgosz (Poland)
Vice President: Xingxing Li (China)

Commission 4 website - www.com4.iag-aig.org

1 Terms of Reference

IAG Commission 4 is dedicated to uniting scientists, researchers, and professionals across the expansive field of Positioning, Navigation, Timing (PNT), and their various applications. To this end, it commits to fostering research that harnesses both current and evolving positioning methods and technologies, aiming to offer theoretical and practical advancements in positioning technologies, multi-frequency and multi-constellation Global Navigation Satellite Systems (GNSS), positioning integrity and quality assurance, GNSS alternatives and backups, sensor integration, atmospheric remote sensing and modeling, as well as innovative engineering geodesy technologies and applications derived from geodetic methods. Commission 4 will execute its mission closely with the IAG Components and Services and through connections with entities across scientific and professional organizations.

With the pivotal role of GNSS in meeting today's and future positioning needs in mind, Commission 4 will prioritize research that refines models and methodologies to improve and secure GNSS-based positioning performances for a broadening range of end-user applications. It recognizes the growing threats and vulnerabilities to GNSS-only positioning systems and seeks to explore technologies and strategies to counteract these challenges. The Sub-Commissions are tasked with developing theories, strategies, and tools for modeling or mitigating interference, signal disruptions, and atmospheric disturbances relevant to precise GNSS positioning technologies. They will tackle both technical and institutional challenges essential for establishing GNSS alternatives, integrated PNT solutions, automated processing capabilities, and quality assurance protocols. Moreover, Commission 4 will explore geodetic remote sensing through the use of Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR), and Satellite Altimetry (SA) for geodetic and engineering purposes.

Commission 4, at the start of the new period, consists of four Sub-Commissions (SCs) with their Working Groups (WGs), plus one Joint Study Group (JSG) and three Joint Working Groups (JWG), all of them jointly with other Commissions and/or services. Additional WGs and Study Groups (SGs) can be established as needed, and existing ones may be dissolved should they become inactive.

1.1 Objectives

The main objectives of Commission 4 are as listed in the IAG Bylaws:

- Terrestrial and satellite-based positioning systems development, including sensor and information fusion
- Navigation and guidance of platforms
- Interferometric laser and radar applications
- Applications of geodetic positioning using three-dimensional geodetic networks, including monitoring of deformations
- Applications of geodesy to engineering
- Atmospheric investigations using space geodetic techniques

1.2 Program of Activities

Commision 4 "Positioning and Applications" fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing Symposia, either independently or at major conferences in geodesy. The activities of its sub-entities, as described below, constitute the activities of the Commission, which will be coordinated and summarized in annual reports to the IAG Bureau.

The status of Commission 4, with links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the web site: https://com4.iag-aig.org/.

1.3 Structure

Sub-Commissions

SC 4.1 Emerging Positioning Technologies and GNSS Augmentation
Chair: Heidi Kuusniemi (Finland)
SC 4.2 Multi-frequency Multi-constellation GNSS
Chair: Jianghui Geng (China)
SC 4.3 Atmosphere Remote Sensing
Chair: Ningbo Wang (China)
SC 4.4 Engineering Geodesy
Chair: Janis Kaminskis (Latvia)

Working Groups

WG 4.1.1 Integrity Monitoring of Collaborative Positioning
Chair: Liang Li (China)
WG 4.1.2 Upcoming GNSS services for accuracy, reliability and resilience
Chair: Paolo Zoccarato (Italy)
WG 4.1.3 LEO-PNT Systems
Chair: Fabricio S. Prol (Finland)
WG 4.1.4 Low-Cost GNSS receiver systems
Chair: Dinesh Manandhar (Japan)
WG 4.1.5 Wireless positioning with terrestrial instruments
Chair: Andrea Masiero (Italy)
WG 4.1.6 Smart Wearable Positioning
Chair: You Li (China)

WG 4.2.1 Precise GNSS time and frequency transfer
Chair: Jiang Guo (Belgium)
WG 4.2.2 Advances and unification of PPP-AR
Chair: Marcus Franz Wareyka-Glaner (Austria)
WG 4.2.3 Mass-market high-precision GNSS and applications
Chair: Guangcai Li (China)
WG 4.2.4 Quality Control and Integrity Monitoring of Precise Positioning
Chair: Krzysztof Nowel (Poland)
WG 4.2.5 Multi-GNSS for Natural Hazards and Disaster Resiliency
Chair: Xiaoming Wang (China)
WG 4.3.2 Ionospheric state predictions and early warnings for space weather services
Chair: Murat Durmaz (Türkiye)
WG 4.3.3 Analysis and prediction of ionospheric scintillations
Chair: Dmytro Vasylyev (Germany)
WG 4.3.4 Indices for characterizing ionospheric perturbations
Chair: Grzegorz Nykiel (Poland)
WG 4.3.5 Ionosphere and space weather monitoring using ground and spaceborne GNSS
Chair: Zhe (Jenny)Yang (China)
WG 4.3.8 Troposphere Modeling and Monitoring
Chair: Cuixian Lu (China)
WG 4.3.9 Observing convective and volcanic clouds with geodetic remote sensing techniques
Chair: Hugues Brenot (Belgium)
WG 4.3.10 Remote sensing using GNSS reflected signals
Chair: Milad Asgarimehr (Germany)
WG 4.4.1 Novel GNSS applications in engineering geodesy
Chair: Junbo Shi (China)
WG 4.4.2 InSAR engineering geodesy for infrastructure health monitoring
Chair: Liming Jiang (China)
WG 4.4.3 Multisensor Displacement and Deformation Monitoring
Chair: Maya Ilieva (Bulgaria)
WG 4.4.4 TLS and LiDAR Scanning for Building Information Modelling (BIM) Services
Chair: Janina Zaczek-Peplinska (Poland)

Joint Working Groups

JWG 4.3.1 Real-time ionosphere monitoring and modeling
(joint with IGS and GGOS)
Chair: Zishen Li (China)
JWG 4.3.6 Validation of ionospheric models for positioning applications
(joint with IGS)
Chair: Anna Krypiak-Gregorczyk (Poland)
JWG 4.3.7 Machine learning for the atmosphere
(joint with GGOS)
Chair: Yury Yasyukevich (Russia)

Joint Study Groups

JSG 4.1.7 Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)
(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)

1.4 Steering Committee

- President Commission 4: Paweł Wielgosz (Poland)
- Vice President Comm. 4: Xingxing Li (China)
- Chair Sub-Comm. 4.1: Heidi Kuusniemi (Finland)
- Chair Sub-Comm. 4.2: Jianghui Geng (China)
- Chair Sub-Comm. 4.3: Ningbo Wang (China)
- Chair Sub-Comm. 4.4: Janis Kaminskis (Latvia)
- ICCM representative: Kaifei He (China)
- Member-at-Large: Safoora Zaminpardaz (Australia)
- Member-at-Large: Daniele Barroca Marra Alves (Brazil)
- ISPRS representative: Charles Toth (USA)
- FIG representative: Allison Kealy (Australia)
- ION representative: Dorota Grejner-Brzezinska(USA)
- Representative of Early Career Scientists: Artur Fischer (Poland)

1.5 Overview of Working Groups and Study Groups

Groups related to SC 4.1

WG 4.1.1 Integrity Monitoring of Collaborative Positioning
Chair: Liang Li (China)
WG 4.1.2 Upcoming GNSS services for accuracy, reliability and resilience
Chair: Paolo Zoccarato (Italy)
WG 4.1.3 LEO-PNT Systems
Chair: Fabricio S. Prol (Finland)
WG 4.1.4 Low-Cost GNSS receiver systems
Chair: Dinesh Manandhar (Japan)
WG 4.1.5 Wireless positioning with terrestrial instruments
Chair: Andrea Masiero (Italy)
WG 4.1.6 Smart Wearable Positioning
Chair: You Li (China)
JSG 4.1.7 Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)
(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)

Groups related to SC 4.2

WG 4.2.1 Precise GNSS time and frequency transfer
Chair: Jiang Guo (Belgium)
WG 4.2.2 Advances and unification of PPP-AR
Chair: Marcus Franz Wareyka-Glaner (Austria)
WG 4.2.3 Mass-market high-precision GNSS and applications
Chair: Guangcai Li (China)
WG 4.2.4 Quality Control and Integrity Monitoring of Precise Positioning
Chair: Krzysztof Nowel (Poland)
WG 4.2.5 Multi-GNSS for Natural Hazards and Disaster Resiliency
Chair: Xiaoming Wang (China)

Groups related to SC 4.3

JWG 4.3.1 Real-time ionosphere monitoring and modeling
(joint with IGS and GGOS)
Chair: Zishen Li (China)
WG 4.3.2 Ionospheric state predictions and early warnings for space weather services
Chair: Murat Durmaz (Türkiye)
WG 4.3.3 Analysis and prediction of ionospheric scintillations
Chair: Dmytro Vasylyev (Germany)
WG 4.3.4 Indices for characterizing ionospheric perturbations
Chair: Grzegorz Nykiel (Poland)
WG 4.3.5 Ionosphere and space weather monitoring using ground and spaceborne GNSS
Chair: Zhe (Jenny)Yang (China)

JWG 4.3.6 Validation of ionospheric models for positioning applications
(joint with IGS)
Chair: Anna Krypiak-Gregorczyk (Poland)
JWG 4.3.7 Machine learning for the atmosphere
(joint with GGOS)
Chair: Yury Yasyukevich (Russia)
WG 4.3.8 Troposphere Modeling and Monitoring
Chair: Cuixian Lu (China)
WG 4.3.9 Observing convective and volcanic clouds with geodetic remote sensing techniques
Chair: Hugues Brenot (Belgium)
WG 4.3.10 Remote sensing using GNSS reflected signals
Chair: Milad Asgarimehr (Germany)

Groups related to SC 4.4

WG 4.4.1 Novel GNSS applications in engineering geodesy
Chair: Junbo Shi (China)
WG 4.4.2 InSAR engineering geodesy for infrastructure health monitoring
Chair: Liming Jiang (China)
WG 4.4.3 Multisensor Displacement and Deformation Monitoring
Chair: Maya Ilieva (Bulgaria)
WG 4.4.4 TLS and LiDAR Scanning for Building Information Modelling (BIM) Services
Chair: Janina Zaczek-Peplinska (Poland)

2 Sub-Commisions, Working Groups and Study Groups

SC 4.1: Emerging Positioning Technologies and GNSS Augmentation

Chair: Heidi Kuusniemi (Finland)
Vice-Chair: Fabricio S. Prol (Finland)

Terms of Reference

Emerging technologies in positioning and applications play a crucial role in addressing location determination limitations and enhancing the capabilities beyond traditional solutions like standalone GNSS. Urban environments and indoor navigation, where GNSS signals may be weak, unreliable or unattainable, need to utilize a variety of location information solutions, for example in the context of Augmented Reality (AR), Indoor Positioning Systems (IPS), and Computer Vision (CV) within buildings or densely populated urban areas. Autonomous vehicles and systems require high-precision and real-time navigation information for safe operation via harnessing technologies such as LiDAR, Radar, 5G, inertial systems, V2X communication and sensor fusion approaches complementing GNSS for accurate and resilient positioning. The work of this Sub-Commission focuses on the benefits of various emerging positioning technologies extending to improved safety, efficiency, security, and overall advancements in society, industry, and geodesy.

Objectives

- Development of new techniques for positioning;
- Analyzing the integrity levels of PPP and PPP-RTK for collaborative positioning;
- Enhancing PPP for real-time applications;
- Providing perspectives of how the positioning and augmentation technologies should develop utilizing, e.g., LEO systems;
- Advancing solutions for low-cost receivers as well as smart wearable systems;
- Exploring the future opportunities of quantum navigation.

Program of Activities

- Promote international collaboration to advance emerging positioning solutions.
- Organize and/or participate in scientific events (workshops, conferences, seminars etc.)
- Organize special issues on the emerging technologies for positioning.
- Increase cooperation with international organizations, such as Institute of Navigation (ION), International Federation of Surveyors (FIG), Nordic Institute of Navigation (NNF), Nordic Geodetic Commission (NKG), and the United Nations (UN).

WG 4.1.1: Integrity Monitoring of Collaborative Positioning

Chair: Liang Li (China)
Vice-Chair: Liang Wang (China)

Terms of Reference

With the rapid development of automatic and intelligent transportation, the collaborative positioning become increasingly indispensable to provide high-precision and credible positioning information. This WG mainly focuses on the integrity monitoring structure design, algorithms development for the signal, information, data processing and critical nodes of collaborative positioning. The PPP/PPP-AR/PPP-RTK will be one of critical components of collaborative positioning. The accurate integrity of multiple risks of collaborative positioning requires to be estimated, evaluated, and validated. The integrity risk resources include the high accuracy correction products generated from service providers, the user terminal based on multi-sensor system, and the communication link between the cloud and the user.

Objectives

- Develop integrity monitoring algorithms and software for PPP/PPP-AR/PPP-RTK correction products including the satellite orbit, clock, code/phase bias corrections, and atmospheric corrections.
- Integrity monitoring of GNSS/INS integrated navigation based on multiple hypothesis solution separation.
- Development of autonomous integrity monitoring methods for multi-sensor integrated navigation under different collaborative modes.
- Data processing and statistical evaluation of integrity risk parameters like the priori fault probability.
- Integrity risk allocation framework construction among multiple potential risks which results in collaborative positioning failure.
- Integrity risk estimation, evaluation, and validation of collaborative positioning.
- Investigate the integrity of collaborative positioning for the liability-critical applications, including autonomous vehicles and precision ocean engineering.

Members

Liang Li (China); Chair
Liang Wang (China); Vice-Chair
Yiping Jiang (China-Hong Kong)
Yang Gao (Canada)
Fuxin Yang (China)
Kazuma Gunning (USA)
Chun Jia (China)
Mathieu Joerger (USA)
Liuqi Wang (China)
Mingqiang Xie (China)
Zhen Lyu (China)
Xin Li (China)

WG 4.1.2: Upcoming GNSS services for accuracy, reliability and resilience

Chair: Paolo Zoccarato (Italy)

Terms of Reference

By integrating advanced facilities and data processing directly into the system architecture, GNSS is starting to offer freely-available firsthand services to sustain user needs on accuracy, reliability and resilience in navigation. Examples of these services are the Galileo High Accuracy Service (HAS), in its initial phase since 24th January 2023, or the Galileo Open Service Navigation Message Authentication (OSNMA). These services, anticipating fundamental technological advancements in GNSS signals and infrastructures, are extending not only the consolidated GNSS capabilities but also the perimeter of the system support, providing reference algorithms, guidelines, and standards to be implemented by the users to achieve the service goals. This WG focuses on research targeting the adoption of these emerging real-time GNSS services to support geodetic applications, survey and monitoring (e.g. earthquake and tsunami events). The investigation aims to improve the performance and resilience of GNSS-based Position Navigation and Timing (PNT) solutions by extending algorithms and technologies and integrating alternative systems with the emerging GNSS services.

Objectives

- Promote algorithms, technologies and alternative systems for PNT to be integrated with the emerging GNSS services for improving performance and resilience in geodetic applications and monitoring.
- Identify geodesy applications in need of the emerging GNSS services and develop methodologies for their utilization (e.g. catastrophes/atmosphere/tsunami monitoring, Earth dynamics, climate change analysis).
- Propose recommendations for future developers and users of emerging GNSS services in geodetic applications.
- Evaluate and extend established real-time methodologies for PNT enhanced by emerging GNSS services to achieve accurate and reliable (including integrity of message) PNT solutions.
- Explore limitations on the guidelines and standards about the utilization of the emerging GNSS services and collect feedback, requests and ideas to be provided to the GNSS services for better sustaining/fitting the user needs in geodesy applications.
- Establish open processing campaigns and dataset sharing for testing and comparison of the identified solutions and dissemination of the results through the IAG community.

Members

Paolo Zoccarato (Italy); Chair
Ignacio Fernandez Hernandez (Spain)

Gianluca Caparra (Italy)
Sophie Damy (France)
Beatrice Mottella (Italy)
Nicola Laurenti (Italy)
Dimitrios Psychas (Greece)
Francesco Darugna (Italy)
Patrick Henkel (Germany)
Lotfi Massarweh (Netherlands)
André Hauschild (Germany)
Adria Rovira (Spain)
Urs Hugentobler (Germany)
Mirko Reguzzoni (Italy)

WG 4.1.3: LEO-PNT Systems

Chair: Fabricio S. Prol (Finland)
Vice-Chair: Elena Simona Lohan (Finland)

Terms of Reference

Given the current interest in deploying multiple satellites within low Earth orbit (LEO), the time is opportune to understand the advantageous implications of LEO-PNT missions for Geodesy. This WG is focused on understanding the possible enhancements that LEO-PNT systems can provide for navigation solutions when compared to classic GNSS systems. We aim to understand the contributions of communication, augmentation, and dedicated LEO satellite systems for PNT. To this end, new methods, instrumentation, and data analysis will be developed.

Objectives

- Advance instrumentation to collect data and perform PNT through LEO satellites;
- Development of algorithms to enable PNT solution based on current and upcoming LEO satellite missions;
- Explore limitations of the LEO-PNT systems and possible enhancements in comparison to GNSS;
- Propose recommendations for future developments in the field.

Members

Fabricio S. Prol (Finland); Chair
Elena Simona Lohan (Finland); Vice-Chair
Francesco Menzione (Italy)
Heidi-Kuusniemi (Finland)
Miguel Cordero Limon (Netherlands)
Lotfi Massarweh (Netherlands)
Jindrich Dunik (Czech Republic)
Mayank Mayank (Finland)
Miquel Garcia Fernandez (Spain)

WG 4.1.4: Low-Cost GNSS receiver systems

Chair: Dinesh Manandhar (Japan)
Vice-Chair: Bruno Nava (Italy)

Terms of Reference

This WG will focus on low-cost GNSS receiver systems for high-accuracy PNT and associated applications. We target receiver systems with cost of a few hundred dollars, which include all necessary components and are easy to use in the field without requiring expert knowledge. This type of system will further enhance capacity building, deployment of base-station, and new application development at a large scale. The team will collaborate closely with the United Nations Office for Outer Space Affairs (UNOOSA).

Objectives

- Explore different types of receivers, antennae, data processing devices, software, and other necessary tools for high-accuracy PNT and associated applications for GNSS augmentation, such as space weather (TEC, S4 computation), EWS (Early Warning System) message, and signal authentication;
- Design and develop prototype receiver systems for base-station and rover units;
- Evaluate existing software and customize for low-cost receiver system;
- Promote the discussion of the future perspectives of low-cost receiver developments.

Members

Dinesh Manandhar (Japan); Chair
Bruno Nava (Italy); Vice-Chair
Sharafat Gadimova (Austria)
Alison Moraes (Brazil)
Andrzej Krankowski (Poland)
Anindya Bose (India)
Kaito Kobayashi (Japan)
Avinab Malla (Nepal)
Eugenio Realini (Italy)
Ayman Mahrous (Egypt-Japan)
Jorge Del Rio Vera (Austria)
Roberto Capua (Italia)
Ayoub Ben-Adim (Morocco)

WG 4.1.5: Wireless positioning with terrestrial instruments

Chair: Andrea Masiero (Italy)
Vice-Chair: Kai-Wei Chiang (China-Taipei)

Terms of Reference

PNT systems had a remarkable impact on a number of applications, including a visible influence on the everyday life of most of the World population and causing an increasing interest in location based services (LBSs). Most of the PNT systems currently available on the market are satellite-based: they do exploit GNSS in order to assess their own position and to synchronize on a common time. Nevertheless, the usability of GNSS-based systems for accurate positioning is currently mostly limited to open-sky scenarios, whereas the performance of such systems dramatically decreases indoors, in urban canyons, and in the other GNSS-denied environments. Extending accurate localization to scenarios challenging for GNSS typically implies the use of additional sensors, including inertial ones, radio-based, cameras, LiDAR. The goal of this WG is to investigate the contribution of radio-based positioning with terrestrial instruments in applications where GNSS is not available or not reliable, including outdoor-to-indoor (and vice versa) transitions. Such investigation aims at exploiting in particular the interconnection between smart devices, which, also thanks to the spread of technologies such as 5G, is expected to become increasingly common for most of the devices provided with positioning tools available in the market in the near future. WiFi solution will take advantage of the RTT (round-trip-time) measurements, recently available on several devices on the market. In addition to WiFi, the WG will investigate the use of radio transceivers in general, such as Bluetooth and UWB, as standalone or integrated solutions, involving for instance also vision and LiDAR. The goal is to improve the overall positioning performance of the system, focusing on the potential of device interconnection, leading to collaborative solutions, which can be particularly useful to enable positioning in devices working in critical conditions (e.g. not fully provided of sensors, and/or when the radio-based positioning system is associated to a low density infrastructure of anchors of known position). In such investigation several navigation platforms will be considered, including smartphones, drones and ground vehicles.

Objectives

- Development of algorithms for positioning based of WiFi, focusing in particular on the evaluation of RTT-based solutions;
- Development of algorithms for positioning with radio-based solutions, exploiting sensors currently mounted on smart devices such as WiFi, Bluetooth, UWB;
- Explore collaborative positioning strategies, reporting on the selection of best algorithms in terms of performance and to ensure scalability of the proposed approach;
- Assessment of the performance of WiFi and other radio-based methods once integrated with other sensors;
- Establishing links between this WG and other IAG, FIG and ISPRS WGs addressing the positioning problem with alternative sensors with respect to GNSS.

Members

Andrea Masiero (Italy); Chair
Kai-Wei Chiang (China-Taipei); Vice-Chair

Charles Toth (USA)
Vassilis Gikas (Greece)
Harris Perakis (Greece)
Salil Goel (India)
Jelena Gabela (Austria)
Paolo Dabove (Italy)
Vincenzo Di Pietra (Italy)
Wioleta Blaszczak-Bak (Poland)
Czeslaw Suchocki (Poland)

WG 4.1.6: Smart Wearable Positioning

Chair: You Li (China)
Vice-Chair: Baoding Zhou (China)

Terms of Reference

Smart wearable devices have been applied in Earth observation, smart cities, internet-of-things (IoT), mobile healthcare, public security, augmented reality/virtual reality, and other fields. They have become important platforms for human-computer interaction, environmental perception, life, and entertainment. Based on the integrated sign, movement, computing, communication, and other sensor chips in wearable devices, it is expected to greatly expand human perception and cognitive ability, accurately locate and perceive personalized and unstructured data of different users, coordinate the relationship between people and the environment, and even change the lifestyle of modern people. The popularity of wearable platforms also brings new opportunities and challenges for the realization of intelligent, ubiquitous navigation and space-time services.

Objectives

- Scalable and intelligent wearable positioning and motion-tracking sensors, algorithms, and systems;
- Smart human-computer interaction and human-in-the-loop motion and environmental perception;
- Self-improving and adaptive wearable navigation systems;
- The combination of intelligent wearable devices, artificial intelligence and robots;
- Geo-centric cloud/edge computing with wearable data;
- Wearable motion sensing for the smart city, smart home and smart transportation;
- Application of smart wearable motion sensing in IoT, mobile healthcare, public security, AR/VR, and other fields;
- Precise positioning and mobile mapping with sensors in capsule robots.

Members

You Li (China); Chair
Baoding Zhou (China); Vice-Chair

Xin Xia (USA)
Wei Liu (USA)
Yiran Luo (Canada)
Fuqiang Gu (China)
Weisong Wen (China-Hong Kong)
Zengke Li (China)
Chi Chen (China)
Shengjun Tang (China)
Jianping Li (Singapore)
Zhouzheng Gao (China)
Bing Wang (China-Hong Kong)

JSG 4.1.7: Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)

(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)
Vice-Chair: Jelena Gabela (Austria)

Terms of Reference

PNT stands as an essential utility of modern society, spanning across sectors such as defense, disaster management, finance, telecommunications, agriculture, and energy. The precise determination of absolute location, a cornerstone of PNT, traditionally relies on GNSS and their timing signals. However, a paradigm shift is underway, powered by compact quantum sensors. Leveraging the principles of quantum physics, these sensors encompass a wide range of functionalities, including ultra-precise atomic clocks, accelerometers, gyroscopes, magnetometers, and gravitometers. Their emergence heralds a transformative era in PNT, promising unparalleled precision and resilience, particularly in GNSS-denied environments. This imminent revolution necessitates a comprehensive exploration of quantum sensors' capabilities and their potential impact on PNT.

Objectives

- Quantum Sensor Assessment: Conduct a thorough evaluation of the performance, precision, and resilience of next-generation quantum sensors, dissecting their individual capabilities, limitations, and real-world applications.
- Quantum Sensors in GNSS-Challenged Environments: Investigate the suitability and robustness of quantum sensors for PNT applications in GNSS-deprived or compromised environments, addressing the challenges of signal degradation and signal loss.
- Interplay of Quantum Sensing Technologies: Explore the interplay and synergy among different quantum sensing technologies, such as atomic clocks, accelerometers, gyroscopes, magnetometers, and gravitometers, elucidating their combined potential for enhancing PNT.

- Recent Advances in Quantum Sensing: Analyze recent advancements in quantum sensor development, providing insights into cutting-edge research, technological breakthroughs, and potential cross-disciplinary applications.
- Anticipating Future Quantum Sensor Developments: Predict and anticipate future developments in quantum sensor technology, assessing their potential impact on PNT and emerging use cases, including quantum communication and quantum computing.
- Integration Strategies: Develop strategies and recommendations for the seamless integration of next-generation quantum sensors into existing and evolving PNT infrastructures, considering compatibility, inter-operability, and standards.
- Technical Report and Knowledge Dissemination: Summarize research findings, recommendations, and best practices in a comprehensive technical report, facilitating knowledge dissemination within the scientific and engineering communities.
- Scientific Publications: Explore opportunities for scientific publications to share research outcomes and insights with a broader scientific audience, contributing to the advancement of quantum sensor technology and its applications.

SC 4.2: Multi-frequency Multi-constellation GNSS

Chair: Jianghui Geng (China)
Vice-Chair: Panagiotis Psimoulis (UK)
Secretary: Kunlun Zhang (China)

Terms of Reference

The GNSS has witnessed rapid development in recent years, providing increasingly refined PNT services worldwide. The construction of multi-constellations and the utilization of multi-frequency have expanded the spatial coverage, catering to the diverse application requirements across various scenarios and levels. These applications encompass autonomous driving, instantaneous high-precision positioning, precise time and frequency transfer, as well as meteorological disaster monitoring and early warning, highlighting the immense potential of GNSS. Furthermore, GNSS chips integrated into consumer devices are progressively supporting multi-system and multi-frequency carrier phase observations, presenting extensive prospects for application.

However, these advancements have also introduced new technological challenges. For instance, GNSS positioning performance is vulnerable to fragility, the issue of ambiguity resolution remains persistently challenging, and consumer device data often suffers from significant degradation. SC 4.2 aims to facilitate research activities and focuses on addressing multi-level application issues, including high-precision global time and frequency transfer, valid and reliable ambiguity resolution, high-accuracy positioning in consumer devices, and precise monitoring of meteorological disasters. SC 4.2 will coordinate various activities to provide both theoretical and practical solutions for engineering and scientific applications, thereby bridging the gaps in the application domain.

Objectives

The main objective of SC 4.2 is to facilitate collaborative research on innovative and diverse applications within the evolving landscape of GNSS, characterized by multiple systems and frequencies. It aims to promote the dissemination and translation of scientific research accomplishments and foster close cooperation among researchers, international organizations, and industry stakeholders.

Program of Activities

- Identify and investigate theoretical, methodological, and technological issues arising from the development of multi-constellation and multi-frequency systems;
- Promote and facilitate close collaboration among researchers, fostering knowledge exchange and cooperation;
- Organize international conferences and workshops to provide platforms for sharing research findings and advancements;
- Promote interdisciplinary scientific research and encourage the application of engineering solutions in various domains.

WG 4.2.1: Precise GNSS time and frequency transfer

Chair: Jiang Guo (Belgium)
Vice-Chair: Giulio Tagliaferro (France)

Terms of Reference

In the realm of precise time transfer, GNSS has played a pivotal role, enabling synchronization across the globe with remarkable accuracy. The commonly employed methods such as Common-View (CV)and Two-Way Time Transfer (TWTT) have been instrumental in achieving this, yet they come with certain limitations. CV and TWTT have significantly contributed to global time transfer, primarily by utilizing shared satellite observations. However, they heavily rely on a limited set of common-view satellites, which restricts their applicability in wide regions with obstructed satellite visibility.

Precise Point Positioning Ambiguity Resolution (PPP-AR) holds the key to independent global time transfer, free from the constraints of common-view satellites. By resolving ambiguities in GNSS signals, we empower precise time transfer without the need for synchronized satellite observations. This breakthrough enables us to disseminate time information seamlessly across the world, enhancing the accessibility and accuracy of time transfer. This WG will mainly work on the technique details of PPP-AR; it is dedicated to verifying the effects of related GNSS error sources to PPP-AR time and frequency transfer.

Objectives

- Combining multi-constellation GNSS (GPS/GLONASS/Galileo/BDS-3) as well as multi-frequency signals (L5/E6/B1C/B2a) for PPP-AR time /frequency transfer. To harness their combined capabilities to improve the reliability and availability of time transfer service.
- Decreasing the effects of multipath errors on short- and medium-term (tens of minutes to several hours) frequency stability by generating multipath mitigating or correcting products.
- Mitigating the long-term (more than one day) frequency stability limitations inherent in GNSS-based time and frequency transfer. Analyse the factors that are deteriorating the long-term stability of GNSS time links from the aspects of the error of precise satellite orbit and clock products, troposphere delay and the receiver-end phase hardware bias.
- Working for the method to precisely align the integer daily boundaries between the time links of two adjacent days originating from the discontinuities of satellite clock products. Most importantly, trying to mitigate the fractional day boundaries which cannot be aligned directly like integer ones.

Members

Jiang Guo (Belgium); Chair
Giulio Tagliaferro (France); Vice-Chair
Frédéric Meynadier (France)

Antoine Baudiquez (France)
Pascale Defraigne (Belgium)
Elisa Pinat (Belgium)
Bin Jian (Canada)
Xiaolong Mi (China)
Ahmed Elmaghraby (Germany)

WG 4.2.2: Advances and unification of PPP-AR

Chair: Marcus Franz Wareyka-Glaner (Austria)
Vice-Chair: Tomasz Hadaś (Poland)

Terms of Reference

GNSS enable a worldwide positioning and navigation service independent of time, location, and weather. Nowadays, multiple GNSS transmit various signals on 3+ frequencies, enabling innovative developments and techniques. Over the past decades, the principle of Precise Point Positioning (PPP) has proven itself as a substantial GNSS method. PPP is an absolute positioning method using complex observation models and relying on precise satellite orbits, clocks, and biases. Various analysis centers and agencies publicly provide such satellite products in real-time and post-processing with slightly different computation strategies. This circumstance provides some challenges for the PPP user because consistency is essential.

Nowadays, multiple PPP software packages, mostly publicly available, offer innovative approaches. Discussing and linking these advantages should benefit the whole PPP community. Typically, PPP achieves accuracies similar to relative positioning methods like Real-Time Kinematic (RTK) and offers several benefits in comparison (e.g., global corrections). However, the convergence time of PPP is still an issue limiting its application in real-time and time-critical applications. It must be reduced to way below one minute ("instantaneous convergence") to make PPP completely competitive with relative positioning methods. PPP with integer ambiguity fixing (PPP-AR) has proven to effectively reduce or even eliminate the convergence time. In particular, approaches besides the ionosphere-free linear combination based on 2+ frequencies are currently heavily investigated. Fully utilizing all current GNSS constellations and their signals on 3+ frequencies for PPP and ambiguity resolution is an ongoing topic.

Objectives

- To discuss effective methods for reducing the convergence time of PPP;
- To give a recommendation for defining PPP convergence and coordinate accuracy;
- To create an overview and comparison of satellite products and software packages enabling PPP-AR;
- To define test cases to compare different PPP algorithms and software packages;
- To disseminate the major findings through journal papers and conference proceedings.

Members

Marcus Franz Wareyka-Glaner (Austria); Chair
Tomasz Hadaś (Poland); Vice-Chair
Salih Alcay (Türkiye)
Berkay Bahadur (Türkiye)
Thomasz Hadas (Poland)
Kamil Kazmiersky (Poland)
Pan Li (China)
Massarweh Lotfi (Netherlands)
Naser Naciri (USA)
Sermet Ötgütcü (Türkiye)
Yuanxin Pan (Switzerland)
Guorui Xiao (China)
Qiyuan Zhang (China)

WG 4.2.3: Mass-market high-precision GNSS and applications

Chair: Guangcai Li (China)
Vice-Chair: Himanshu Sharma (Germany)

Terms of Reference

Mass-market GNSS chips embedded into consumer devices, such as smartphones, now offer broad support for multi-frequency and multi-constellation high-precision carrier phase observations. This advancement is opening up opportunities for them to be effectively utilized in high-precision positioning applications. Since Google announced the availability of GNSS raw measurements in the Android N operating system in 2016, there has been a proliferation of research on mass-market GNSS signal quality, positioning algorithms and applications. This emerging trend gives a glimpse of the potential for centimeter positioning using mass-market GNSS data. The achievement of such high-precision positioning will significantly improve the user navigation experience and facilitate the emergence of new location-based applications such as assisted driving and semi-professional tasks, and even become a favorable complement to geodetic grade receivers in geosciences applications. Nonetheless, attaining precise positioning in mass-market GNSS devices like smartphones remains a substantial challenge. These obstacles encompass severe multipath errors, frequent cycle slips, emerging phase biases, unknown antenna phase center offsets and variations, among others. Consequently, this WG is committed to confronting these issues and delving into their prospective applications in navigation, positioning, and selected geosciences fields.

Objectives

- To perform a thorough assessment of the quality of mass-market/smartphone GNSS signals, and identify and investigate anomalies present in the observation data;

- To develop innovative methods and techniques for mass-market/smartphone GNSS multipath mitigation;
- To estimate and calibrate the Phase Center Offset (PCO) and Phase Center Variation (PCV) parameters of mass-market/smartphone GNSS antennas;
- To devise robust ambiguity resolution methods and verification techniques tailored to the challenges posed by mass-market/smartphone GNSS data;
- To explore and implement the integration of mass-market GNSS data with inertial and visual sensors to enhance the availability and reliability of positioning solutions;
- To investigate and unlock the potential of mass-market GNSS applications across various domains, including navigation, positioning, meteorology and geological disaster monitoring.

Members

Guangcai Li (China); Chair
Himanshu Sharma (Germany); Vice-Chair
Umberto Robustelli (Italy)
Paolo Dabove (Italy)
Francesco Darugna (Germany)
Anja Hesselbarth (Germany)
Changsheng Cai (China)
Weikai Miao (China)
Robert Odolinski (New Zealand)
Xianlu Tao (China)
Marcin Uradzinski (Poland)
Lambert Wanninger (Germany)
Chenyu Xue (UK)
Farzaneh Zangenehnejad (Canada)
Yuanxin Pan (Switzerland)
Martin Hakansson (Sweden)
Roland Hohensinn (Switzerland)
Zhetao Zhang (China)
Zengke Li (China)

WG 4.2.4: Quality Control and Integrity Monitoring of Precise Positioning

Chair: Krzysztof Nowel (Poland)
Vice-Chair: Ahmed El-Mowafy (Australia)

Terms of Reference

GNSS are the prime source of precise position information for a variety of applications including intelligent transport systems, autonomous driving, precision agriculture, civil aviation drones, marine and deformation monitoring. For such applications,

the position information needs to be highly reliable; even small errors may have serious consequences like the loss of human lives, liability, and damage to infrastructure.

Any positioning platform, either based on standalone- or augmented-GNSS, is subject to a series of vulnerabilities, e.g. signal faults, interference, satellite orbital and clock biases, carrier phase cycle slips and wrong integer ambiguity resolution. All these can dramatically deteriorate the reliability and disruption of the positioning and timing solutions. As such, it is crucial to have proper quality control mechanisms in place for the timely detection of hazardous threats and faults. In addition, monitoring the integrity of the system is an essential part of this quality control procedure, to ensure that the resulting positioning errors are bounded by protection levels that are determined according to the application's allowable risk probability.

The components of a quality control and integrity monitoring procedure will vary depending on the positioning sensors in use, the positioning method, and the performance requirements. This will in turn raise the need for thorough research into factors contributing to the quality of a positioning platform as well as their interactions, so as to enable the development of optimal application-dependent quality control and integrity monitoring procedures.

Objectives

- To derive optimal statistical testing regimes, capable of detection and exclusion of multiple alternative fault hypotheses using the underlying positioning models;
- To develop integrity monitoring algorithms for precise positioning methods using carrier phase measurements such as RTK and PPP;
- To consider new elements in integrity monitoring of the augmented-GNSS positioning, for example, the involvement of LEO satellites;
- To disseminate the developed algorithms and numerical results through journal papers and conference proceedings.

Members

Krzysztof Nowel (Poland); Chair
Ahmed El-Mowafy (Australia); Vice-Chair
Kan Wang (China)
Amir Khodabandeh (Australia)
Nobuaki Kobu (Japan)
Ivandro Klein (Brazil)
Ling Yang (China)
Artur Fischer (Poland)
Anja Hesselbarth (Germany)
Safoora Zaminpardaz (Australia)
Sandra Verhagen (Netherlands)
Yang Gao (Canada)

WG 4.2.5: Multi-GNSS for Natural Hazards and Disaster Resiliency

Chair: Xiaoming Wang (China)
Vice-Chair: Haobo Li (Australia)

Terms of Reference

Climate change is resulting in heightened intensity and frequency of hazardous weather and climate extremes such as severe storm, drought, tropical cyclone, and flood. Numerous challenges, e.g., major gaps in the observing networks, continue to impede the provision of sound observations, effective early warning systems, as well as comprehensive climate and weather services. It is therefore imperative to improve our understanding of weather and climate systems and the ability to reduce detrimental impacts on current and future generations.

With the rapid development of multi-frequency multi-constellation GNSS and the explosion in new data streams and information, this WG focuses on improving the analysis of climate change process and the monitoring of weather and climate extremes by fully harnessing the potential and capabilities of the next-generation space/air/ground-based GNSS atmospheric sounding techniques, thereby constructing weather- and climate-resilient communities.

Objectives

- Collect multi-GNSS observations through international collaborations to create a long-term and homogeneous GNSS climate dataset.
- Enhance the performance of near real-time and real-time processing of multi-GNSS products suitable for rapid-update NWP and weather nowcasting.
- Assess the qualitative and quantitative contributions of multi-GNSS products to climate modeling; develop robust methods for the monitoring of climate change fingerprints, atmospheric circulation, e.g., atmospheric river, and the detection of climate extremes, e.g., ENSO and drought.
- Evaluate the qualitative and quantitative contributions of multi-GNSS products to NWP systems; enrich the data assimilation techniques to improve weather forecasts and the acquisition of atmospheric parameters and background fields; investigate miscellaneous statistical methods, e.g., AI-empowered models, for the nowcasting of weather extremes using multi-GNSS atmospheric products.
- Encourage the transfer of knowledge and expertise, the dissemination of data, software, and techniques regarding the aforementioned issues; stimulate cross-sectional collaboration for articulating climate action plans, facilitating risk-informed decision-making, and supporting sustainable development goals.

Members

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SC 4.3: Atmosphere Remote Sensing

Chair: Ningbo Wang (China)
Vice-Chair: Mainul Hoque (Germany)

Terms of Reference

The Earth's atmosphere can be structured into various layers depending on physical parameters such as temperature or charge state. From the geodetic point of view the atmosphere is nowadays not only a disturbing quantity which has to be corrected but also a target quantity, since almost all geodetic measurement techniques, such as GNSS, satellite altimetry, VLBI, SLR, DORIS and radio occultations, provide valuable information about the state and the dynamics within the atmosphere. One up-to-date challenge is to combine all these data efficiently to extract as much information as possible. Space weather events, gravity waves, natural hazards, climate change and autonomous driving are a few modern catchwords in this context.

For decades the International GNSS Service (IGS) is delivering high-precision tropospheric and ionospheric, i.e. atmospheric products. The Ionosphere Associated Analysis Centers (IAAC), for instance, provide routinely maps of the Vertical Total Electron Content (VTEC), i.e. the integral of the electron density along the height to correct measurements for ionospheric influences, usually disseminated to the user with latencies of days to weeks and based on post-processed observations and final orbits. Precise GNSS applications, however, such as autonomous driving or precision farming, require the use of high-precision and high-resolution atmospheric correction models in real-time. Thus, real-time modeling of the atmosphere is one of the key tasks of the SC 4.3.

Space weather and especially its impacts and risk are gaining more and more importance in politics and sciences, since our modern society is highly depending on space-borne techniques, e.g., for communication, navigation and positioning. Besides sounding the atmosphere and studying space weather effects by modern evaluation methods, the promising GNSS reflectometry technique (GNSS-R) is another research topic within the SC 4.3.

Objectives

- Studying and solving problems of atmosphere research for up-to-date applications such as autonomous driving.
- Bridging the gaps between modern geodetic observation techniques such as radio occultations or GNSS reflectometry, measurements from other scientific branches such as astrophysics and geophysics with the geodetic community.
- Exploring the synergies between geodesy and other scientific branches such as astrophysics and geophysics.
- Investigating ionosphere phenomena such as disturbances and scintillations.
- Supporting atmospheric prediction models based on the combination of data from different observation techniques and, sophisticated estimation procedures, e.g. machine learning.

- Improving precise positioning and navigation on the basis of new atmosphere models.
- Developing real- and near real-time techniques for atmosphere monitoring.

Program of Activities

- To promote research collaboration among geodetic groups and other branches worldwide dealing with atmosphere research and applications.
- To organize and/or participate in scientific and professional meetings (workshops, conference sessions, etc.).
- To maintain a web page concatenating the Sub-Commission's activities and reports.
- To encourage journal special issues on research, applications, and activities related to the topics of this Sub-Commission.
- Close cooperations with other entities of the IAG and GGOS.

JWG 4.3.1: Real-time ionosphere monitoring and modeling

(joint with IGS and GGOS)
Chair: Zishen Li (China)
Vice-Chair: Heng Yang (China)

Terms of Reference

This WG focuses on the methodology development for real-time ionosphere monitoring and modeling with the use of multiple space-geodetic observations during the upcoming maximum activity of solar cycle 25. This involves integrating ground-based ionospheric data from the multi-GNSS systems (e.g. GPS, Galileo and BeiDou), ionosonde measurements, as well as the spaceborne observations from altimetry, DORIS, GNSS Precise Orbit Determination (POD) and Radio Occultations (RO). Additionally, the in-situ observations, such as Langmuir Probe (LP), are also taken into account. The approaches for the retrieval of precise ionospheric parameters (e.g. Total Electron Content, electron density), generation of two-and/or three-dimensional ionosphere maps on regional and global scales, independent validation and combination of ionospheric information from different providers in real-time will be developed and analyzed. The dissemination of real-time ionospheric information following RTCM, 5G, satellite internet access or other standards will be discussed in support of both scientific researches and technological applications. Connections to IGS, iGMAS, IDS, IRI, NeQuick and other communities will also be involved for the possible establishment of sub-groups or experimental campaigns on real-time ionosphere monitoring.

Objectives

- Close connections to different scientific communities (e.g. IGS, iGMAS and IDS) for the coordination of RT/NRT ground-based, spaceborne, and in-situ measurements in support of real-time ionosphere monitoring.

- Assessment campaigns, e.g. every 6 months, of the performance of real-time ionosphere models/services subjected to different solar activity intensities, such as accuracy, availability and latency. This will allow to compare different approaches for real-time ionosphere modeling by considering the combination of multi-constellation observations with distinct characteristics (e.g. biases and time latencies).
- Development of methods for the NRT/RT independent assessment, utilizing direct ionospheric measurements from altimetry satellites like JASON-3, and alternative methods such as in-situ ionospheric measurements and DORIS observations.
- Share the IGS methods for combination of real-time global/regional real-time ionospheric information from different RT-IGS providers. The ionospheric analysis centers are welcome to consider the possibility of joining RT-IGS service.
- Discussions on the distribution of real-time ionospheric information within scientific and technological communities (e.g. target parameter, data format and time latency).
- Generation and dissemination of experimental two-and/or three-dimensional ionospheric information in support of real-time ionosphere monitoring and associated scientific applications.
- Possible joint sub-groups or experimental campaigns on real-time ionosphere monitoring in close scientific collaboration with IGS and IDS WGs, COSPAR, URSI, IRI and NeQuick WGs, among others.

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WG 4.3.2: Ionospheric state predictions and early warnings for space weather services

Chair: Murat Durmaz (Türkiye)
Vice-Chair: Marjolijn Adolfs (Germany)

Terms of Reference

Disturbances in the state of upper atmosphere especially in ionosphere may adversely affect power grids, navigation, information and communication infrastructures. As the technology advances space-based communication and internet services are becoming ubiquitous covering the entire civilization around the world. Even some natural processes on Earth such as earthquakes may have signatures in the ionospheric state. Providing timely predictions and early warnings on ionospheric state and dynamics can help protecting critical infrastructures. Thus, developing solutions for accurate and timely predictions of ionospheric state and generating early warnings is still an extremely important and challenging issue.

Remote sensing of ionospheric state utilizing GNSS during the last decades has resulted in an invaluable legacy of long-term ionospheric state estimates provided by different analysis centers. Ensemble model (IGS final maps) with a weighted average of each analysis center resulted in a realistic representation of daily ionosphere in terms of Total Electron Content (TEC). Besides, radio occultation (RO) technique using GNSS receivers on board of LEO satellites is another space-based method for sounding the atmosphere. In addition, radio beacon measurements from DORIS receivers onboard LEO satellites may also be used. Vertical sounding of atmosphere is possible with satellite altimetry (e.g., TOPEX-Poseidon, Jason 2 & 3 missions). On the other hand, various ground-based techniques such as vertical sounding (VS), Incoherent Scatter Radar (ISR), Very Low Frequency (VLF) or Radio Beacon (RB) provide additional remote sensing capabilities for different parts of the global ionosphere. Although the availability of these observations has enormously increased during the last decades, the global coverage is still not enough, especially over the oceans. Recent studies try to overcome the issue by filling the gaps in the observations/products with the help of machine learning (ML) and especially in deep learning (DL) techniques. In the meantime, various applications of ML and DL for space weather prediction have been reported in the literature.

In the development of successful ML and DL models applied in different disciplines maybe the most important driver is to establish challenging test cases and provide the necessary reference datasets. At the same time, metrics on the effectiveness of the models need to be well established and reflect the operational capability of the

predictions and early warnings. Establishing reference test cases and metrics results in a fair comparison on different models and drives the improvement of each model. In the previous four years a study has been conducted to compare various global vertical TEC (VTEC) predictions in an established test case. The initial findings suggest that ML and DL may provide better results for ionospheric state predictions both for short and long-term horizons. In addition, ensembles of these models may provide even more realistic results in terms of accuracy. With the developments in end-to-end DL methods and also hybrid methods real-time or near real-time raw data may be used directly in the prediction process, which may provide better accuracy and shorten response times.

Objectives

- Analyzing operational requirements for early warning and prediction of ionospheric state and establish metrics on accuracy assessment. Compile reference datasets on space weather parameters and electron density/content of ionosphere.
- Developing end-to-end and hybrid ML and DL models for timely and improved ionospheric state predictions as well as early warnings on ionospheric disturbances (including e.g., electron content, gradients, TID, density variations).
- Developing techniques utilizing ML and DL tools to improve the accuracy of existing historical archive of global and regional ionospheric products (Global Ionosphere Maps) by combining all existing unused space and ground-based measurements.
- Develop ML and DL techniques to distinguish space weather induced ionospheric anomalies from ionospheric signatures of Earth system processes such as earthquakes.

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WG 4.3.3: Analysis and prediction of ionospheric scintillations

Chair: Dmytro Vasylyev (Germany)
Vice-Chair: Rafał Sieradzki (Poland)

Terms of Reference

Trans-ionospheric radio signals of GNSS (GPS, GLONASS, GALILEO and BeiDou) may suffer from rapid and intensive fluctuations of their amplitude and phase caused by small-scale irregularities of the ionospheric plasma. Such disturbances occur frequently in the equatorial region during the evening hours due to plasma flow inversion or during geomagnetic storms in the polar region. This phenomenon is called radio scintillation and can strongly disturb or even disrupt the signal transmission. The main effects of scintillation on trans-ionospheric radio system are signal loss and phase cycle slips, causing difficulties in the signal lock of receivers. All GNSS signals are affected, but the influence of the small-scale irregularities is expected to differ since the signals are transmitted by different carrier frequencies and are constructed in different ways. Furthermore, the sensitivity of receivers to scintillation events differs between various GNSS receiver types and an advanced analysis using "bitgrabber" systems is needed to rate their vulnerability. In spite of the importance of irregular density variations for the science of the ionosphere and for space weather operations, no fully sufficient global model for such disturbances is available.

Objectives

- Understanding the climatology of ionospheric scintillations, namely, its variation with latitude, season, local time, magnetic activity and solar cycle.
- Investigation of the GNSS signal frequency and receiver impact on signal loss and phase cycle slips during scintillation events.
- Global modeling and forecasting of scintillations taking into account temporal and regional (polar and equatorial region) differences.
- Establishing parametric statistical models for scintillation occurrence on a global scale aiming at improvements in scintillation models and forecasting capabilities.

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WG 4.3.4: Indices for characterizing ionospheric perturbations

Chair: Grzegorz Nykiel (Poland)
Vice-Chair: Andres Cahuasqui (Germany)

Terms of Reference

Perturbations in the ionosphere have different physical background and thus different nature and temporal-spatial extent. Their occurrence significantly impacts radio signal propagation, such as in communications and GNSS. Therefore, the detection and characterization of ionospheric disturbances are of interest for scientific research and applications. One way to monitor perturbations is to use ionospheric indices, which provide a clear and consistently simple representation of the state of the ionosphere (usually in the form of a single value). Their use can be essential for maintaining the safety of systems and making appropriate decisions for customers. Despite much research in recent years, there are still numerous issues to be resolved. Within this WG, we want to focus on investigation of options how measurable ionospheric variables can effectively be utilized to get condensed information on the spatial and temporal behavior of the electron density distribution at local, regional, and global scales. Recommendations should be given how the perturbation degree of the ionosphere can be quantified by indices considering different geophysical conditions. This includes the development of corresponding scales and thresholds usable in space weather services.

Objectives

- Select suitable ionospheric variables in relation to the available database.
- Develop and standardize algorithms for calculating ionospheric indices. Define thresholds for separating regular ionosphere conditions from perturbed conditions.
- Develop index-related scale(s).
- Study and demonstrate the relevance of these indices for research and for mitigating ionospheric errors in modern radio systems.
- Validate the results by independent measurements.
- Demonstrate the utilization of indices by impact studies on applications like GNSS and remote sensing radars.
- Compare the applicability of different ionospheric indices (e.g., ROTI, GIX, SIDX) and determine which indices perform better in which geographic regions and geophysical conditions.

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Ningbo Wang (China)
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WG 4.3.5: Ionosphere and space weather monitoring using ground and spaceborne GNSS

Chair: Zhe (Jenny) Yang (China)
Vice-Chair: Yang Wang (USA)

Terms of Reference

This WG focuses on advancing the use of ground and spaceborne GNSS observations for the ionosphere and space weather monitoring. Our current observation and study of the ionosphere relies significantly on the total electron content (TEC) and scintillation measurements from ground GNSS networks. There are large data voids over the ocean and polar areas, where it is not feasible to deploy a (dense) network of GNSS receivers. Spaceborne GNSS measurements, such as from radio occultation and reflectometry, show good promise in filling the data gaps. Our major goals are to bridge the gaps between ground and spaceborne GNSS observation techniques and in the utilization of their measurements, to improve our capabilities of monitoring, nowcasting, and forecasting of ionospheric states and space weather impacts, and to obtain a more comprehensive understanding of the space environment and the physical processes by continuously observing and analyzing the ionospheric conditions and disturbances.

Objectives

- Developing data processing techniques and algorithms to enable the utilization of combined ground-based and satellite-based observations to obtain high-resolution monitoring of the ionospheric states.
- Assembling a comprehensive collection of historical data, spanning a substantial duration, for quantitative characterizations of space weather impacts on GNSS services with respect to variable ionospheric states (such as TEC or electron density gradients) and to support scientific studies of ionospheric responses to space weather activities.
- Assessing and quantifying the cascading impacts of space weather events, such as geomagnetic storms and radio blackouts, on the disruptions of GNSS signals and the degradation of positioning accuracy, for an enhanced understanding of the lead time in space weather forecasting.
- Developing algorithms to improve the nowcasting and forecasting capabilities for ionospheric disturbances at regional scales across the entire globe in response to geomagnetic storms, acknowledging their significant influence on the availability and accuracy of GNSS systems.

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JWG 4.3.6: Validation of ionospheric models for positioning applications

(joint with IGS)
Chair: Anna Krypiak-Gregorczyk (Poland)
Vice-Chair: Xiaodong Ren (China)

Terms of Reference

Global and regional ionospheric models are routinely used in Space Weather studies, but also in high-precision applications like e.g. GNSS positioning. There are currently many analysis centers and research groups providing operational and test ionospheric maps. The global ionospheric maps (GIMs) provided as an official product by the IGS Ionosphere Working Group (IIWG) are developed by performing a weighted mean of the various Analysis Centers (AC) VTEC maps. There are also important empirical models like the International Reference Ionosphere (IRI) or NeQuick that are based on statistical analysis of the results of measurements.

Reliable modeling of the ionospheric propagation errors is still one of the most challenging aspects of precise GNSS positioning and GNSS-based geodetic and geodynamic studies. However, IGS ACs and other groups use different mathematical models and estimation techniques resulting in different resolutions, accuracies and time delays of their products. Therefore, there is a need to compare and validate existing ionospheric models in order to better understand their performance and quality, and to foster the usage of ionospheric models in geosciences community.

Objectives

- Comparison of GNSS-derived ionospheric maps and empirical models;
- Validation of ionospheric models in precise GNSS positioning;
- Validation of existing and new ionospheric models for different geomagnetic activity levels;
- Development of new validation techniques.

Members

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JWG 4.3.7: Machine learning for the atmosphere

(joint with GGOS)
Chair: Yury Yasyukevich (Russia)
Vice-Chair: Venkata Ratnam D (India)

Terms of Reference

Machine learning (ML) techniques are becoming more and more popular in different fields of research. ML is used for different tasks: forecasting, classification, clustering, anomaly detection and others. Scientists use different ML algorithms to create models of the ionosphere and atmosphere, to reveal effects from different sources, and to cluster or classify the data. Today new ML-based ionospheric models appear regularly. However, there are almost no rules (in contrast to other ML fields) on how to compare the models, and how to describe a model and its code. That often prevents reproducing the results and undermines the ML reliability. Open science would assist significantly in overcoming some of such problems. Within this WG, we will focus on how to provide reproducable ML-based results and to benefit more from ML, and especially to find out which new fields of atmospheric physics could involve ML. Today, the atmospheric community does not reveal trends, benefits and shortcomings of different ML approaches for particular tasks. We suppose that ML (as quite a new technique) could assist in involving young scientists in the problems of atmosphere and ionosphere physics – promoting ML within the atmospheric and ionospheric community can also be a task of the WG.

Objectives

- Review the current state of ML applications for the ionosphere.
- Identify areas within atmospheric and ionospheric research which could benefit from ML algorithms.
- Initiate discussions to uncover potential pitfalls associated with the application of ML techniques in the above contexts.
- Develop and establish guidelines for the publication of source code and datasets in articles utilizing ML for atmospheric and ionospheric science. Demonstrate these guidelines through practical application in our articles.

- Formulate recommendations and prepare a dataset for the ionospheric ML-based model testing.
- Promote the adoption of ML approaches among young scientists through seminars, lectures, and dedicated conference sections.
- Perform experiments showing tangible benefits from ML for atmospheric and ionospheric studies.
- Organizing special issues dedicated to ML application in the ionosphere or atmosphere and actively reviewing corresponding papers to encourage dissemination of valuable research in this field.

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WG 4.3.8: Troposphere Modeling and Monitoring

Chair: Cuixian Lu (China)
Vice-Chair: Jonathan Jones (UK)

Terms of Reference

Advanced GNSS tropospheric products will contribute to resolving and understanding extreme weather, mitigating the negative impact of natural disasters. The main objective of this WG is to develop, optimize, and assess advanced GNSS tropospheric products, and exploit their full potential in troposphere monitoring, modeling, precise positioning, and numerical and non-numerical weather forecasting. The action aims to produce a variety of reliable real-time/post-processed GNSS tropospheric products by using the precise point positioning (PPP) method. It will foster a better understanding of the influence of atmospheric water vapor in different weather processes and systems and reduce uncertainties in weather predictions. Besides, multi-source water vapor information will be taken into account to enrich the tropospheric modeling and monitoring. Furthermore, the action will seek to leverage the power of data-driven methods to enhance the accuracy and reliability of the tropospheric delay models. Last, but not

least, investigating the contribution of applying the a priori tropospheric information to improving the GNSS precise positioning is also one of the focuses.

Objectives

- Develop and optimize advanced GNSS tropospheric products, such as zenith total delays, tropospheric horizontal gradients, slant total delays, water vapor maps, and other parameters.
- Assess the benefit of GNSS tropospheric products in monitoring and forecasting different weather processes and systems (extreme precipitation, convective storms, drought...) and exploit their full potential in initializing rapid-update NWP and nowcasting applications.
- Make full use of the current water vapor sensing systems to establish advanced tropospheric models for applications in both meteorology and geoscience.
- Develop enhanced global/regional/local tropospheric delay models by using machine learning or deep learning methods to fuse multi-source and multi-scale information.
- Explore the full potential of tropospheric delay models in enhancing GNSS precise positioning.
- Stimulate the development of application software for routine production.
- Setup a link to the potential users, review product format and requirements.

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WG 4.3.9: Observing convective and volcanic clouds with geodetic remote sensing techniques

Chair: Hugues Brenot (Belgium)
Vice-Chair: Riccardo Biondi (Italy)

Terms of Reference

All the regions of the neutral atmosphere of the Earth, from the equator to the pole, passing through temperate zones, show climate changes. The anthropogenic activity and the volcanic eruption are the two main identified sources that trigger such changes. Severe weather clouds (deep convection, intensive storms, severe precipitation, ice clouds, wet, cold and heat wave) are continuously increasing, causing destructive flooding, fatalities, material damages or drought situation. The occurrence of hazardous clouds (from volcanic eruption or from accidental or provoked industrial explosion) is also a consequent threat for the health of neighboring populations. Both convective and volcanic clouds represent a risk for the safety of aviation air traffic.

The main objective of this WG is to improve the detection and awareness of hazardous structures of the neutral atmosphere by looking at disruption or attenuation in the radio wave signals propagated by GNSS satellites and received by ground-based stations or by LEO satellites (radio-occultation). Case studies to better characterize the composition of convective and volcanic clouds but also nowcasting applications are required to detect, warn and mitigate the risk of extreme clouds.

To reach this objective, the synergy with other remote sensing techniques can bring consequent improvement in severe and hazardous clouds detection (case studies of extreme events but also near real-time situation). Measurements of the ground-deformation and the seismicity bring substantial information for understanding the mechanisms of an eruption and analyzing the composition of gas emissions and the structure of the volcanic plume. The detection and the awareness of extreme clouds requires a quantification of the atmospheric refractivity (benefits of the improvement in real-time troposphere monitoring conducted by WG 4.3.8) with the aim of 1) generating anomaly detection with respect to reference data; 2) using nowcasting system or potential assimilation in numerical meteorological models. The development of tropospheric parameters from multi-GNSS is critical to retrieve 3D-structure from tomography technique or to develop diagnostic tool from slant delays observations. Long-term time-series are essential for making references and anomaly detections of extreme clouds.

Objectives

Within the next four years, this WG on the detection of extreme clouds in the neutral atmosphere intends to develop nowcasting tools in synergy with other remote sensing techniques and to address current challenges in 3D-monitoring by focusing on GNSS tomography principles and synergic approach. Hereby, the main objectives are:

- Setting-up benchmark campaigns (convective and volcanic clouds) for studying the combination of ground-based multi-GNSS with radio-occultation and other observation techniques (e.g., InSAR);
- Synergic approach by using LEO hyperspectral sensors, GEO multispectral imagers and weather radar, combined with GNSS radio-occultations and measurements from GNSS ground-based network to characterize the 3D-structure of convective and volcanic clouds: retrievals of the composition, cloud height, thickness, and density;
- Improvement of GNSS tomography by decreasing the ill-conditioned and ill-posed system (e.g., novel iterative approach, machine learning technique);
- Development of nowcasting tool to detect convective and volcanic clouds;
- Investigation on ray-tracing approaches for the reconstruction of space-based observations using radiative transfer model.

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Chi. O. Ao (USA)
George Hajj (USA)
Kuo-Nung (Eric) Wang (USA)
Soyoung Ha (USA)
Kristine M. Larson (USA)

WG 4.3.10: Remote sensing using GNSS reflected signals

Chair: Milad Asgarimehr (Germany)
Vice-Chair: Maximilian Semmling (Germany)

Terms of Reference

GNSS Reflectometry represents an innovative remote sensing method using GNSS signals reflected off the Earth's surface to gain new insights into our environment and Earth system. This initiative aims to foster collaboration and propel research about diverse potential applications of reflectometry across atmosphere, ionosphere, land surfaces, and oceanic properties.

This WG seeks to facilitate joint endeavors focused on leveraging reflectometry data obtained from various platforms, including airborne, ground-based, and space-based systems. An emphasis will be placed on using information from recently deployed satellites like the ESA PRETTY mission and upcoming missions such as ESA HydroGNSS. The investigations have a broad spectrum, encompassing the physics behind observations, methodological advancements, and the steps to the geophysical application. These efforts aim to enhance the quality of observations and retrievals while broadening the spectrum of applications, leading to better understanding of the Earth system and climate change impacts.

Objectives

- Explore novel applications of reflectometry, particularly focusing on recent missions and new instruments. This includes estimation of sea surface height, total electron content, studying ionospheric disturbances, soil and vegetation moisture content and land climate parameters and hydrological processes, aligning with the objectives of missions like PRETTY and HydroGNSS.

- Enhance the quality of reflectometry products by advancing physical understanding or proposing innovative methodologies. This maintains synergy with the JSG "AI for GNSS Remote Sensing" of the GGOS focus area "AI for Geodesy".
- Identifying the potential of reflectometry for Earth system modeling such as properties like soil moisture, vegetation characteristics, ocean winds, sea surface height, ionospheric, and atmospheric conditions. This integration can occur through conventional methods like data assimilation or modern methods such as AI-driven approaches.
- Identify common objectives and synergies with related societies (e.g., IEEE Geoscience and Remote Sensing Society, GRSS) and collaborate with technological, engineering, and operational entities linked to GNSS (e.g., IGS).
- Host workshops, seminars, and training sessions to disseminate knowledge and raise awareness about reflectometry techniques among the scientific community and stakeholders.
- Foster international cooperation and the exchange of visiting scientists.

Members

Milad Asgarimehr (Germany); Chair
Maximilian Semmling (Germany); Vice-Chair
Adriano Camps (Spain)
Clara Chew (USA)
Andreas Dielacher (Austria)
Yusof Ghiasi (Canada)
Jyh-Ching Juang (China-Taipei)
Weiqiang Li (Spain)
Manuel Martin-Neira (Netherlands)
Mario Moreno (Germany)
Jade Morton (USA)
Hossein Nahavandchi (Norway)
Serge Reboul (France)
Minfeng Song (China)
Georges Stienne (France)
Jens Wickert (Germany)
Tianqi Xiao, (Germany)
Daixin Zhao (Germany)
Florian Zus (Germany)
Dongliang Guan (China)
Fan Gao (China)

SC 4.4: Engineering Geodesy

Chair: Janis Kaminskis (Latvia)
Vice-Chair: Eimuntas Parseliunas (Lithuania)

Terms of Reference

Engineering geodesy focuses on the capture, setting-out, and monitoring of local and regional geometry-related phenomena, emphasizing quality assessment, sensor systems, and reference frames. An engineering geodesist must possess advanced technical skills and be well-versed in the terminology of adjacent disciplines and related industries.

As an application-oriented science, engineering geodesy employs its own conceptual and methodological approaches. Initially defined by its applications in civil engineering, it is increasingly recognized as a discipline within an interdisciplinary field. The development and optimization of measurement concepts, setups, and data analysis strategies, considering both technical and non-technical criteria and employing theoretical-methodological as well as numerical simulation and optimization techniques, are among the core competencies of engineering geodesy.

This Sub-Commission intends to unite scientists, researchers, and professionals under the theme: "Engineering geodesy - continuous innovation in modern space and time". Looking forward, we anticipate that engineering geodesy will continue to evolve technically and creatively, leading to innovative developments and next-level technical achievements.

Objectives

- Surveying and field measurements.
- Setting-out is defined as the transfer of predetermined geometric dimensions from a planning model to the construction site.
- Monitoring based on data acquisition, observation, and supervision of natural and artificial systems.
- Geometry-related phenomena (to determine and model further spatial parameters).
- Quality assessment and management (quality of the measurements and analysis of results).
- Sensor technology and geodetic metrology.
- Reference systems (observation domain and coordinate domain).

Program of Activities

- To promote research collaboration among geodetic groups and other branches worldwide dealing with engineering geodesy.
- To organize and/or participate in scientific and professional meetings (workshops, conference sessions, etc.).
- To maintain a web page concatenating the Sub-Commission's activities and reports.

- To encourage journal special issues on research, applications, and activities related to the topics of this Sub-Commission.
- Close cooperations with other entities of the IAG and GGOS.

WG 4.4.1: Novel GNSS applications in engineering geodesy

Chair: Junbo Shi (China)
Vice-Chair: Li Zhang (Germany)

Terms of Reference

This WG focuses on the methodology development for novel GNSS applications in engineering geodesy. We intend to establish the theoretical framework of local engineering coordinate reference frame. We are also dedicated to exploring the maximum concurrency user volume of GNSS CORS network. We will optimize GNSS positioning methods to meet the demands of complex engineering projects, which are large in horizontal size and in height difference. Finally, we intend to provide a multi-modal, multi-scale, high-quality engineering geodetic dataset and support it by AI methods. Through our efforts, we aim to drive innovation and advancement in the field.

Objectives

- Establishing the theoretical framework for the transition from global ITRF coordinate reference frame to local engineering coordinate reference frame, as well as methods for the maintenance and updating of the local coordinate reference frame.
- Exploring the optimal division scheme for GNSS CORS virtual grids in engineering application scenarios with high-concurrency users.
- Optimizing GNSS high-precision positioning and projection methods for complex engineering projects with large height difference and long horizontal distance.
- Developing fine-grained signal separation methods for GNSS positioning coordinate sequences in ultra-large and ultra-high engineering projects.
- Constructing the multi-modal, multi-scale high-quality engineering geodetic dataset, and developing corresponding AI-enabled data mining and prediction methods.

Members

Junbo Shi (China); Chair
Li Zhang (Germany); Vice-Chair
Hongzhou Yang (Canada)
Chenhao Ouyang (China)

WG 4.4.2: InSAR engineering geodesy for infrastructure health monitoring

Chair: Liming Jiang (China)

Terms of Reference

Due to various geological issues and human activities, structural deformation is a serious threat to large-scale infrastructure safety, typically including bridges, airports, buildings, highways, railways, subways, dams, and heritage sites. As an imaging geodesy, Interferometric Synthetic Aperture Radar (InSAR) techniques have distinct advantages over other engineering methods for infrastructure deformation monitoring, with large-scale and noncontact monitoring capabilities, high spatial resolution and acceptable measurement accuracy. This WG focuses on InSAR theoretical methods, cut-edge algorithms, and new ground-based/UAV SAR instrument towards novel applications in engineering geodesy for infrastructure health monitoring.

Objectives

- To promote algorithms and technologies of InSAR geodesy for improving accuracy and robustness in monitoring surface deformation and infrastructure health.
- To develop new ground-based/UAV SAR instruments to be integrated with spaceborne InSAR measurements for performances and resilience in InSAR engineering geodetic applications and monitoring.
- To combine multidisciplinary knowledge (such as hydrology, geology, geotechniques, and meteorology), numerical models and emerging cutting-edge technologies (e.g. deep learning, 5G communication services) to develop early-warming decision-making systems to assist in the maintenance of urban infrastructures.
- To establish links with other WGs of SC 4.4 addressing the infrastructure health monitoring problem with other engineering geodetic sensors, such as GNSS, TLS.

Members

Liming Jiang (China); Chair
Peifeng Ma (China-Hong Kong)

WG 4.4.3: Multisensor Displacement and Deformation Monitoring

Chair: Maya Ilieva (Bulgaria)
Vice-Chair: Jan Kapłon (Poland)

Terms of Reference

This WG is dedicated to advancing the field of displacement and deformation monitoring by integrating various observation and computation techniques, exploiting new technologies, and developing effective strategies for monitoring the changes of Earth's surface, infrastructure and objects. On one hand, the challenges imposed in the integration of data from different sensors and measuring techniques are mostly related with the difference in the temporal and spatial resolution of the data coverage, format and coordinate frames. While, on the other hand, the combination of data acquired by satellite, aerial and terrestrial measurements also adds the scale variable for the

monitoring objects. Another still open question is the presentation of a proper weight frame for the data in the integrated models. This WG focusses on providing a scientific platform for discussion and seeking for solutions to the above-mentioned arguments. The WG is also adopting the fastly developing ML algorithms in multisensor data integration and 3D spatial analyses. The knowledge gained from the synthesis of distinctive data will strengthen the possibility of building comprehensive deformation monitoring systems and developing early-warning systems for strategic infrastructure and territories.

Objectives

- Propose strategy for integrated deformation monitoring systems.
- Evaluation of the mathematical modeling of multisensory observations.
- Explore the integration of measurement techniques for monitoring of non-linear deformation.
- Explore the new generation of space-borne radar and terrestrial sensors.
- Developing scenarios for displacement and deformation monitoring utilising the real-time and non real-time sources of multisensor data.
- Promote real-time and near-real time deformation monitoring using geodetic observation techniques, e.g. satellite, aerial and terrestrial.
- Study the displacement and deformation information for early warning systems.
- Explore new ML methods in displacement and deformation detection.

Members

Maya Ilieva (Bulgaria); Chair
Jan Kapłon (Poland); Vice-Chair
Jacek Paziewski (Poland)
Jacek Rapiński (Poland)

WG 4.4.4: TLS and LiDAR Scanning for Building Information Modelling (BIM) Services

Chair: Janina Zaczek-Peplinska (Poland)
Vice-Chair: Ales Marjetic (Slovenia)

Terms of Reference

In the construction investment process, there are several stages in which geodetic surveying and inventory measurements are necessary. They are necessary during the execution of construction works, installation of machinery and equipment, commissioning and trial operation of facilities, and inventory of the completed stage of work. Routine, cyclic observations related to the monitoring and analyzing of their geometry and technical condition are required for many construction, industrial, and technical infrastructure elements put into operation. For this purpose, satellite, aerial, and ground measurement technologies are used. Currently, LiDAR (Light Detection And Ranging) laser scanning techniques are gaining popularity. Laser scanners provide precise and

detailed data on measured objects. Thanks to their universal applicability, terrestrial laser scanners (TLS) are increasingly replacing and displacing other equipment and classical surveying techniques. Laser scanning is a measurement method in which the measured object's surface is sampled with a laser beam. Information about the position of points representing the object is collected during spatial measurement. In addition, data on the color and intensity of the reflection of the laser beam from the measured elements are recorded. The collected information can be used in many industries. Most often, the products of this technology are used to create digital documentation in the form of 2D drawings or 3D spatial models, to build databases about objects, BIM (Building Information Modeling) technology, or spatial information systems.

The goal of the WG will be to study and develop laser scanning techniques in the broad field of engineering surveying. The experience gathered will be aimed at, among other things: verifying the precision and accuracy of measurement of building structures, optimizing laser scanning techniques, building algorithms for conducting measurements, and processing data. The research will contribute to increasing efficiency in applying laser scanning techniques for BIM.

Objectives

- Development of BIM technology in rail transport;
- Development of BIM technology in the construction and monitoring of concrete dams;
- Application of TLS technology and LiDAR scanning in surveying engineering;
- Application of TLS technology for monitoring natural objects and engineering structures;
- Develop algorithms that optimize laser scanning techniques for higher accuracy in determining the geometry of building objects;
- Assessment of the possibility of using laser scanning techniques for diagnostic tests of building objects.

Members

Janina Zaczek-Peplinska (Poland); Chair
Ales Marjetic (Slovenia); Vice-Chair
Zbigniew Muszyński (Poland)
Michał Strach (Poland)
Maria Kowalska (Poland)

Inter-Commission Committee on Theory (ICCT)

https://doi.org/10.82507/iag-gh2024_icct

President: Mattia Crespi (Italy)
Vice President: Amir Khodabandeh (Australia)
Past President: Pavel Novák (Czech Republic)

ICCT website - www.icct.iag-aig.org

1 Terms of Reference

The Inter-Commission Committee on Theory (ICCT) was formally approved and established after the IUGG XXI Assembly in Sapporo, 2003, to succeed the former IAG Section IV on General Theory and Methodology and, more importantly, to interact actively and directly with other IAG entities, namely Commissions, Services, Projects and the Global Geodetic Observing System (GGOS). In accordance with the IAG by-laws, the first two 4-year periods were reviewed in 2011. IAG approved the continuation of ICCT at the IUGG XXIII Assembly in Melbourne, 2011. At the IUGG XXIV Assembly in Prague, 2015, ICCT became a permanent entity within the IAG structure.

Recognizing that observing systems in all branches of geodesy have advanced to such an extent that geodetic measurements
(i) are now of unprecedented accuracy and quality, can readily cover a region of any scale up to tens of thousands of kilometres, yield non-conventional data types, and can be provided continuously; and consequently,
(ii) demand advanced mathematical modelling in order to obtain the maximum benefit of such technological advance.

The ICCT:

1. strongly encourages frontier mathematical and physical research, directly motivated by geodetic need and practice, as a contribution to science and engineering in general and theoretical foundations of geodesy in particular;
2. provides the channel of communication amongst different IAG entities of commissions, services and projects on the ground of theory and methodology, and directly cooperates with and supports these entities in the topical work;
3. helps IAG in articulating mathematical and physical challenges of geodesy as a subject of science and in attracting young talents to geodesy. ICCT strives to attract and serve as home to all mathematically motivated and oriented geodesists as well as to applied mathematicians; and
4. encourages closer research ties with and gets directly involved in relevant areas of Earth sciences, bearing in mind that geodesy has always been playing an important role in understanding the physics of the Earth.

1.1 Objectives

The overall objectives of the ICCT are:

- to act as international focus of theoretical geodesy,
- to encourage and initiate activities to advance geodetic theory in all branches of geodesy,
- to monitor developments in geodetic methodology.

To achieve the objectives, the ICCT interacts and collaborates with other IAG entities (Commissions, Services, GGOS, other ICCs, Projects).

1.2 Program of Activities

The ICCT's program of activities include:

- participation as (co-)conveners of geodesy sessions at major conferences, such as IAG Assemblies, EGU General Assemblies and AGU Meetings,
- organization of Hotine-Marussi Symposia,
- initiation of summer schools on theoretical geodesy,
- and maintaining a website (http://icct.iag-aig.org) for dissemination of ICCT related information.

1.3 Structure

The structure of Inter-Commission Committees (ICCs) is specified in the IAG by-laws. The ICCT Steering Committee consists of the President, Vice President, Past President, representatives from each of the IAG Commissions, Services, GGOS, other ICCs (ICCC, ICCM), Projects (QuGe), Early Career Scientists (ECSs) and two Members-at-Large. ICCT activities are undertaken by Joint Study Groups (JSGs), affiliated to two or more IAG entities.

1.4 Steering Committee

The Steering Committee will usually meet once per year.

- President: Mattia Crespi (Italy)
- Vice President: Amir Khodabandeh (Australia)
- Past President: Pavel Novák (Czech Republic)

Representatives of IAG entities

- Commission 1: Paul Rebischung (France)
- Commission 2: Robert Tenzer (China-Hong Kong)
- Commission 3: Janusz Bogusz (Poland)
- Commission 4: Katarzyna Stępniak (Poland)
- Services - IGFS: Riccardo Barzaghi (Italy)
- Services - IERS: Geoffrey Blewitt (USA)
- GGOS: Michael Schmidt (Germany)

- ICCC: Marius Schlaack (Germany)
- ICCM: Shun-ichi Watanabe (Japan)
- QuGe: Jakob Flury (Germany)

Members-at-Large

- Laura Fernandez (Argentina)
- Yap Loudi (Cameroon)

Representative of Early Career Scientists

- Michela Ravanelli (Italy)

1.5 Overview of Joint Study Groups

Hereafter, the ICCT Joint Study Groups (JSGs) for the 2023-2027 period are listed, together their Chairs (and Vice-Chairs, for some of them) and their affiliations with other IAG entities.

JSG T.38 Exploring the similarities and dissimilarities among different geoid/quasi-geoid modelling techniques in view of cm-precise and cm-accurate geoid/quasigeoid
Chair: Ropesh Goyal (India)
Vice-Chair: Sten Claessens (Australia)
Affiliations: Commission 2, IGFS

JSG T.39 Gravitational field modelling and analysis for oblate and prolate planetary bodies
Chair: Michal Šprlák (Czech Republic)
Affiliations: Commission 2, ICGEM

JSG T.40 Modelling the gravity field of irregularly shaped celestial bodies
Chair: Zhi Yin (China)
Affiliations: Commissions 1,2, IGFS

JSG T.41 Geodetic quality/integrity modelling, monitoring and design
Chair: Safoora Zaminpardaz (Australia)
Affiliations: Commissions 1,2,3,4

JSG T.42 Theoretical developments and applications of combined methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics
Chair: Robert Tenzer (China-Hong Kong)
Affiliations: Commissions 2,3

JSG T.43 Statistical methods in regional gravity field modelling
Chair: Mehdi Eshagh (Czech Republic)
Affiliations: Commissions 1,2, IGFS

JSG T.44 Atmospheric coupling studies
Chair: Andres Calabia Aibar (Spain)
Vice-Chair: Binod Adhikari (Nepal)
Affiliations: Commission 4, GGOS (GSWR)

JSG T.45 Dynamic gravity modelling of given distributions
Chair: Dimitrios Tsoulis (Greece)
Affiliations: Commissions 2,3

JSG T.46 Deformation, rotation and gravity field modeling for Earth and space
Chair: Yoshiyuki Tanaka (Japan)
Affiliations: Commissions 2,3

JSG T.47 Height datum: Definition, New Concepts, and Standardization
Chair: Xiaopeng Li (USA)
Vice-Chair: Marcelo Santos (Canada)
Affiliations: Commission 2, IGFS

JSG T.48 Theoretical Foundations of Machine and Deep Learning in Geodesy
Chair: Lotfi Massarweh (The Netherlands)
Vice-chair: Mostafa Kiani Shahvandi (Switzerland)
Affiliations: Commissions 2,3,4, GGOS (AI4G)

JSG T.49 High-resolution probing of the troposphere and ionosphere
Chair: Michela Ravanelli (Italy)
Affiliations: Commission 4, GGOS (Geohazards Monitoring, GSWR)

JSG T.50 High-precision GNSS theory and algorithms
Chair: Dimitrios Psychas (The Netherlands)
Affiliations: Commissions 1,4

2 Joint Study Groups

JSG T.38: Exploring the similarities and dissimilarities among different geoid/quasigeoid modelling techniques in view of cm-precise and cm-accurate geoid/quasigeoid

Chair: Ropesh Goyal (India)
Vice-Chair: Sten Claessens (Australia)
Affiliations: Commission 2, IGFS

Terms of Reference

It is over 170 years since George Gabriel Stokes published his seminal formula for geoid determination using gravity anomalies. The formula was derived in spherical approximation and is valid under some well-known assumptions. Since then, geoid modelling has revolved more or less around handling these assumptions. As a result, there are now various geoid and quasigeoid computation methods of both types, i.e., methods with and without requiring the Stokes integration. However, despite this long-elapsed time, the determination of a cm-precise and/or cm-accurate geoid and quasigeoid remains an ongoing quest, although it has been achieved in a few studies.

With the computation of cm-precise and/or cm-accurate geoid, a supposition can be formed that solutions from different geoid modelling methods should converge within a given threshold, with an ideal threshold value being one-cm. The rationale is that, for a region, all the methods can be used to calculate the geoid using the same data and underlying theory. Still, methods differ primarily due to different handling of the data, and assumptions and approximations. Different methods provide different solutions due to many aspects including but not limited to: 1. different modifications

of Stokes's kernel, 2. different prediction/interpolation/extrapolation methods for non-Stokes integrating geoid modelling methods, 3. use of geodetic versus geocentric coordinates, 4. different Global Geopotential Models, 5. different gridding and merging techniques, 6. different parameter sweeps (integration radius and kernel modification degree), and 7. different handling of topography, atmosphere, spherical approximation, and downward continuation.

Given these possible sources for differences in geoid models, it becomes inevitable to first create a rigorous definition of a "cm-precise" and "cm-accurate" geoid followed by a comparative study of intermediate steps of different geoid modelling methods, in addition to comparing only the final results from different methods separately. Comparative study of intermediate steps is essential given the fact that if using the same datasets in different methods, it is expected to have geoid differences less than one cm when the methods are designed to take into account all effects greater than one cm.

Further, in view of cm-precise and/or cm-accurate geoid, it is important to compare multiple methods and parameter sweeps in different areas. This is because it would form an ideal strategy for a consistently precise/accurate geoid model. The difference between the precise geoid and consistently precise geoid is that the precision, in the latter, should be preserved when a geoid model is validated region-wise in addition to the validation with the complete ground truth. Otherwise, cm-precise geoid may have limited meaning.

Objectives

- Develop a statistical definition of cm-precise and cm-accurate geoid/quasi-geoid.
- Study and quantify the differences in handling the topography, atmosphere, ellipsoidal correction, and downward continuation in different geoid/quasigeoid modelling methods.
- Study, quantify and reduce the assumptions and approximations in different geoid modelling methods to attain congruency within some threshold.
- Study the requirement for merging various components/steps of different geoid modelling methods.
- Develop external validation techniques to determine region- or nationwide consistency in precision and accuracy of developed geoid/quasigeoid models.

Program of Activities

- Presenting research findings at major international geodetic conferences, meetings, and workshops.
- Preparation of joint publications with JSG members.
- Organizing a session at the Hotine-Marussi Symposium 2026.
- Organizing splinter meetings at major international conferences and a series of online workshop.
- Supporting and cooperating with IAG commissions, services, and other study and working groups on gravity modelling and height systems.

Members

Ropesh Goyal (India); Chair
Sten Claessens (Australia); Vice-Chair
Ismael Foroughi (Canada)
Jonas Ågren (Sweden)
Xiaopeng Li (USA)
Bihter Erol (Turkey)
Jack McCubbine (Australia)
Pavel Novák (Czech Republic)
Koji Matsuo (Japan)
Riccardo Barzaghi (Italy)
Michal Šprlák (Czech Republic)
Jianliang Huang (Canada)
Yan-Ming Wang (USA)
Cheinway Hwang (China-Taipei)
Neda Darbeheshti (Australia)

Associate Members

Jack McCubbine (Australia)

JSG T.39: Gravitational field modelling and analysis for oblate and prolate planetary bodies

Chair: Michal Šprlák (Czech Republic)
Affiliations: Commission 2, ICGEM

Terms of Reference

Gravitation belongs to the four known fundamental physical interactions and represents a crucial quantity reflecting the state of attracting masses. Its knowledge stands at the core of important applications, e.g., 1) establishing planetary reference systems for positioning and predicting orbits of artificial satellites in geodesy; 2) studying inner structures, (sub-)surface processes, and thermal evolutions of planetary bodies in geophysics and planetary sciences; 3) detecting mass transport for understanding climate change and mechanisms of natural hazards in environmental sciences; or 4) navigating terrestrial or space vehicles in transport, military and space exploration. In general, gravitation is indispensable for advancing science, industry, and research; and for addressing a broad range of societal issues, such as sustainable energy, environmental aspects, or infrastructure development.

The science of determining gravitational fields at macroscales is called physical geodesy. This intriguing subject has been an inherent component of the International Association of Geodesy (IAG) and is officially considered one of main pillars of the modern geodetic research. The current status of physical geodesy may even be understated as countless scientists take numerous key products, i.e., static and time-variable gravitational fields, for granted and access them freely from IAG international services,

e.g., the International Centre for Global Earth Models (ICGEM), International Gravimetric Bureau, International Gravity Field Service and International Service for the Geoid, as well as from ESA's Planetary Science Archive or NASA's Planetary Data System Geoscience Node.

The international services and their products originate from an intricate modelling. This non-trivial process essentially combines these three key components:

- Experimental data are geometric, gravitational, and auxiliary measurements collected by various sensors. For the Earth, these data originate from an ultimate infrastructure of the IAG called the Global Geodetic Observing System.
- Methodology is the underlying mathematical apparatus. Physical geodesy employs potential theory by studying and advancing boundary-value problems (BVPs), integral transformations and equations, and forward modelling of potential fields. Alternatively, statistical methods, e.g., the least-squares collocation, have been developed.
- Computational tools are elements of discrete mathematics and computer science, e.g., numerical methods and algorithms, software, and hardware.

The standard conceptual framework for the gravitational field determination by potential theory often relies on spherical approximation. Nevertheless, as proved by the expeditions of the French Academy of Sciences to South America and Lapland already in the 18th century, Earth's shape is much closer to a rotational ellipsoid flattened at the poles (flattening $\approx 1/298$). Contemporary investigations of solar system planetary bodies have revealed that many resemble prolate or oblate ellipsoids with many of them flattened more significantly than the Earth. Four such spheroidal bodies have recently been of an immense research interest: 1) Mars (flattening $\approx 1/170$) being intensely explored by satellite and lander missions as it represents a potential target for future colonisation, 2) the asteroid Bennu (flattening $\approx 1/8.5$) explored by the sample-return satellite mission OSIRIS-REx, 3) the dwarf planet Ceres (flattening $\approx 1/13.4$), and 4) the asteroid Vesta (flattening $\approx 1/5.7$), both explored by the satellite mission Dawn. In addition, several comets and asteroids with spheroidal (ellipsoidal) shapes have been subject to an intense small body research. Thus, there is an urgent need for formulating a modern conceptual framework for the gravitational field determination.

Objectives

- To complete the class of spheroidal integral transformations relating various types of gravitational data.
- To derive the mathematical theory for the spheroidal forward modelling in the spatial and in the spectral domain.
- To propose a rigorous method for estimating surface mass variations for flattened planetary bodies.
- To develop efficient and accurate software tools for the spheroidal gravitational field modelling.

Program of Activities

- To cooperate with related IAG entities (Commission 2, ICGEM).

- To present research findings at geodetic and geophysical conferences.
- To monitor research activities of JSG members and of other scientists, whose research interests are related to the scopes of JSG.
- To organise a session at Hotine-Marussi Symposium 2026.

Members

Michal Šprlák (Czech Republic); Chair
Blažej Bucha (Slovakia)
Sten Claessens (Australia)
Mehdi Eshagh (Sweden)
Khosro Ghobadi-Far (USA)
Elmas Sinem Ince van der Wal (Germany)
Martina Idžanović (Norway)
Pavel Novák (Czech Republic)
Vegard Ophaug (Norway)
Georgios Panou (Greece)
Martin Pitoňák (Czech Republic)
Mahdiyeh Razeghi (Australia)
Natthachet Tangdamrongsub (Thailand)

JSG T.40: Modelling the gravity field of irregularly shaped celestial bodies

Chair: Zhi Yin (China)
Affiliations: Commissions 1,2, IGFS

Terms of Reference

Deep space exploration missions such as the past (e.g., ROSETTA and Hayabusa), present (e.g. OSIRIS-REx) and planned missions (e.g., HERA, Psyche, MMX, and Chang'e-2) will significantly change the way how we understand and utilize the solar system. In deep space exploration activities, the modelling of the targeted extraterrestrial bodies' gravity fields is an important work. However, unlike the sphere-like Earth, small solar system bodies like asteroids and comets are usually irregularly shaped in geometry, making the so-called complex-boundary value problems (CBVPs) of them more challenging than the geodetic boundary value problem (GBVP) of the Earth. For instance, the divergence problem of the spherical harmonic expansion in the CBVP is more complicated than that in the GBVP. To some extent, the small solar system bodies' CBVPs can be treated as extreme cases of the Earth's GBVP, and theories and methods for solving the CBVP can be applied to the GBVP in a downwardly compatible way.

One aim of this JSG is to investigate, develop and verify new theories and methods on solving the irregularly shaped celestial bodies' CBVPs. It mainly focuses on the potential flow theory regarding a gravitational vector field as an equivalent potential-flow velocity field. In this way, the gravitational vector field is mapped onto a potential-flow

velocity field, and the CBVP is able to be made amenable to off-the-shelf computational fluid dynamics (CFD) techniques. The other aim of this JSG is to investigate fast-computing integration techniques for modelling irregularly shaped celestial bodies' gravity fields in either spatial or frequency domain. It is an extension of the fast integration algorithms for the Earth's gravity field, allowing efficient assessments on the asteroids' or comets' gravity field solutions derived from the potential flow theory.

This JSG is open to the investigation on the highly nonlinear structure of an irregularly shaped celestial body's gravity field, in terms of equipotential surfaces, plumb lines or gravity tensors. It is also open to the research of irregularly shaped celestial bodies' surface environment simulations based on their gravity field models, such as the deep-space data processing, the gravity field visualization, the height system definition, the geophysical analysis, etc.

Objectives

- Develop and study new CBVP-solving theories and methods for modelling irregularly shaped celestial bodies' gravity fields.
- Investigate the innovative gravity field modelling approaches based on the potential flow theory and the numerical computation techniques.
- Develop fast-computing algorithms as well as parallel computation techniques for integrating an irregularly shaped celestial body's gravity field, in either space or frequency domain.
- Compare systematically the gravity fields calculated by CFD techniques and harmonic series expansions inside Brillouin surfaces.
- Investigate the highly nonlinear structure of an irregularly shaped celestial body's gravity field, via equipotential surfaces, plumb lines or high-order gravity tensors, by using the above new gravity field modelling theories and methods.
- Investigate the interior structure like the density distribution of an irregularly shaped celestial body by analyzing its exterior gravity field model.
- Develop a web-based or stand-alone software for visualizing and analyzing an irregularly shaped celestial body's gravity field, based on the Geographic Information System (GIS) technology.

Program of Activities

- Presenting findings at international geodetic conferences, meetings and workshops.
- Organizing working meetings at international symposia.
- Organizing sessions at international meetings and workshops (EGU, AGU, IAG, Hotine-Marussi Symposium, etc.) as needed.
- Releasing a webpage or a stand-alone software for cataloguing, visualizing and analyzing the irregularly shaped celestial body's gravity field.

Members

Zhi Yin (China); Chair
Michal Šprlák (Czech Republic)
Biao Lu (Denmark)

Zuzana Minarechová (Slovakia)
Marek Macák (Slovakia)
Xiaole Deng (Germany)
Junsheng Liu (China)
Georgia Gavriilidou (Greece)
Yabo Duan (China)
Leyuan Wu (United Kingdom)
Blažej Bucha (Slovakia)
Qinglu Mu (China)
Dimitrios Tsoulis (Greece)
Kefei Zhang (China)
Nico Sneeuw (Germany)

JSG T.41: Geodetic quality/integrity modelling, monitoring and design

Chair: Safoora Zaminpardaz (Australia)
Affiliations: Commissions 1,2,3,4

Terms of Reference

Geodetic observations are essential for a variety of applications including positioning, surveying and mapping, deformation monitoring, establishing reference frames, modelling the Earth's gravitational field, and atmospheric studies. Although, often, there exist well-established mathematical models (null hypothesis) used to estimate application-dependent parameters based on these observations, geodetic data is subject to a series of vulnerabilities, which, if passed unnoticed, make the mathematical model misspecified, thus deteriorating the reliability of the estimation results. Therefore, it is crucial to implement quality control and integrity monitoring mechanisms to ensure that the results produced by the estimation process meet the requirements of the application at hand. This can be achieved through combining parameter estimation with a statistical testing procedure aimed at finding the most likely model misspecification (multiple alternative hypotheses).

In combining estimation with testing, the outcome of testing determines how the parameters of interest get estimated. Therefore, the estimator that is outputted by combined estimation-testing schemes will inherit the characteristics of both the estimation and testing process. However, the customary procedure followed in practice often does not consider the impact of testing on estimation, thus providing faulty quality descriptions. This highlights the need to conduct comprehensive research on the individual elements and their interplay that influence geodetic quality control and integrity monitoring, with the aim of facilitating the development of tailored quality control procedures that are optimal for specific applications.

Objectives

- Characterize the link between statistical testing and parameter estimation in geodetic data processing.

- Develop rigorous quality indicators for the output of combined estimation-testing schemes including confidence region, confidence level and integrity risk.
- Investigate challenges, posed by testing multiple alternative hypotheses of different dimensions.
- Design optimal estimation-testing schemes the output of which meets application-dependent requirements.
- Develop computationally-efficient algorithms for evaluating the quality of the output of combined estimation-testing schemes.
- Disseminate the developed algorithms and numerical results through journals and conference proceedings.

Program of Activities

- Presenting research findings at international geodetic conferences, meetings and workshops.
- Interacting with other IAG entities.
- Monitoring research activities of JSG members and other scientists whose research interests are related to scopes of this JSG.
- Organizing working meetings at international symposia.
- Organizing a session at the Hotine-Marussi Symposium 2026.

Members

Safoora Zaminpardaz (Australia); Chair
Jinling Wang (Australia)
Vinicius Francisco Rofatto (Brazil)
Krzysztof Nowel (Poland)
Cemal Özer Yiğit (Turkey)
Zhetao Zhang (China)
Ling Yang (China)
Carlos Fortuny Lombraña (Netherlands)
Christian Lisdat (Germany - QuGe representative)

JSG T.42: Theoretical developments and applications of combined methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics

Chair: Robert Tenzer (China-Hong Kong)
Affiliations: Commissions 2,3

Terms of Reference

The Earth's lithosphere is a rigid, outer layer of the Earth, consisting of the oceanic and continental parts. The origin, formation, and geological history of the oceanic and continental lithosphere differ significantly. Whereas a relatively homogenous structure of the oceanic lithosphere is mainly controlled by its thermal state and mantle flow

dynamics, the formation of a much more complex structure of the continental lithosphere involved early stages of the Earth's cooling, the supercontinent cycle associated with the global tectonics, and many other geological processes. The study of the lithospheric structure and dynamics is essential for several scientific, societal, and economic aspects including the mitigation of natural hazard, the exploration of natural resources and geothermal energy, and the understanding of its influence on the Earth's climate and environmental changes.

Seismic, gravity, magnetic, and heat flow data have mainly been used to investigate the Earth's lithospheric structure. Seismic tomography (especially surface waves) and seismic reflection and refraction experiments provide images of the Earth's inner structure, importantly of density interfaces (such as the sediment basements, crust-mantle boundary (commonly called Moho), and lithosphere-asthenosphere boundary). Seismic velocities could also be inverted for density and temperature, and seismic attenuation and seismic anisotropy are correlated with temperature and strain, respectively. Global heat flow measurements help constrain the lithospheric geothermal gradient and the Earth's energy budget. Magneto-telluric studies image the Earth's electrical conductivity. Gravity field manifests the Earth's density structure and this information is used in studies of isostasy, lithospheric stresses, basement morphology, seafloor relief, or lithospheric elastic thickness.

Over the last few decades, the amount of these geophysical and geodetic data increased exponentially. Gravity dedicated satellite missions, for example, provide the information about the Earth's gravitational field and its changes globally with a relatively high accuracy and resolution. The satellite altimetry measurements provide information about the sea level topography and have been used to determine marine gravity data that are further used to predict the seafloor relief. The Global Navigation Satellite Systems (GNSS) together with the Interferometric Synthetic Aperture Radar (InSAR) techniques have been essential in monitoring tectonic motions, ground deformations, and changes in glacier cover. The Very Long Baseline Interferometry (VLBI) and other space geodetic techniques have been providing extremely accurate information on the tectonic motions and the parameters of the Earth's rotation and orientation, defined by the Earth's orientation parameters (EOPs), namely the polar motion, precision-nutation, universal time (UT1), and the length of day.

The substantial achievement in improved quality and increased amount of geophysical and geodetic data allows us to better understand the Earth's lithospheric structure and dynamics as well as its relationship with other geoscientific studies (such as the relationship between the tectonic configuration and the oceanic-atmospheric circulation). Until now several theoretical models and methodologies have been developed and practically applied in modelling and prediction of various geophysical, geological, geochemical, and environmental phenomena that are related to the lithospheric structure and processes. The substantial improvement of geophysical and geodetic data obviously offers a unique opportunity to develop and apply new methods that allow us to better understand already known as well as identify new phenomena and relationships in geosciences.

In the context of the current and future development, the focus of this study group is to develop and apply methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics based on joint processing of various geodetic and

geophysical data and constraining information. We expect that our research activities will substantially contribute to the current knowledge of the lithospheric structure and processes, including but not limited to the compensation stage of the crust/lithosphere, the lithospheric strength, mechanisms behind the oceanic subduction, the relation between the mantle convection pattern and the global tectonic configuration (and its spatiotemporal variations), and influence of the lithospheric structure on EOPs. Among specific topics of a high interest a novel research question is the influence of the global tectonic configuration (involving not only the continental and oceanic configuration but essentially also the lithospheric thickness) and the lithosphere-asthenosphere interaction on the EOPs. In this context we will also conduct geodynamic studies to investigate the difference in polar motion between an observation-based terrestrial reference frame and Tisserand's mean axes of the body (i.e., a mean mantle reference frame). The members of this study group will address some of these aspects within the following overall objectives.

Objectives

- Improvement of (regional and continental-scale) lithospheric density models based on combining geodetic and geophysical data and additional geological constraining information, focusing on regions with insufficient seismic data coverage.
- Development of a preliminary global density model of the mantle below the lithosphere-asthenosphere boundary based on the combined analysis of seismic and gravity data, focusing on the seismic data conversion to mass densities within the gravimetric inversion scheme constrained by geothermal, geochemical, geodynamic, and other information.
- Contributing to a better understanding of the interaction between the mantle dynamics and tectonic motions.
- Improvement of the supercontinent cycle models.
- Study of the influence of the lithospheric structure and dynamics on EOPs.
- Study of the sea surface changes and its relation with the global climate change

Program of Activities

- Presenting research findings at major international geodetic or geophysical conferences, meetings, and workshops.
- Interacting with related IAG Commissions.
- Monitoring research activities of JSG members and of other scientists, whose research interests are relevant to the scopes of JSG.
- Providing a bibliographic list of publications from different branches of science relevant to JSG scopes.
- Organizing a session at the Hotine-Marussi Symposium 2026.

Members

Robert Tenzer (China-Hong Kong); Chair
Mohammad Bagherbandi (Sweden)
Mirko Reguzzoni (Italy)

Aleksej Baranov (Russia)
Franck Ghomsi (Cameroon)
Wenjin Chen (China)
Mehdi Eshagh (Sweden, Czech Republic)
Jianli Chen (China-Hong Kong)
Luan Thanh Pham (Vietnam)
Rebekka Steffen (Sweden)
Jose Manuel Ferrandiz Leal (Spain)
Bernhard Steinberger (Germany)

JSG T.43: Statistical methods in regional gravity field modelling

Chair: Mehdi Eshagh (Czech Republic)
Affiliations: Commissions 1,2, IGFS

Terms of Reference

These days, owing to significant advancements in sensor technology, vast amounts of precise data are being collected. Physical Geodesy is undergoing a modernisation process, largely due to the integration of highly precise data sensors, such as those based on quantum technology. Statistical methods have become an integral tool in contemporary Physical Geodesy dedicated to the measurement and comprehension of the Earth's shape, gravity field, and dynamic processes that shape our planet's surface. Given the intricate and variable nature of geodetic data, acquired from diverse sources like satellite missions, ground-based observations, and remote sensing, the need for advanced statistical techniques has become apparent. These techniques enable the accurate analysis and interpretation of this wealth of information. In this context, statistical methods serve not only to describe and model geodetic data but also to quantify uncertainties of geodetic solutions and to evaluate their reliability.

The primary objective of Physical Geodesy is to model the geoid and gravity field of the Earth, for which numerous methods have been developed. However, less attention has been given to providing a comprehensive quality description of the products of Physical Geodesy from a statistical perspective. In many instances, these products are validated using independent data to gain insights into their quality. While attempts have been made to estimate uncertainties in global gravity models, which typically result from least-squares estimation processes, less emphasis has been placed on assessing the internal quality of results, especially when dealing with local gravity field or geoid modelling. Statistical tests play a crucial role in justifying and distinguishing gravitational signals from the noise generated by various measurement tools, including terrestrial, marine, airborne, or satellite sensors. Therefore, more in-depth investigations into downward continuation, regularisation methods, least-squares collocation, variance-covariance component estimation, time-series analysis, and robust statistics, are necessary to handle data collected by modern sensors and extract valuable insights regarding Earth's gravity field modelling.

These studies extend beyond gravity field modelling and encompass applications in other disciplines such as Oceanography, Hydrology, Geophysics, as well as space

and planetary science. The scope of this study group also involves the development of statistical methods for quality assessment in other relevant disciplines.

Objectives

- Investigate the propagation of errors arising from all gravimetric measurements to enhance the accuracy of Physical Geodesy products.
- Investigate the accuracy of determining the (high-frequency) gravity field and international vertical reference frame, considering the stochastic characteristics of regional gravity data (including surface, shipborne, altimetry-based, airborne, etc.).
- Assess the level of precision required in measured data to achieve a specified quality in the resulting Physical Geodesy products.
- Do research and develop various inversion and regularisation methods endowed with stochastic properties, thereby advancing the precision of geodetic solutions, specifically for integral equations in downward continuation.
- Develop variance-covariance component estimation techniques to provide comprehensive quality descriptions and facilitate the optimal integration of gravimetric data and products such as geoid models and heights.
- Extend the horizons of least-squares collocation techniques, exploring further developments and applications to refine geodetic computations.
- Enhance and refine spectral combination methods with a focus on error estimation, ensuring robust and reliable geodetic results.
- Statistically analyse of time-variable global and local gravity field products and their applications.

Program of Activities

- Presenting findings at international geodetic or geophysical conferences, meetings, and workshops.
- Interacting with other IAG entities.
- Monitoring research activities of JSG members and other scientists whose research interests are related to scopes of this JSG.
- Organising a session at the Hotine-Marussi Symposium 2026.

Members

Mehdi Eshagh (Czech Republic); Chair
Michal Šprlák (Czech Republic)
Juraj Janák (Slovakia)
Peiliang Xu (Japan)
Pavel Novák (Czech Republic)
Lorant Földváry (Hungary)
Martin Pitoňák (Czech Republic)
Christian Gerlach (Germany)
Lars E. Sjöberg (Sweden)
Riccardo Barzaghi (Italy)

Robert Tenzer (China-Hong Kong)
Dimitrios Tsoulis (Greece)
Ismael Foroughi (Canada)
Majid Abrehdary (Sweden)
Petr Vaníček (Canada)
Ling Yang (China)
Ryan A. Hardy (USA)

JSG T.44: Atmospheric coupling studies

Chair: Andres Calabia Aibar (Spain)
Vice-Chair: Binod Adhikari (Nepal)
Affiliations: Commission 4, GGOS (GSWR)

Terms of Reference

We are a dedicated team of academics, researchers, and scientists committed to enhancing our understanding of the interactions between solar wind and Earth, including the coupling processes within the magnetosphere, thermosphere, and ionosphere. Our work involves conducting comprehensive simulations of solar wind to understand its characteristics and variability, and studying the effects of solar wind on Earth's upper atmosphere. We are also focused on developing predictive models to forecast these effects, which can help mitigate potential detrimental effects on orbiting, aerial, and ground-based technologies.

In addition to our research, we believe in the power of collaboration and knowledge sharing. We plan to create a platform for sharing data and model products that are freely available for the scientific community. We also strive to enhance international cooperation by sharing knowledge and research tools, co-supervising theses, and helping to improve manuscripts. We are excited about the journey ahead and look forward to making significant contributions to the scientific community.

Objectives

The primary objective of the JSG is to enhance our understanding of the interactions between solar wind and Earth, including the coupling processes within the magnetosphere, thermosphere, and ionosphere. This will be achieved through the study of solar wind simulations and the effects of solar wind on Earth's upper atmosphere.

The scope of the JSG includes but is not limited to:

- Atmosphere Coupling: Investigating the effects of solar wind on Earth's upper atmosphere. This includes studying the coupling processes within the magnetosphere, thermosphere, and ionosphere.
- Solar Wind Simulations: Conducting comprehensive simulations of solar wind to understand its characteristics and variability. This includes studying the effects of solar wind on the magnetosphere, thermosphere, and ionosphere
- Predictive Modelling: Developing predictive models to forecast the effects of solar wind on Earth's upper atmosphere. This will help in mitigating the potential detrimental effects on orbiting, aerial, and ground-based technologies.

- Data Sharing: Creating a platform for sharing data and model products that are freely available for the scientific community. This will foster collaboration and accelerate research in this field.
- International Cooperation: Enhancing international cooperation by sharing knowledge and research tools, co-supervising theses, and helping to improve manuscripts.

Program of Activities

- Presenting findings at international geodetic or geophysical conferences, meetings, and workshops.
- Interacting with other IAG entities.
- Monitoring research activities of JSG members and other scientists whose research interests are related to scopes of this JSG.
- Organising a session at the Hotine-Marussi Symposium 2026.

Members

Andres Calabia Aibar (Spain); Chair
Binod Adhikari (Nepal); Vice-Chair
Yury Yasyukevich (Russia)
Anoruo Chukwuma (Nigeria)
Munawar Shah (Pakistan)
Astrid Maute (USA)
Gang Lu (USA)
Naomi Maruyama (USA)
Christine Amory-Mazaudier (France)
Ayomide Olabode (Germany)
MD Rodriguez Frias (Spain)
Nadia Imtiaz (Pakistan)
Aurora Segrelles (Spain)
Virginia Klausner de Oliveira (Brazil)
Yan Xiang (China)
Ashok Silwal (Nepal)
Mohamed Ahmed Ahmed Freeshah (Egypt)

JSG T.45: Dynamic gravity modelling of given distributions

Chair: Dimitrios Tsoulis (Greece)
Affiliations: Commissions 2,3

Terms of Reference

Forward gravity field modelling is a core topic in geodetic theory. The geometrical definition of the shape and the numerical evaluation of the corresponding gravity signal of a known mass distribution is an indispensable tool for gravity modelling and interpretation studies at different scales. Involving different theoretical and computational strategies of potential field theory and including the comparison of the computed signal

with the observed gravity field, the specific research topic determines a characteristic interface between geodesy and geophysics.

The computation of precise terrain effects, gravity anomalies and geoid, the downward continuation of satellite data, or solving for an extended family of integral equations of potential theory are only some of the most common applications. Directly correlated with the real density distributions in the Earth's interior, the evaluation of the gravitational potential of a given distribution and its spatial derivatives up to higher orders is the shared objective.

The availability of an abundance of terrestrial and satellite data of global coverage and increasing spatial resolution provides a challenging background for revisiting known theoretical aspects and especially investigating the computational limits and possibilities of forward gravity modelling induced by known mass distributions. Satellite observations provide global grids of gravity related quantities at satellite altitude, global crustal databases offer detailed layered information of the shape and consistency of the Earth's crust, while satellite methods produce Digital Elevation Models that represent the continental part of the topographic surface with unprecedented resolution.

At the same time, in the era of dedicated satellite gravity missions, one of the most prominent research objectives for the scientific exploitation of current and future satellite data is capturing real mass changes in the Earth's interior. These mass balance studies, related, for example, to the water cycle or seismic activity, are linked to the gravity signal of specific distributions.

In this context, the complete theoretical framework that evaluates the gravity effect of a given distribution using analytical or numerical techniques emerges again at the forefront of research interest, examining both ideal bodies and real distributions. Thereby, of special interest is the ability to evaluate numerically the spherical harmonic coefficients for the gravitational potential of a finite source, thus providing a bandlimited spectral input for the observed gravity signal. Variations in the numerical values of these coefficients can also be obtained by algorithms that arise from a stochastic procedure, enabling an association with the corresponding observed mass changes. In this manner the task in question is reformulated to a dynamic gravity signal evaluation procedure, that can be tailored to real phenomena.

Objectives

- Examine new theoretical developments (numerical or analytical) in expressing the gravity signal of ideal geometric distributions
- Implement and validate different techniques for the evaluation of potential spherical harmonic coefficients for finite three dimensional sources
- Revisit and expand the stochastic approach for spherical harmonics evaluation of given sources
- Perform forward gravity modelling validation studies at different scales, using the available high resolution digital elevation models and focusing on optimization methods that reduce the high computational load and take the accuracy estimates of the input data into account
- Compute the gravity effect of structures in the Earth's interior and embed this effort in the frame of mass change and mass balance problems

Program of Activities

- Participation in forthcoming IAG conferences with splinter meetings and proposed sessions
- Preparation of joint publications with the JSG members
- Organising a session at the Hotine-Marussi Symposium 2026

Members

Dimitrios Tsoulis, (Greece); Chair
Judit Benedek, (Hungary)
Georgia Gavriilidou, (Greece)
Christian Gerlach, (Germany)
Ropesh Goyal, (India)
Michael Kuhn, (Australia)
Pavel Novák, (Czech Republic)
Paolo Panicucci, (Italy)
Gábor Papp, (Hungary)
Alberto Pastorutti, (Italy)
Daniele Sampietro, (Italy)
Matej Varga, (Switzerland)
Jérôme Verdun, (France)

JSG T.46: Deformation, rotation and gravity field modeling for Earth and space

Chair: Yoshiyuki Tanaka (Japan)
Affiliations: Commissions 2,3

Terms of Reference

Measurements of deformation, rotation and gravity field are the three pillars of modern geodesy and the Global Geodetic Observation System (GGOS). To interpret the measured temporal variations by the GGOS, various geophysical phenomena have been dynamically modelled. The spatiotemporal resolution of recent space geodetic observations has improved dramatically. This trend is expected to continue through an increase in the number of GNSS and InSAR satellites and ground stations including those operated by private companies as well as planned satellite gravity missions like the Mass-Change and Geosciences International Constellation (MAGIC). In addition, novel sensors have been developed to measure gravity gradients and potential changes. Based on such techniques, observation targets are expected to extend to those occurring on other celestial bodies.

The diverse data with high spatiotemporal resolutions motivate us to develop theories to describe the processes causing deformation, rotation and gravity field variations. The Joint Study Group consists of scientists working on dynamic modelling based on different approaches. The targets of the modelling include local, regional and global variations which occur near the surface down to the inner core of the Earth

and other celestial bodies. Observations include contributions from a variety of geophysical phenomena. The developed models can also be used as a correction model to separate those contributions. To share different perspectives for modelling stimulates the activities of each member and can produce and/or evolve collaborative studies.

Objectives

- Forward modelling:
  - Target phenomena: co- and post-seismic deformation, other tectonic processes, surface loading and mass transports, hydrological effects, glacial isostatic adjustment, tides and rotation, etc.
  - Properties of the material structure to be modelled: elasticity, viscoelasticity, plasticity, poroelasticity, electromagnetic, thermal and chemical properties, heterogeneities and anisotropies, etc.
  - Modelling approaches: analytical, semianalytical and fully numerical methods and associated approximation methods, etc.
  - Comparison between different theories.
  - Opening developed software (if possible)
- Inverse modelling:
  - Integration of diverse data.
  - Effective processing of big data.
  - Applications of the developed theories to real observations for new scientific findings.

Program of Activities

- To launch an e-mail list to share information concerning research results and to interchange ideas for solving related problems.
- To open a web page to share information, such as publication lists and its update.
- To propel collaborations with related working groups and projects (e.g., Hydrologic signature in geodetic observations, Chair: Carla Braitenberg (WG in Commission 3), Novel Sensors and Quantum Technology for Geodesy: QuGe).
- To have sessions at international meetings and workshops as needed.
- Software comparison (co- and post-seismic deformation)
- Organising a session at the Hotine-Marussi Symposium 2026

Members

Yoshiyuki Tanaka (Japan); Chair
Shin-Chan Han (Australia)
Hom Nath Gharti (Canada)
Guangyu Fu (China)
Isabelle Panet (France)
Volker Klemann (Germany)
Zdeněk Martinec (Ireland)
Alberto Pastorutti (Italy)
Carla Braitenberg (Italy)

Daniel Melini (Italy)
Elia Giliberti (Italy)
Giorgio Spada (Italy)
Junichi Okuno (Japan)
Taco Broerse (Netherlands)
Riccardo Riva (Netherlands)
Wouter van der Wal (Netherlands)
Peter Vajda (Slovak Republic)
José Fernández (Spain)
Kuanhung Chen (China-Taipei)
Jeanne Sauber (USA)

JSG T.47: Height datum: Definition, New Concepts, and Standardization

Chair: Xiaopeng Li (USA)
Vice-Chair: Marcelo Santos (Canada)
Affiliations: Commissions 2, IGFS

Terms of Reference

Since geometric heights above the reference ellipsoid (as obtained by transformation of geocentric Cartesian coordinates estimated routinely by GNSS) have no physical meaning, the concept of various physical heights, such as orthometric and normal, has been developed in geodesy. All physical heights use a height reference surface (height datum) the geoid defined as a reference equipotential surface of the Earth's gravity field.

To transform geometric heights into orthometric heights, the geoid height defined as ellipsoidal normal separation of the geoid and the reference ellipsoid, must be precisely known. However, given the definition of normal heights using an analytic model of the Earth's gravity field (known as the normal field in geodesy), the so-called height anomaly must alternatively be estimated. Thus, local or global models of the geoid height/height anomaly must be estimated with high precision (1 cm or better).

Through the past decades, various definitions of the height datums for physical heights have been used, both officially and unofficially. For example, a classical textbook definition of the geoid reads as "equipotential surface of the Earth's gravity field approximated by the temporal mean sea level over the oceans". This definition is easy to understand; however, the estimation of such a surface over the continents leaves some theoretical issues to be resolved. Moreover, the concept of the normal heights based on the quasi-geoid has even some serious theoretical issues as some recent studies reported.

The main goal of this joint study group is to establish new or to extend existing international cooperation of researchers within the physical geodesy community in order to review and specify the definition of the height reference surfaces used in connection with physical heights in geodesy. The ultimate goal of the group is to provide a clear, rigorous, and manageable guideline for their precise (1 cm or better) realization.

The updated or new concepts for the height datum realization will consider data from various observation systems, including modern ones such as those based on precise clocks (chrono-geodesy using relativistic effects). Additionally, it will be investigated how to link seamlessly and errorlessly the geoid height/height anomaly models with local high-resolution and accurate spirit levelling observations as the concept and realization of height datums must serve real world applications of physical heights.

Objectives

The scope of this JSG will cover theoretical aspects of the geoid height or height anomaly modelling. In particular, the group will focus on:

- physical parameters such as GM and W_0
- geo-center conventions with respect to the International Terrestrial Reference Frame (ITRF)
- Geodetic Reference System
- tide system conventions
- combination of various gravity field data
- new geodetic boundary-value problems
- consolidate the theory of physical heights

Program of Activities

The JSG will achieve its objectives through:

- Specifying height datum definitions and providing official documentation to IAG.
- Suggesting recommendations regarding the practical use of normal heights related to the geoid.
- Updating and unifying required systems and parameters (which sea surface and which epoch).
- New convention of atmospheric correction
- Seamless connection of local, regional, marine datums, and global datum
- Circulating and sharing information, ideas, progress reports, papers, presentations.
- Organizing a session at the Hotine-Marussi Symposium 2026.
- Supporting and cooperating with IAG Commission 2, ISG, and IGFS, namely their working groups and other entities related to gravity field and height systems.

Members

Xiaopeng Li (USA); Chair
Marcelo Santos (Canada); Vice-chair
Ana Cristina Matos (Brazil)
David Avalos (Mexico)
Elena Osorio-Tai (Mexico)
Fabio Albarici (Brazil)
Gabriel Guimarães (Brazil)
Georgios Vergos (Greece)
Hussein Abd-Elmotaal (Egypt)

Ismael Foroughi (Canada)
Jianliang Huang (Canada)
Jurai Janák (Slovakia)
Laura Sanchez (Germany)
Miao Lin (China)
Nicolaas Sneeuw (Germany)
Pavel Novák (Czech Republic)
Riccardo Barzaghi (Italy)
Robert Kingdon (Canada)
Yanming Wang (USA)

Associate members

Fernando Sansò (Italy)
Rachelle Winefield (New Zealand)

JSG T.48: Theoretical foundations of Machine & Deep Learning in Geodesy

Chair: Lotfi Massarweh (The Netherlands)
Vice-chair: Mostafa Kiani Shahvandi (Switzerland)
Affiliations: Commissions 2,3,4, GGOS (AI4G)

Terms of Reference

The new Joint Study Group is dedicated to a rigorous investigation of Artificial Intelligence/Machine Learning state-of-the-art techniques in the context of current and/or future geodetic applications.

The adoption of Machine Learning (ML) in various domains of Geodesy has become more popular in the past decade. In particular, the rise of Deep Learning (DL) techniques has further increased the adoption of Artificial Intelligence (AI) methods for tackling several complex problems. This widespread use has become possible by a greater availability of computing power, but it has also been motivated by the vast amount of geodetic data that is currently accessible. The latter not only concerns fields such as the Global Navigation Satellite System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR), but also the Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR) data.

However, most of research works still focus on applying promising AI/ML algorithms as a black box system, which is viewed in terms of its inputs/outputs without any knowledge of its internal processing or any clear 'uncertainty quantification' of the solutions. However, the lack of 'explainability' might hinder the accurate analysis of real-world problems and thus, one of the goals of the study group is to address this problem. A second issue is related to the 'reproducibility' of results, a fundamental aspect of the scientific method for real-world datasets. Often, AI/ML algorithms fail in achieving outcomes that can easily be reproduced by others and therefore, a part of the joint study will be devoted to this aspect.

One of the primary goals of this Joint Study Group is to identify machine learning use cases in Geodesy, as well as best practices, methods, and algorithms when applying machine learning to geodetic data. In particular, the group focuses on addressing – from a theoretical viewpoint – both 'explainability' and 'reproducibility' aspects in scientific research. This will include methodologies for better understanding underlying assumptions of each model, while also providing a clear quantification of the uncertainty of AI/ML outcomes. In this way, we aim at enhancing the reliability of algorithms and methods, while combining these ones with known physical models and well-established geodetic theories. We recognize the great potential of this AI/ML revolution in Geodesy, whereas a more rigorous theoretical approach is still necessary to fully integrate such novel techniques into the current body of knowledge.

Objectives

- To rigorously investigate, from a theoretical perspective, both methods and assumptions related to machine learning algorithms in different areas of Geodesy.
- To provide a better quantification of the uncertainty for ML/DL techniques, including a more comprehensive statistical description of the solutions.
- To address the problems of 'explainability' and 'reproducibility' in machine learning methods, bridging the gap with traditional data analysis approaches.
- To closely collaborate with the GGOS Focus Area 'AI4G (Artificial Intelligence for Geodesy)' in order to identify open problems in the processing and generation of geodetic products, and therefore including the potential issues of reliability.
- To develop best practices in the adoption of ML/DL techniques, meanwhile further consolidating a standardized terminology for the geodetic community.

Program of Activities

The Joint Study Group will achieve its objectives through:

- To create a web page about machine learning in geodesy, thus providing technical information and raising awareness about the topic in our community. This page will include:
  - an inventory of AI/ML algorithms and their methodology;
  - benchmark datasets to test the performance of AI/ML solutions,
  - a comprehensive record of all previous activities/publications related to machine learning and deep learning in geodesy,
  - a description of key activities performed by the JSG members
- To work toward a comprehensive literature review paper about machine learning in geodesy coauthored by the JSG members, while also addressing traditional data analysis approaches.
- To promote sessions and presentation of the research results at international scientific assemblies (IAG/IUGG, EGU, AGU), technique-specific meetings (IGS, IVS, ILRS, IDS) and the next Hotine-Marussi Symposium in 2026.
- To enhance collaborations with GGOS "AI4G", along with IAG Commissions.

Members

Lotfi Massarweh (The Netherlands); Chair
Mostafa Kiani Shahvandi (Switzerland); Vice-Chair
Michela Ravanelli (Italy)
Kyriakos Balidakis (Germany)
Alireza Amiri-Simkooei (The Netherlands)
Junyang Gou (Switzerland)
Andrea Nardin (Italy)
Mohammad Mahdi Kariminejad (Iran)
Amir Khodabandeh (Australia)

JSG T.49: High-resolution Probing of the Troposphere and Ionosphere

Chair: Michela Ravanelli (Italy)
Affiliations: Commission 4, GGOS (Geohazards Monitoring, GSWR)

Terms of Reference

Nowadays, geodetic measurements are routinely used to probe the Earth's atmosphere both from space and ground. In detail, tropospheric and ionospheric sounding is more and more essential in a variety of applications.

Tropospheric sounding has an important role both in meteorology, in weather forecasting and nowcasting. Global Navigation Satellite Systems (GNSS), GNSS Radio Occultation (GNSS-RO) and Interferometric Synthetic Aperture Radar (InSAR) are the most common used techniques. GNSS and InSAR can be used in complementary way, whereas the GNSS-RO and GNSS can act in a synergistic way.

Through the integration of the afore-mentioned techniques, this JSG aims to improve the high resolution of tropospheric sounding in both zenith and slant directions. In this background, our goals involve studying of severe weather events, the impact of lowcost instrumentations and/or moving platform observations on assimilation approaches, numerical modelling and tomography. The final outcome will help to enhance the real-time capability of models for severe weather nowcasting. To this point, the use of highperformance computing platforms should be encouraged. Furthermore, tropospheric observations could increase the knowledge on the effects and monitoring of climate change.

GNSS-TEC and GNSS-RO offer complementary insights into the ionosphere. The former provides horizontal information on electron content, while the latter offers altitude-wise profiles of electron contents. These observations play a fundamental role in the analysis of natural and man hazard-related ionospheric perturbations, being useful to enhance early warning systems. In this direction, this JSG fosters the improvement of real-time ionospheric monitoring. Data-driven and model-based methodologies for realtime detection of earthquakes and tsunamis should be also improved and integrated into operating tools. The sharing of local GNSS data coming from regional network and private space company (Spire, CubeSats) as well and from moving platform and low-cost instrumentations (smartphones, single-frequency receivers)

should be bolstered, going towards a denser ionospheric coverage especially over the oceans. These denser ionospheric observations are necessary to improve the reliability of ionospheric maps (both regional and global) for TEC forecasting and nowcasting, being useful for space weather monitoring, as the 2022 Starlink satellite loss event showed.

The opportunity to reconstruct the 3D ionospheric structure (ionospheric tomography) is increasing thanks to LEO nanosatellites equipped with GNSS (e.g., Astrocast).

Furthermore, studies related to the impact of tropospheric events such as lightning and severe convective weather in the ionosphere should be encouraged. Indeed, these events are about to increase in frequency due to climate change variability. Nonetheless, these investigations should also be fostered to overcome the compartmental use of geodetic observations, typical of the academic world, to gain a holistic and comprehensive angle on the lower/upper atmosphere coupling.

Ultimately, machine learning plays an increasingly significant role in forecasting and nowcasting parameters in tropospheric sounding, as well as in detecting natural hazards for early warning systems. In this regard, fostering interrelation and collaboration with JSG 48 about foundations of machine and deep learning in geodesy is crucial to harness the expertise from both fields.

Finally, it is clear that this unprecedented dense coverage of troposphere and ionosphere sounding enabled by commercial all available ground and spacebased geodetic techniques represents a great opportunity for future investigations in Earth sciences. This underscores the importance of integrating different techniques and products to fully harness their potential and extract optimal information. This is the reason why it is worth having a JSG about highresolution probing of the troposphere and ionosphere using geodetic techniques within the ICCT.

Objectives

- To produce inventories of:
  - commercial and publicly space and groundbased geodetic techniques, with a distinction between troposphere and ionosphere observations, and a classification based on the different acquisition parameters (e.g., sampling rate, vertical or temporal resolution, altitude range of acquisition, tracking mode),
  - present and desired applications of dense troposphere and ionosphere sounding for science and engineering, with a special concern to the estimated physical quantities (e.g., temperature, pressure and TEC), in order to focus on related problems (still open and possibly new) and draw future challenges.
- To address known problems related to dense troposphere and ionosphere sounding using geodetic observations as (not an exhaustive list): natural-hazard anomalies detection, localization and classification; revision and refinement of inversion techniques; temporal variability of receivers DCBs and evaluation of their impact in the calibrated process; data quality assessment and validation; outlier detection and removal; in-situ sensors evaluation, cross-calibration and integration.
- To describe the different analytical and physical implications of combining observations collected with different observational geometries, such as: ground-based receivers tracking signals transmitted by GNSS satellites in MEO and GEO orbits;

space-based receivers tracking GNSS signals at different elevation angles (from positive to negative and vice versa). Furthermore, investigate different ways of combining these remote sensing observations to retrieve fundamental atmospheric parameters, and disentangle the spatial and temporal variability of the atmosphere.

Program of Activities

- To participate at IAG assembly in 2025 in Rimini
- To organize a session at the forthcoming Hotine- Marussi symposium in 2026
- To convene at international conferences such as IAG/IUGG, EGU, AGU
- Interacting with JSG T.48 on foundations of machine and deep learning in geodesy

Members

Michela Ravanelli (Italy); Chair
Elvira Astafyeva (France)
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Alessandra Mascitelli (Italy)
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Lucie Rolland (France)
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JSG T.50: High-precision GNSS theory and algorithms

Chair: Dimitrios Psychas (The Netherlands)
Affiliations: Commissions 1,4

Terms of Reference

The family of modernized and recently-developed global and regional navigation satellite systems is being further extended by plentiful Low Earth Orbit (LEO) navigation satellites that are almost 20 times closer to Earth as compared to current GNSS satellites. This namely means that navigation sensory data with much stronger signal power will be abundantly available, being in particular attractive in GNSS-challenged environments. Next to the development of new navigation signal transmitters, a rapid growth in the number of mass-market GNSS and software-defined receivers would at the same time demand efficient ways of data processing in terms of computational power and capacity.

Such a proliferation of multi-system and multi-frequency measurements, that are transmitted and received by mixed-type sensing modes, raises the need for a thorough research into the future of next-generation navigation satellite systems, thereby

appealing rigorous theoretical frameworks, models and algorithms that enable such GNSS-LEO integration to serve as a high-accuracy and high-integrity tool for Earth-, atmospheric- and space sciences.

Objectives

- Identify, investigate, and tackle challenges that are posed by the integration and processing of multi-GNSS data with heterogeneous sensory measurements, like LEO observations, that are sensed by, e.g., next generation navigation-oriented and communication-oriented constellations.
- Develop and study theory for multi-GNSS integrity and quality control, taking into account the combination of parameter estimation and statistical testing.
- Conduct an in-depth analysis of low-cost, low-power and mass-market GNSS sensory data, such as those of smartphones, and investigate their performances in geoscience applications, considering also fusion with other sensors.
- Develop algorithmic frameworks and strategies to deal with computational challenges encountered in parameter estimation and testing in the presence of a huge number of GNSS and LEO sensing nodes.
- Articulate theoretical developments and findings through journals, conference proceedings, and online and in-person workshops.

Program of Activities

While the investigation will strongly be based on the theoretical aspects of the GNSS-LEO observation modelling and challenges, they will be also accompanied by numerical studies of both the simulated and real-world data. Given the expertise of each member, the underlying studies will be conducted on both individual and collaborative bases. The output of the group study is to provide the geodesy and GNSS communities with well-documented models and algorithmic methods through the journals, conference proceedings, and workshops, primarily including IAG assembly in Rimini in 2025, Hotine-Marussi symposium in 2026, and the annual EGU and AGU assemblies.

Members

Dimitrios Psychas (The Netherlands); Chair
Andreas Brack (Germany)
Pengyu Hou (China)
Amir Khodabandeh (Australia)
Lotfi Massarweh (The Netherlands)
Nacer Naciri (USA)
Robert Odolinski (New Zealand)
Jacek Paziewski (Poland)
Sandra Verhagen (The Netherlands)
Kan Wang (China)
Safoora Zaminpardaz (Australia)
Baocheng Zhang (China)

Inter-Commission Committee on Geodesy for Climate Research (ICCC)

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President: Annette Eicker (Germany)
Vice President: Carmen Blackwood (USA)

ICCC website - www.iccc.iag-aig.org

1 Terms of Reference

The Inter-Commission Committee on Geodesy for Climate Research (ICCC) was established in 2019 to advance the use of geodetic observations for climate research. The growing data record from numerous geodetic observation techniques (GNSS station observations, satellite radio occultation and reflectometry, satellite gravimetry, satellite altimetry, InSAR, VLBI, GNSS-controlled tide gauges, etc.) provides a new quantitative view on various variables that are relevant for climate research, such as tropospheric water vapor, thermospheric neutral density, terrestrial water storage, ice sheet and mountain glacier mass , steric and barystatic sea level, ocean surface winds, ocean waves, subsurface and surface currents, and sea ice extent and -thickness. Many of these are listed as Essential Climate Variables (ECV) according to the definition by the Global Climate Observing System (GCOS).

Geodetic methods provide unique information on the Earth's surface geometry, its large-scale mass transports such as fluctuations in Earth's water cycle, and the global energy imbalance. Time series of geodetic data start to reveal a complex picture of natural climate variability, long-term climate change, and anthropogenic modifications. Combined with other observations by means of, e.g., global or regional Earth system simulations or reanalyses, they provide excellent tools to improve our understanding of climate-related processes. Furthermore, due to their advantage of being independent of other data commonly used to drive and evaluate coupled climate models, geodetic observations have strong potential for either being used as input for numerical models as constraints (e.g. water budget, sea level budget) or for a posteriori model assessment. While it is generally recognized that geodetic data provide invaluable information for studying the planet's changing climate, programmatic obstacles, technical limitations such as the length of time series, and scientifically open questions have been identified that hamper the broader recognition of geodesy as an important source of information for climate research. The Inter-Commission Committee on "Geodesy for Climate Research" shall help to better promote and facilitate the use of genuinely geodetic data in the climate community, and to better explore the synergies between the different geodetic branches with respect to observing climate signals.

The topic of the ICC is positioned at the interface between geodesy and climate science and is of high relevance for the entire scientific discipline geodesy. Various geodetic observables provide complementary information on climate change processes.

Examples include (but are not limited to) the following: climate change related mass transport (e.g., ice melting, sea level rise, changes in the continental and oceanic water cycle as well as their impact on water resources) are among the primary signals derived from (satellite) gravity observations and can also be detected directly by geometrical measurements of volume change (satellite altimetry for water bodies/ice, InSAR over aquifers) or indirectly via crustal deformations induced by surface loads (terrestrial GNSS, InSAR, VLBI). Furthermore, by changing the Earth's moments of inertia and relative momentum term, mass transports also lead to measurable variations in Earth orientation parameters. Climate change related variations of the atmosphere affect the propagation of geodetic signals and thus can be inferred from long time series of VLBI and ground and satellite based GNSS observations. Finally, a stable global geodetic reference frame (GGRF) is an indispensable requirement for providing a uniform reference for monitoring global change processes, as has recently been recognized by the corresponding UN resolution1. However, synergies between the different geodetic observing systems for monitoring climate change have not yet been fully exploited and the interaction with the climate communities needs to be intensified in order to achieve a broader – and better recognized – use of geodetic data for climate research.

1.1 Objectives

- To deepen the understanding of the potential (and limitations) of geodetic measurements for the observation, analysis and identification of climate signals
- To advance the development of geodetic observing systems, analysis techniques and data products regarding their sensitivity to and impact on Essential Climate Variables, this way also supporting activities of the IPCC
- To advance the improvement of numerical climate models, climate monitoring systems, and climate reanalysis efforts through incorporating geodetic observations
- To stimulate scientific exchange and collaboration between the geodetic and the climate science communities
- To make geodetic variables more user-friendly by sharing them publicly and explaining their usefulness

1.2 Program of Activities

- The ICCC will continue the successful workshop series established to intensify the exchange between different geodetic communities and the climate monitoring and modeling communities.
- The ICCC will continue the online seminar series "Geodesy4Climate" to specifically invite scientists from climate communities to bring them into contact with geodesists.
- The ICCC will create opportunities for communication and discussion through suggesting/organizing sessions at international scientific meetings and conferences.
- The ICCC will develop reference (best-practice) methods for evaluating/improving climate models with geodetic data and publish these methods (e.g., in a "white paper").
- The ICCC will seek to organize special issues on its topic in appropriate international journals.

- The ICCC will work towards a better recognition of geodesy as an essential provider of precise information about long-term changes in the Earth system.
- The ICCC will establish links to other climate science related bodies, e.g. the IUGG Union Commission on Climatic and Environmental Change (CCEC) or the IAMAS International Commission on Climate (ICCL).
- The ICCC will maintain a website for dissemination of ICC related information and will actively communicate results and events via social media (e.g., the former Twitter).

1.3 Structure

The structure of Inter-Commission Committees (ICCs) is specified in the IAG by-laws. The ICCC Steering Committee consists of the President, Vice-President, representatives from each of the IAG Commissions, GGOS, one Early Career Scientist (ECS) and one Member-at-large. ICCC activities are undertaken by Joint Working Groups (JWG), affiliated to two or more IAG entities.

1.4 Steering Committee

- President: Annette Eicker (Germany)
- Vice-President: Carmen Blackwood (USA)
- Representative of Comm.1: Jeff Freymueller (USA)
- Representative of Comm.2: Rebecca McGirr (Australia)
- Representative of Comm.3: Grace Carlson (USA)
- Representative of Comm.4: Anna Klos (Poland)
- Representative of GGOS: Laura Sanchez (Germany)
- Member-at-large: Fernanda Camisay (Argentina)
- Representative of Early Career Scientists: Franck Ghomsi (South Africa)

1.5 Overview of Joint Working Groups

JWG C.1 Climate Variability and Climate Change in Earth Orientation Parameters
Chair: Henryk Dobslaw (Germany)
Vice-Chair: Jolanta Nastula (Poland)
Affiliations: Commission 3, IERS, GGOS

JWG C.2 Polar geodesy for understanding climate change
Chair: Ingo Sasgen (Germany)
Vice-Chair: Bert Wouters (Netherlands)
Affiliations: Commissions 2 and 3, GGOS

JWG C.3 Assessing Earth's Energy Balance with geodetic observations
Chair: Maria Hakuba (USA)
Vice-Chair: Felix Landerer (USA)
Affiliations: Commission 2, GGOS

JWG C.4 Hydrological loading: measuring and modeling
Chair: Mohammad J. Tourian (Germany)
Vice-Chair: Joelle Nicolas (France)
Affiliations: Commissions 2 and 4, GGOS

JWG C.5 Exploitation of ground-based GNSS Interferometric Reflectometry for climate applications
Chair: Makan Karegar (Germany)
Vice-Chair: Dongju Peng (China-Hong Kong)
Affiliations: Commission 4, GGOS

JWG C.6 GNSS mass-market devices in climate and environmental sensing: approaches, opportunities, challenges, and social impact
Chair: Tobias Kersten (Germany)
Vice-Chair: Balaji Devaraju (India)
Affiliations: Commission 4, GGOS

JWG C.7 Ground-GNSS trends for climate models
Chair: Marcelo Santos (Canada)
Vice-Chair: Rosa Pacione (Italy)
Affiliations: Commission 4, IGS, IVS, GGOS

JWG C.8 Optimal processing and homogenization of GNSS-PW climate data records
Chair: Olivier Bock (France)
Vice-Chair: Galina Dick (Germany)
Affiliations: Commission 4, IGS, GGOS

JWG C.9 Climate Change Signals in High Resolution Surface Water Observations
Chair: Luciana Fenoglio (Germany)
Vice-Chair: Jessica Fayne (USA)
Affiliations: Commission 2, GGOS

JWG C.10 Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry
Chair: Marius Schlaak (Germany)
Vice-Chair: João de Teixeira da Encarnação (Netherlands)
Affiliations: Commission 2, ICCT, GGOS, IGFS

2 Joint Working Groups

JWG C.1 Climate Variability and Climate Change in Earth Orientation Parameters

Chair: Henryk Dobslaw (Germany)
Vice-Chair: Jolanta Nastula (Poland)
Affiliations: Commission 3, IERS, GGOS

Introduction

Earth orientation parameters comprising variations of both the position of the rotational pole and the spin rate are precisely observed by modern space geodetic techniques for several decades. In addition, optical astrometric observations extending back in time over more than 100 years carry information about the mass transport and mass distribution processes acting on Earth at historical times that might be explored to quantify slow and subtle variations in the Earth's climate due to both natural variability and anthropogenic impacts.

This working group will study the various contributors of the global and interactively coupled climate system to the observed changes of the Earth's orientation on time-scales from days to centennials. It will explore possibilities to validate numerical climate models and its individual components by means of assessing the angular momentum budget and the associated torques. The working group will further investigate present-day uncertainties of various Earth system state and flux variables in order to attribute residual (i.e., yet unexplained) signals in polar motion and changes in the length-of-day, and assess time-scales for potentially skillfull forecasts of Earth orientation parameters with numerical models.

Objectives

- Exploring temporal limits of predictability of individual Earth orientation parameters with (partially) coupled climate models
- Quantification of contributions from various components of the (anthropogenically altered) Earth's system to rotational variations on time-scales from days to centennials
- Assessment of angular momentum budgets of global numerical climate and Earth system models

Program of Activities

- Regular online working group seminars as well as in-person meetings aligned to major conferences
- Establishment of "best practices" for deriving angular momentum and torque estimates from numerical climate model data
- Contributions to the future development of the Global Geophysical Fluid Centre (GGFC) of the International Earth Rotation and Reference Systems Service (IERS)

Members

Christian Bizouard (France)
Sigrid Boehm (Austria)
Lara Boerger (Germany)
Benjamin Fong Chao (China-Taipei)
Masato Furuya (Japan)
Yavor Chapanov (Bulgaria)
Jianli Chen (China)
Alberto Escapa (Spain)
José Manuel Ferrandiz (Spain)
Laura Fernandez (Argentina)
Richard Gross (USA)
Sébastien Lambert (France)
Arya Paul (India)
David Salstein (USA)
Michael Schindelegger (Germany)

Adam Scaife (Great Britain)
Florian Seitz (Germany)
Justyna Sliwinska (Poland)

JWG C.2 Polar geodesy for understanding climate change

Chair: Ingo Sasgen (Germany)
Vice-Chair: Bert Wouters (Netherlands)
Affiliations: Commissions 2 and 3, GGOS

Introduction

Geodetic observations play a pivotal role in comprehending the current state of the cryosphere under climate change. Mass change data from missions like GRACE, GRACE-FO, and upcoming missions such as GRACE-C (scheduled launch 2027) and the MAGIC constellation including NGGM (scheduled launch 2032) represent crucial variables that have to be monitored space. In addition, gravity field measurements, observations like GNSS surface deformations are essential for untangling complex sources of mass change originating from various processes.

In the past decades, geodetic observations have proven to be critical for refining cryosphere change trajectories, and, particularly in assessing the sea-level contribution of ice sheets and glaciers for climate projections. Nevertheless, the exploitation of the data has not been achieved to their full potential.

Therefore, our working group focuses on facilitating the direct utilization of geodetic mass change products by the ice and polar climate modeling communities. Historically, challenges hindered the full use of geodetic data, including issues like accessibility, limitations in temporal and spatial resolution, lack of expert validation, meaningful uncertainty descriptions, misconceptions about the data, and independence from auxiliary sources entering more complex inversion approaches. This has led to restraints concerning use of geodetic data within the ice and polar climate modeling communities.

Objectives

To enhance the use of mass change data, we propose improvements in three main areas improving the interface between geodetic data providers and ice and polar climate modelers:

- Evaluate approaches for combining gravimetry with other data for downscaling
- Conduct a testcase on transient calibration of ice sheet projections using geodetic data
- Explore prospects for resolving critical processes in future gravity missions

Sequentially, these points aim to enhance mass change data, apply the data in a testcase, and anticipate limitations lifted by future missions.

Program of Activities

The means to achieve the objectives stated above are:

- In-person workshops
- Online conferences
- Regular consultations with working group leads
- Promotion of young researchers at conferences
- Dedicated scientific paper (potentially)

The involvement of early career scientists is crucial, particularly for point (3), to train the next generation of geodesists for future missions. Established links of the working group leaders to younger ice and polar climate modelers open to using geodetic data will also be utilized for point (2). Substantial experience in different satellite observations is required for point (1), which the working group leads are more than willing to share with early career polar geodesists in the context of the working group.

Members

Mike Bevis (USA)
William Colgan (Denmark)
Xavier Fettweis (Belgium)
Dana Floricioiu (Germany)
Kristine Larson (USA)
Lin Liu (China-Hong Kong)
Malcolm McMillan (UK)
Brice Noël (Belgium)
Masashi Niwano (Japan)
Louise Sandberg Sørensen (Denmark)
(pending conf.) Michael Zemp (Switzerland)
(pending conf.) Mark Tamisiea (USA)
(pending conf.) Mariia Usoltseva (Germany)
(pending conf.) Matthias Willen (Germany)

JWG C.3 Assessing Earth's Energy Balance with geodetic observations

Chair: Maria Hakuba (USA)
Vice-Chair: Felix Landerer (USA)
Affiliations: Commission 2, GGOS

Introduction

The Earth's Energy Imbalance (EEI), defined as the long-term global mean net radiative flux at the top-of-the-atmosphere (TOA), represents the rate at which our planet accumulates heat in response to radiative forcings and feedbacks, making it a key metric for quantifying ongoing global warming. EEI is often used as a target value in global climate model tuning and to constrain the equilibrium climate sensitivity, although its

accurate quantification is challenging. In principle, the absolute EEI magnitude is the small difference between large incoming and outgoing radiative fluxes at the TOA. But due to calibration and retrieval uncertainties that are one order of magnitude larger than EEI itself, EEI cannot be derived from radiometric observations, unless adjustments are made to match the global net radiative flux to independent estimates of long-term planetary heat uptake. These heat uptake estimates have ranged between 0.4 and 1.2 W m^{-2} over the past few decades.

Since the ocean absorbs about 90% of the incoming energy surplus, EEI assessments largely hinge on ocean heat uptake (OHU). To date, standard approaches to estimate OHU are: (a) to derive ocean heat content (OHC) changes from direct subsurface ocean temperatures through hydrographic profiles; (b) to derive the oceans' thermosteric expansion through sea level budget assessments using geodetic observations from space; (c) to estimate the ocean state using global ocean models and reanalyses that assimilate various ocean and atmosphere observations.

The geodetic approach estimates OHU throughout the entire ocean volume as a residual of global mean sea-level (GMSL) and ocean-mass changes (2002 to present). Changes in GMSL are caused by thermal expansion due to OHU (thermosteric changes) and by ocean mass changes (barystatic), the latter being driven by ice-mass and terrestrial water storage (TWS) changes. Subtracting the ocean-mass change from the change in GMSL yields an indirect estimate of full-column steric sea-level change, provided that corrections for glacial isostatic adjustments (GIA) and sea-floor deformations due to contemporary mass changes (GRD) are accounted for. The relation between steric sea-level change and OHU requires knowledge of the ocean's expansion efficiency of heat. The difference between the upper-ocean OHU from hydrographic observations and the geodetic full-column estimate could provide information on the sparsely observed deep-ocean steric expansion; however, to unambiguously detect the small deep OHU, requires to reduce the combined uncertainties from the hydrographic and geodetic methods.

Objectives

- Exploit geodetic observations to close Earth's energy budget and derive change in Earth's energy imbalance.
- Provide global and regional satellite-based Ocean Heat Uptake for model validation/calibration and climate analysis (e.g., variability and trends, constraints on climate sensitivity, international EEI assessments).

Program of Activities

- Take stock of and bring together groups who provide geodetic global and regional Ocean Heat Content (OHC) products.
- Intercompare methods, uncertainty derivation, and investigate regional/global discrepancies.
- Work toward best practices for deriving global Ocean Heat Uptake (OHU) and change therein.
- Work towards regional OHC estimates from geodetic data: Treatment and computation of the halosteric component and expansion efficiency.

- Assessment of global/regional OHC and OHU against in-situ observations and ocean models/reanalysis.
- Application of geodetic OHC and OHU estimates in global climate model evaluation, and study of EEI variability.
- Outstanding GRACE/GRACE-FO-centered investigations to improve EEI estimates.

Members

Anne Barnoud (France)
Gael Forget (USA)
Sebastien Fourest (France)
William Llovel (France)
Audrey Miniere (France)
Gavin Schmidt (USA)
Bernd Uebbing (Germany)
Karina von Schuckmann (France)

JWG C.4 Hydrological loading: measuring and modeling

Chair: Mohammad J. Tourian (Germany)
Vice-Chair: Joelle Nicolas (France)
Affiliations: Commissions 2 and 4, GGOS

Introduction

Water distribution in its various forms on Earth surface, the so-called hydrological loading, leads to the deformation of the solid Earth and gravity field variation. Space-borne geodetic techniques, among all, contribute in monitoring and modeling of hydrological loading. Our joint working group will undertake a multidisciplinary approach, benefiting from expertise from geodesists, hydrologists and climate scientists. We will collaborate on data collection, analysis, and modeling efforts to achieve our objectives. Within this joint working group following objectives are envisaged.

Objectives

- Exploring the signature of climate change in hydrological signals
- Better understanding the hydrological loading: investigating the role of different compartments and different scales
- Feasibility assessment of the reconciliation of different measurement techniques and models and exploring their associated uncertainties
- Understanding the impact of the hydrological cycle and mass fluxes on geodetic response, aiming to enhance our understanding of the space-time scales linked to diverse deformation processes

To achieve these goals we will

- investigate how hydrological loading serves as a sensitive indicator of climate change. By analyzing long-term geodetic records and climate data, we will seek to identify distinct patterns and trends that signify the impact of changing climate conditions.
- explore the intricate relationship between hydrological compartments (e.g., groundwater, surface water, snow, ice) and different spatial and temporal scales. This will involve dissecting the contributions of individual compartments and their interaction within larger hydrological systems.
- explore the challenge of reconciling various geodetic measurement techniques (e.g., GNSS, InSAR, GRACE) and hydrological models (e.g., land surface models, hydrological models) used to study hydrological loading. We will assess the strengths and limitations of each approach and propose strategies for integration. We will conduct intercomparisons of different hydrological models and geodetic measurement techniques to understand their relative strengths and weaknesses.
- develop guidelines and roadmaps for quantifying uncertainties associated with hydrological loading measurements and modeling.

We expect the following outcomes:

- Enhanced understanding of hydrological loading's role in detecting climate change signatures.
- Insight into the contributions of different hydrological compartments and scales.
- Improved reconciliation of diverse measurement techniques and models.
- Guidelines and roadmaps for uncertainty quantification. Collaborative research publications and presentations.
- A network of experts contributing to ongoing advancements in geodesy for climate research.

Program of Activities

- Organizing workshops, webinars, and conferences to facilitate knowledge sharing and dissemination of research findings.
- Organizing Special Issue in a Suitable Journal
- Organizing summer/autumn schools (hackweeks) to transfer knowledge to students.
- Regular meetings/discussion Organizing sessions at international conferences and also, ICCC meetings

Members

Donald Argus (USA)
Jean-Paul Boy (France)
Peter Clarke (UK)
Omid Elmi (Germany)
Vagner Ferreira (China)
Yuning Fu (USA)
Wei Feng (China)

Yuning Fu (USA)
Khosro Ghobadi-Far (USA)
Kévin Gobron (France)
Mahmud Haghshenas (Germany)
Makan Karegar (Germany)
Achraf Koulali (UK)
Matt King (Australia)
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Hilary Martens (USA)
Anthony Mémin (France)
Henry Montecino (Chile)
Daniel Moreira (Brazil)
Paulo Sérgio de Oliveira Jr (Brazil)
Fabrice Papa (France)
Mahdiyeh Razeghi (Australia)
Peyman Saemian (Germany)
Francesca Silverii (Italy)
Alicia Tafflet (France)
Shuang Yi (China)
Susanna Werth (USA)

JWG C.5 Exploitation of ground-based GNSS Interferometric Reflectometry for climate applications

Chair: Makan Karegar (Germany)
Vice-Chair: Dongju Peng (China-Hong Kong)
Affiliations: Commission 4, GGOS

Introduction

GNSS Interferometric Reflectometry (GNSS-IR) is a relatively new ground-based remote sensing technique based on reflected GNSS signals. It has been used to measure water levels, snow accumulation, permafrost melt, soil moisture, vegetation water content, and significant wave height. With the increased numbers of GNSS-IR developers and users, there is a need for community based resources. Our group will focus on expanding and improving the existing open source software for both geodetic and low-cost GNSS-IR sensors, archiving locations of GNSS-IR sensors, and supporting new users. Validation datasets will be archived to allow new users to develop the needed skills to install and operate GNSS-IR sites and to analyze the data from the sites.

Objectives

- Technical improvements of GNSS-IR models
- Maintain/create inventory of GNSS-IR sites that have been used to measure climate variables
- Guidelines for installing good GNSS-IR sites
- Develop and maintain low-cost GNSS-IR sensor hub

- Upgrade and maintenance of open source software/tools and use cases
- Operational showcasing initiative for (near) real-time monitoring of climate variables
- Sponsor software classes

Program of Activities

- We schedule bi-monthly meetings that alternate between member meetings and online GNSS-IR webinar series every other session
- Organizing sessions in international conferences and ICCC workshops.

Members

Brendan Crowell (USA)
John Galetzka (USA)
Médéric Gravelle (France)
Shin-Chan Han (Australia)
Andrew Hoffman (USA)
Tobias Kersten (Germany)
Kristine Larson (USA)
Lin Liu (China-Hong Kong)
Angel Martín (Spain)
Felipe Nievinski (Brazil)
Thalia Nikolaidou (Canada)
Thomas Nylen (Denmark)
David Purnell (Canada)
Alvaro Santamaría-Gómez (France)
Sajad Tabibi (Luxembourg)
Kristy Tiampo (USA)
Wei Wan (China)
Simon Williams (UK)
Surui Xie (USA)

JWG C.6 GNSS mass-market devices in climate and environmental sensing: approaches, opportunities, challenges, and social impact

Chair: Tobias Kersten (Germany)
Vice-Chair: Balaji Devaraju (India)
Affiliations: Commission 4, GGOS

Introduction

At a time of urgent need to combat climate change and promote global cooperation, geo-monitoring with global navigation satellite systems (GNSS) is at the centre of attention. In particular, extreme hydrological and weather situations such as heavy precipitation and floods as well as other hazards such as landslides or rock falls often

happen abruptly and are now more frequently observed under climate change conditions. In order to understand the causes and processes of such changes, long-term monitoring is of high importance. This is also the case for other short to long term changes, e.g., of the snow storage, glaciers, soil moisture, water levels, vegetation, atmosphere, and urban environments. In general, we still know too little about interrelationships of geophysical effects that act in a complex interaction, which is also due to a lack of observations, being often limited by costs, man power or accessibility. Regarding climate and environmental research, all challenges have one thing in common: they are geo-referenced and closely linked to the need to ensure high precision, reliability and repeatability. GNSS is an efficient instrument in the space segment for already 50 years. With the access to mass market products especially in the last two to three decades, geophysical processes of our planet can be monitored more (cost-)effectively also in the user domain, on different scales, from both local to global and in dimension of different time periods.

In this Joint Working Group, we intend to review and redefine methods using mass-market equipment by which dynamic geophysical processes can be monitored by geodetic means and be made available as products or reliable metrics to other disciplines working primarily in the climate and environmental sector. Central to our work is the essential question that goes beyond mere GNSS position determination: how can we exploit the power of mass-market GNSS equipment and data to meet the complex requirements of climate and environmental processes happening on the Earth surface and the atmosphere, not only achieving centimetre or even millimetre-scale accuracies, which is the main focus of positioning, but also exploring the question of what other quantities and variables in each specific domain can be effectively determined. Examples in this context would be the determination of, e.g., snow water equivalent (using GNSS carrier phases and signal strength measurements), the water vapour content in atmospheric layers as well as atmospheric and ionospheric delay (using carrier phase measurements), the wave motion and the sea level height or also the soil moisture, snow height and growth changes of plants and their foliage-effect of trees on GNSS observables (applying e.g., reflected signals). These are all essential variables, which are largely relevant in climate and environmental research.

As climate change is global phenomena, a key objective of this group is not only to bridge the boundaries of technological innovation, but also to enable collaborations and support knowledge transfer among different countries. We see GNSS technology, especially the mass market equipment, as a catalyst for international collaboration including global technology transfer and capacity building. In this way, we are not only advancing geomonitoring, but also contributing to global efforts to combat climate change and its far-reaching consequences.

Objectives

Our JWG goals involve the use of GNSS technology and geomonitoring in various surroundings ranging from fully natural to urban environments to better understand, prepare for, and adapt to the impacts of climate change, such as extreme hydrological and weather events, rising sea levels, changing precipitation patterns as well as changes in short- and long-term hydrological and cryospheric variables. We focus on monitoring

and assessing environmental changes, developing techniques and strategies to make communities and ecosystems more resilient to these challenges.

To achieve our goals, we carefully classify and categorize GNSS units according to their application areas, laying the foundation for seamless integration into global geomonitoring networks. We explore the possibilities of interchangeability between high-performance and low-cost GNSS units, emphasizing their potential to make geomonitoring more efficient and cost-effective, in regions with limited resources and others.

We go on to analyse the practicality and limitations of using mass-market GNSS units in geophysical and geodetic applications, particularly in the context of climate studies. Spatial and temporal scales, result accuracy, and efficiency will be explored to, highlight the way forward.

- Investigate the limitations and capabilities of mass-market GNSS units, w.r.t. standard or high-end devices, with particular emphasis on their applicability to environmental and climate change studies (different scales and resolution i.e., time and space).
- Extend investigation to positioning quality in static and kinematic contexts as applicability to environmental and climate change studies.
- Assessing and finding ways to potentially improve the precision and reliability of mass-market GNSS instruments to meet the critical requirements of geophysical applications.
- Provide a comprehensive overview and classification of GNSS units based on their application areas. Distinguish the unique characteristics of mass-market GNSS units and highlight their potential to make geomonitoring more efficient and cost-effective, especially in resource-limited regions.
- Evaluate interchangeability and interoperability among high-performance, mass-market GNSS units to ensure seamless integration into global geomonitoring networks.
- Promote the use of GNSS technology as a tool to democratize science for international cooperation, technology transfer for effective geomonitoring, and augment climate change adaptation strategies.

Program of Activities

- Ice breaking and closing workshops
- Organising sessions at conferences (such as EGU, AGU, etc.) and (hybrid) splinter meetings
- Commission work (regular meetings)
- Annual webinars on that topic
- Paper / technical report (white paper and/or journal paper) on topics like e.g. review and categorization of devices as well as fields of application / table of scalability vs. precision, field work hints
- Enable the possibility for writing joint research proposals

Members

Franziska Koch (Austria)
Robert Odolinski (New Zealand)
Jens-André Paffenholz (Germany)
Kristine M. Larson (USA)
Inese Varna (Latvia)
Shivam Tripathi (India)
Jacek Paziewski (Poland)
Yong Chien Zheng (New Zealand)
Felipe Geremia-Nievinsk (Brazil)
Makan Karegar (Germany)
Yuanxin Pan (Switzerland)
Günter Retscher (Austria)

JWG C.7 Ground-GNSS trends for climate models

Chair: Marcelo Santos (Canada)
Vice-Chair: Rosa Pacione (Italy)
Affiliations: Commission 4, IGS, IVS, GGOS

Introduction

GNSS Zenith Total Delay (ZTD) estimates are quantities of great interest by climate modellers since atmospheric water vapour is the major greenhouse gas. Therefore, the importance of its accurate, long-term monitoring and evaluation of trends and variability, potentially serving as independent benchmarks to climatological models, both on longer trends derived from GNSS, but also shorter trends, which could be used for assimilation and validation of climate models. ZTD estimates are determined on a regular basis by several processing centers as well as by demand. It has also been demonstrated that series of ZTD estimates can be used for quality control purposes. At the same time, GNSS is reaching the "maturity age" of 30 years when climate normals of ZTD and gradients can be derived. But what would be the best ZTD series to serve the climate community? What series would offer the most realistic trends? A variety of data sets have been used, namely, the ZTD series derived by the third reprocessing campaign (REPRO3), based on a variety of processing modes and models. PPP-based ZTD estimates can also be generated by scientific software suites, including the PPP-derived IGS product. All of that converges to the opportunity to perform quality control and assess ZTD (and gradient) product best suited to climate studies.

Objectives

The main objective is to define proper quality parameters to satisfy the generation and analysis of long-term trends derived from ground GNSS and inter-annual variation. Proposed activities involve the generation of ZTD estimates using PPP by a few centers (e.g., ESA, GFZ, IGS, UNB) and the tropospheric product from IGS, all based

on REPRO3, analysis of trend and harmonics and comparisons with results from the past JWG investigation based on IGS AC estimates.

Program of Activities

- Collaborate with IGS and IVS in the forthcoming reprocessing campaign
- Participate actively in IAG, AGU and EGU conferences and organize sessions
- Organize working group meetings, splinter group meetings at the said symposia

Members

Anna Kloss (Poland)
Galina Dick (Germany)
Haroldo Marques (Brazil)
Jonathan Jones (UK)
Kalev Rannat (Estonia)
Kyriakos Balidakis (Germany)
Mayra Oyola-Merced (US)
Olalekan Isioye (South Africa)
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Raul Valenzuela (Chile)
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Sharyl Byram (US)
Thalia Nikolaidou (Canada)
Yibin Yao (China)
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JWG C.8 Optimal processing and homogenization of GNSS-PW climate data records

Chair: Olivier Bock (France)
Vice-Chair: Galina Dick (Germany)
Affiliations: Commission 4, IGS, GGOS

Introduction

Water vapor plays a key role in the Earth's climate and weather as a dominant greenhouse gas and the most efficient actor of heat transfer from the surface to the atmosphere and from low to high latitudes. As the climate warms, the amount of water vapor in the atmosphere is expected to rise. This implies a cascade of changes in the global and regional water cycles and in weather extremes. Monitoring and understanding the spatial and temporal variability and changes of water vapor are thus of crucial importance. Not surprisingly, water vapor is one of the five priority Essential Climate Variables (ECVs) targeted by the Global Climate Observing System (GCOS). GNSS-Precipitable Water (PW) is currently one of the constituent observing techniques of the GCOS Reference Upper Air Network (GRUAN) and is called to contribute more

massively to GCOS thanks to its widely expanding networks covering all the continents.

In accordance with IAG's general missions, the objectives of this WG are to coordinate the collection, processing, qualification, and interpretation of GNSS-PW observations within the geodetic community and provide scientific guidance on the usage of these data to the climate community.

The motivations for this WG are the following. There are currently no clear guidelines in the geodetic practice on how to produce the most accurate and homogeneous tropospheric parameters (ZTDs, gradients) and convert ZTD to PW. A substantial part of the issues is related with the data processing schemes which are usually tuned to produce accurate station positions and/or satellite products (orbits, clocks), in which the tropospheric parameters are of secondary interest. Whilst station heights and ZTDs are tightly correlated parameters, ZTDs are more prone to absorb short-term observation and modeling errors, and an optimal positioning scheme does not guarantee optimal ZTD estimates. A dedicated tuning of processing models and settings would thus be beneficial to produce more accurate tropospheric products from GNSS measurements (with application also to DORIS and VLBI). Another issue for climate applications comes from the presence of inhomogeneities in the GNSS time series due to instrumental changes, changes in the antenna's environment, or changes in the processing and post-processing procedures. The latter can be circumvented by considering products obtained with fixed processing and post-processing schemes, including consistent and homogeneous auxiliary data. The impact of instrumental changes is handled during the data processing thanks to station metadata (e.g. antenna and radome information provided in site-logs). The other nuisances can be corrected in post-processing homogenization procedures. The elaboration of consistent and valuable GNSS climate data records (CDRs) needs to tackle all these issues and in addition to provide uncertainty estimates associated with each observation.

Objectives

- Bring together experts from the geodetic community to establish optimal processing and post-processing strategies with the aim of minimizing biases and inhomogeneities in tropospheric products (ZTDs, PWs, gradients) and providing realistic uncertainty estimates.
- Provide recommendations on optimal processing and post-processing procedures to produce "climate-grade" tropospheric products, and coordinate their implementation with the IGS Tropo WG and ACs in the framework of future reprocessing campaigns.
- Check with the IGS Infrastructure Committee, IGS ACs, and GGOS that the station metadata information in IGS site-logs and RINEX files is consistent and up to date.
- Evaluate and stimulate the development of Quality Check/Quality Assurance (QC/QA) methods and tools for the analysis and interpretation of GNSS ZTD and PW time series (e.g. outlier detection and screening methods, bias and inhomogeneity detection and correction methods, homogenization tools, noise structure analysis, etc.).

- Provide recommendations on QC/QA methods and tools for the elaboration of consistent GNSS-PW CDRs from reprocessed ZTD solutions.
- Coordinate the intercomparison and qualification of relevant tropospheric data sets (e.g. IGS reprocessings) by comparison with reference observations (e.g. from GRUAN).
- Cooperate with GCOS and the Copernicus Climate Change Service (C3S) to establish a repository of qualified GNSS-PW CDRs (e.g. GRUAN and IGS as reference CDRs and other GNSS networks as baseline CDRs).

Program of Activities

- Organize regular meetings with WG members to share scientific results and coordinate collaborative work
- Elaborate and disseminate recommendations and associated tools for the optimal processing and post-processing/homogenization of GNSS tropospheric products
- Meetings with IGS and GGOS on related topics
- Meetings with GCOS and Copernicus to establish a repository of qualified GNSS-PW climate data records

Members

Samuel Nahmani (France)
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Paul Rebischung (France)
Pierre Bosser (France)
Florian Zus (Germany)
Markus Bradke (Germany)
Tzvetan Simeonov (Germany)
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Alvaro Santamaria (France)
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JWG C.9 Climate Change Signals in High Resolution Surface Water Observations

Chair: Luciana Fenoglio (Germany)
Vice-Chair: Jessica Fayne (USA)
Affiliations: Commission 2, GGOS

Introduction

Altimetry observations cover the global oceans, cryosphere, sea-ice, ice-covered oceans and inland water bodies, providing invaluable geodetic and climatic information for studying the Earth and ocean dynamics and geophysical features. The contribution of surface water change to the global water cycle is monitored globally by satellite altimetric observations of high spatial and temporal resolution. Satellite radar altimeter measurements of sea surface heights have been continuously collected since the early 1990's along the 10-day repeat ground tracks of TOPEX/Poseidon, Jason-1/2/3, and Sentinel-6 missions, along the 35-day repeat ground tracks of ERS-1/2, Envisat and SARAL, and the 27-day repeat ground tracks of Sentinel-3A/-3B. In high pulse repetition frequency radar altimeters, an innovative processing in SAR and SARIN modes reduces the coastal gap and provides water level at higher spatial resolution along-track. This last is increased to about 300 meters by the unfocused-SAR processing and to 0.5 meters, for an integration time of 2 sec, by the fully-focused SAR processing. Since December 2022, the Surface Water and Ocean Topography Mission (SWOT), provides globally observations of Water Surface Elevation (WSE) and water extent (WE) in rivers, lakes, reservoirs and right to the coast with an unprecedent spatial resolution. On ocean, SWOT closes for water height the observational gap between 100 km and 15 km wavelength, while observations of the surface roughness through the backscatter informs on the physical processes at and below the water surface.

To detect climate related signals, we aim to investigate water surface change, river discharge and water storage change on land and surface water level at ice margins, coast and open ocean. For adaptation effort, we look at flood hazard event and to their mapping. We consider to study the impact of the different global terrestrial reference frames, e.g. ITRF2020, DTRF2020, JTRF2020, on both the altimeter measurement processing and the altimeter-derived geophysical parameters. It is agreed that a major limiting factor in the determination of global and regional sea level rise is the uncertainty of the Terrestrial Reference Frames in origin, scale and long-term stability. We propose to investigate the gain obtained by high-resolution (HR) altimetry 1-D and 2-D measurements, and to encourage innovative interdisciplinary research and applications in climate change studies.

Objectives

- Develop an observational-based estimation of the components of the water cycle.
- Extend the existing databases of water height, discharge, water storage, runoff, water extent, sea ice coverage, sea level.
- Develop test cases for flood events to demonstrate the capability of the new space techniques for hazard mapping and early warning application.
- Derive surface component of water cycle collaborating e.g. with space gravimetry, monitor groundwater and total water storage (TWS), sea level, discharge and other Essential Climate Variables (ECV).
- Test different global terrestrial reference frames and their impact on the altimeter-derived parameters, e.g. on sea level rise.

Program of Activities

- Support the IAG International Altimetry Service (IAS) Planning Group in generation of climate-related data products and services
- Support innovative interdisciplinary scientific research and applications for climate change detection
- collaborate with agencies and shakeholders
- Provide a forum for scientific exchange and training courses
- Collaborate with existing ICCC working groups, e.g. JWG C.3, C.4, C.7
- Collaborate with study group SG 2.5.1 of IAG Sub-Commission 2.5 Satellite Altimetry (https://com2.iag-aig.org/sub-commission-25).
- Participate to international science teams, e.g. Ocean Surface Topography (OSTST), SWOT Science Teams and Validation Teams (S3VT, S6VT)
- Collaborate with GGOS Standing Committee PLATO for the improvement of the Reference Frame with Space Techniques (https://ggos.org/about/org/bureau/bno/cwg/plato/).

Members

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Jan Martin Brockmann (Germany)
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JWG C.10 Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry

Chair: Marius Schlaak (Germany)
Vice-Chair: João de Teixeira da Encarnação (Netherlands)
Affiliations: Commission 2, ICCT, GGOS, IGFS

Introduction

Satellite gravity measurements have successfully observed changes in the Earth system for more than two decades and deliver critical information on mass changes linked to climate change. To ensure continuity, the Mass-change And Geoscience International Constellation (MAGIC) is planned to be launched in the next decade, increasing the resolution of mass-change observations. Especially the long-term observation of Terrestrial Water Storage (TWS) and ocean mass are important climate indicators. TWS consists of all water storage over the continents in liquid and frozen states and has recently been declared a new Essential Climate Variable (ECV) in the implementation plan 2022 of the Global Climate Observing System (GCOS). Changes in ocean mass directly impact sea-level changes, and their measurement allows for quantifying Earth's Energy imbalance, essentially driving climate change. The importance of increased resolution and long-term sustained observing systems for TWS is underlined in the IUGG resolution no. 2 in 2023, expressing the chance to enable new science and applications of enormous societal benefit. By ensuring a long-term sustainable operation of satellite gravity missions, applications in the hydrosphere, cryosphere, and ocean can profit from tailored processing products of the long-term data record, trading spatial and temporal resolution for an optimal outcome for the respective cases.

This working group focuses on identifying and implementing spatiotemporally tailored parameterization strategies for satellite gravimetry observations designed for different climate applications. Building up from the simulation environments implemented in previous working groups, parameter models can be evaluated concerning their capabilities to represent climate-related mass transport signals and their feasibility in real data applications. To envision the possibilities that will arise with upcoming satellite gravity missions, improvements expected from MAGIC and future mission concepts shall be investigated next to current single-pair satellite GRACE-type missions. The parameter models shall be defined in close interaction with the respective applications to identify the main criteria to allow new science to emerge from the advanced parameterization strategies.

Objectives

- Create a modeled mass transport series of 30 years for different applications.
- Define temporal-tailored parameter models for specific climate applications in cooperation with the users.
- Compare the impact of local base functions, e.g., Spherical harmonics, Mascon, Slepians, etc., on specific regions and applications.
- Identify frequencies in the interannual variability and evaluate the impact on the long-term trend assessment if they are (not) considered.

Program of Activities

- Meetings within the working group to plan collaboration and share scientific results
- Specialized subgroup meetings for different climate applications
- Contribute actively to ICCC Geodesy for Climate Workshops and organize sessions

- Participation in and contribution to conferences such as GSTM, GGHS, and EGU
- Organizing splinter meetings at said conferences

Members

Alejandro Blazquez (France)
Bert Wouters (Netherlands)
Changqing Wang (China)
David Wiese (USA)
Erik Ivins (USA)
Ingo Sasgen (Germany)
Julia Pfeffer (France)
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Lijing Cheng (China)
Linus Shihora (Germany)
Martin Horwath (Germany)
Matthias Willen (Netherlands)
Özge Günes (Türkiye)
Roland Pail (Germany)
Thorben Döhne (Germany)
Vincent Humphrey (Switzerland)
Wei Feng (China)

Inter-Commission Committee on Marine Geodesy (ICCM)

https://doi.org/10.82507/iag-gh2024_iccm

President: Valérie Ballu (France)
Vice President: Heidrun Kopp (Germany)

ICCM website - www.iccm.iag-aig.org

1 Terms of Reference

The Inter-Commission Committee on Marine Geodesy (ICCM) was first proposed by the Chinese National Committee to the IAG Executive Committee (EC) in Kobe, Japan, in 2017 and then passed at the 6th and 7th meetings of the IAG EC in 2018. The ICCM was formally approved and established following the IUGG General Assembly in Montreal, Canada, in 2019. With over seventy percent of the planet's surface and the most important zones of crustal formation and destruction covered by the oceans, monitoring and understanding the oceans and the seafloor is of highest relevance to secure the human sustainable development. The oceans provide enormous biological and mineral resources while at the same time modulate the climate and weather patterns and serve as an important sink for atmospheric carbon. The oceans and seafloor are crucial to the evolution not only of life, but of the Earth system, yet 80% of marine realm remain unexplored [NOAA]. The research foci of marine geodesy have enormous economic and scientific potential. However, at present, large gaps in ocean surveys, seafloor mapping and remote sensing exist, which necessitate IAG's immediate attention.

Research contributions to marine geodesy have advanced tremendously during the last two decades:

1. seafloor geodetic networks have been initiated and established by countries or regions including North and Central America, Europe, New Zealand and Japan, and in the near future more coastal countries may start seafloor observatory plans;
2. advanced GNSS/acoustic GPS-A techniques have achieved centimeter accuracy in seafloor geodetic positioning, crucial to marine geohazard monitoring, including undersea earthquakes volcanic eruptions, and submarine landslides as well as monitoring of seafloor infrastructure;
3. multi-ocean environment monitoring data are available to potentially improve seafloor geodetic positioning or monitoring of steric sea level and circulations, including temperature and salinity profiles of the Array for Real-time Geostrophic Oceanography (Argo), expendable bathythermograph (XBT) data, ocean-bottom pressure (OBP) data and surface and subsurface ocean current observations.

ICCM strongly encourages research to:

1. enhance frontier research topics on monitoring changes of the ocean and seafloor, such as sea level change, seafloor tectonic motion and seismological events, steric and mass oceanic variations, changes of the surface and subsurface currents, and changes of waves and wind patterns;
2. refine a series of marine geodetic models, including barotropic and baroclinic ocean tide models, marine geoid models, dynamic topography models, and coastal reference models such as the mean high water (MHW) and the high-water line (HWL);
3. improve the accuracy and resolution of the global seafloor topography particularly in the coastal regions by advancing new seafloor geodetic data acquisitions, innovative data processing, and exploring new topography inversion tools;
4. promote the development of seafloor geodesy networks and regional densification, together with reflexions toward the geodetic tying of seafloor reference points into the International Terrestrial Reference Frame (ITRF) in the coastal and deep ocean.

1.1 Objectives

The overall objectives of the ICCM are:

- to shorten the gaps between theory and applications in marine geodesy, and to encourage transdisciplinary integration of the contemporary geodetic sensors, including marine geophysical sensors, oceanic sonar and physical oceanography instrumentation;
- to improve the global realization of the ITRF by connecting the seafloor geodetic network component with it, and to improve current marine geodetic models by including the space, surface and subsurface geodetic observations;
- to encourage the development of marine geodetic methodology, especially for the fusion methods of multi-marine geodetic observations;
- to promote international collaborations in regional marine geodetic surveys, and to develop and establish international conventions for marine geodetic data processing, the seafloor reference frame, and other standards.

ICCM will interact and collaborate with the IAG Commissions, GGOS, and other IAG entities (Services, Projects) to achieve these aims. Stronger interactions with the International Association for the Physical Sciences of the Oceans (IAPSO), the oceanography component of the IUGG is also encouraged.

1.2 Program of Activities

The anticipated ICCM activities include:

- service as (co-)conveners of geodesy sessions at major conferences such as IAG, EGU, AGU, AOGS, IUGG, etc.
- organization of marine geodesy symposia, and publication of special issues of international journals such as Marine Geodesy, Journal of Geodesy, and Advanced Space Research.
- creation and maintenance of a website for disseminating ICCM-related information and data products.

1.3 Structure

The general structure of Inter-Commission Committees is specified in the IAG Bylaws. The Steering Committee includes the President, the Vice President, the Past President, representatives appointed by each Commission, two representatives of the IAG Services, representatives of GGOS, other ICCs (ICCC, ICCT), one Early Career Scientist (ECS) and members. The ICCM activities will be structured in working groups. Due to the inter-commission character of the ICCM, these are always Joint Working Groups (JWGs), affiliated to one or more of the Commissions, GGOS and/or IAG Services. These groups will be established during the first period of the ICCM.

1.4 Steering Committee

- President: Valérie Ballu (France)
- Vice President: Heidrun Kopp (Germany)
- Past President: Yuanxi Yang (China)

Representatives of IAG entities

- Commission 1: Chris Danezis (Cyprus)
- Commission 2: Xiaoli Deng (Australia)
- Commission 3: Carsten Ludwigsen (Denmark)
- Commission 4: Ana Paula Camargo Larocca (Brazil)
- Services - IERS: Henryk Dobslaw (Germany)
- Services - IERS: Ruediger Haas (Sweden)
- GGOS: Yusuke Yokota (Japan)
- ICCT: Shun-ishi Watanabe (Japan)
- ICCC: to be nominated

Members

- Chair of JWG M.1: Pierre Sakic (France)
- Chair of JWG M.2: James Foster (Germany)
- Chair of JWG M.3: Matt Wei (USA)
- Chair of JWG M.4: Tianhe Xu (China)
- Chair of JWG M.5: Shuqiang Xue (China)
- Chair of JWG M.6: Morelia Urlaub (Germany)
- Lifeng Bao (China)
- Rongxing Li (China)
- Felipe Nievinski (Brazil)
- Ian Church (Canada)
- Kaifei He (China)
- Sajad Tabibi (Luxembourg)
- Keiichi Tadokoro (Japan)
- Laurent Testut (France)
- Fanlin Yang (China)

Representative of Early Career Scientists

- Pierre Sakic (France)

1.5 Overview of Joint Working Groups

Hereafter, the ICCM Joint Working Groups (JWGs) for the 2023-2027 period are listed, together their Chairs (and Vice-Chairs for some of them) and their affiliations with other IAG entities.

JWG M.1 Data and tools exchange
Chair: Pierre Sakic (France)
Affiliations: IERS, GGOS

JWG M.2 GNSS-Acoustic technologies and experiments
Chair: James Foster (Germany)
Affiliations: Commissions 1, 3, 4

JWG M.3 Seafloor pressure - an essential variable for monitoring vertical deformation as well as ocean dynamics
Chair: Matt Wei (USA)
Affiliations: Commission 3, ICCC

JWG M.4 Realtime and post-processed kinematic GNSS positioning: status and perspectives for seafloor and sea-surface positioning
Chair: Tianhe Xu (China)
Vice-Chair: Zhiguo Deng (Germany)
Affiliations: Commission 4

JWG M.5 Acoustic Delay Corrections for Submarine Geodesy
Chair: Shuqiang Xue (China)
Affiliations: Commission 4, IERS

JWG M.6 How marine geodesy can better contribute to coastal hazards assessment and mitigation
Chair: Morelia Urlaub (Germany)
Vice-Chair: Lifeng Bao (China)
Affiliations: Commission 3

2 Joint Working Groups

JWG M.1: Data and tools exchange

Chair: Pierre Sakic (France)
Affiliation: IERS, GGOS

Terms of Reference

This JWG aims to enable the shareability of the seafloor geodesy data collected by the different working groups worldwide and then give better visibility to these data while respecting the FAIR principles. Indeed, clearly defined exchange standards and effective data sharing might be a solid foundation for concrete exchanges between the research groups working on seafloor geodesy questions, thus initiating future international collaborations and, in the long term, establishing a global underwater geodetic observation network.

Objectives

- Enable the shareability of the seafloor geodesy data collected by the different working groups around the world;
- Give better visibility to these data;
- Respect the FAIR data principles (Findable, Accessible, Interoperable, Reusable).
- A special emphasis has to be given to the interoperability of seafloor geodetic data, i.e., the possibility to easily use data of one working group with the software of another, for instance.
- Identify how data can be easily stored in existing repositories or establish expectations for new repositories.
- Establish community-supported data standards that can be adopted by the repositories/data centers.

Program of Activities

The working group initially discussed a range of seafloor geodetic techniques. Given the considerable interest in GNSS-Acoustic by those who participated in this discussion, it was agreed to start with this technique. Nevertheless, the task force is interested in a wide range of techniques, and will likely revisit other techniques in the future. Techniques of future interest may include:

- Acoustic ranging
- Ocean bottom pressure sensors (OBP)
- Tiltmeters
- Optical Fiber Strainmeter
- Seafloor gravimetry
- Mast Seafloor <> Surface combining GNSS+attitude measurement
- Multi-beam Bathymetry

It would be highly valuable if other working groups similar to the current one could emerge within the task force to consider the other techniques mentioned above, like the OBP for instance.

Members

Pierre Sakic (France); Chair
Valérie Ballu (France)
Jesse Hutchinson (Canada)
Martin Heesemann (Canada)
Kaifei He (China)
Motoyuki Kido (Japan)
Yuto Nakamura (Japan)
David Schmidt (USA)
John DeSanto (USA)
Keiichi Tadokoro (Japan)
Surui Xie (USA)
Yusuke Yokota (Japan)
Shun-ichi Watanabe (Japan)

JWG M.2: GNSS-Acoustic technologies and experiments

Chair: James Foster (Germany)
Affiliation: Commissions 1, 3, 4

Terms of Reference

GNSS-Acoustic techniques allow us to measure positions and displacements of the seafloor – an environment that was previously almost entirely unobserved by geodetic techniques. In the last decade, there have been major advances in technologies and processing approaches that have lead to a burgeoning range of research experiments and technological developments. In this rapidly evolving field, many different groups, both academic and commercial, are exploring new technical approaches and strategies, investigating new study areas, and employing new processing algorithms. Although the cost for seafloor geodetic equipment, deployments, and measurement campaigns has been greatly reduced over the last few years, it remains an expensive frontier of research and development. Consequently, it becomes imperative to ensure that there is a venue for the exchange of information about the latest seafloor geodetic technologies and experiments in order to ensure that efforts are not duplicated, that the best available existing solutions appropriate for a particular problem can be found, that potential partners for collaborative efforts can be identified, and that people able to provide crucial guidance and information can be connected with. The Joint Working Group for "GNSS-Acoustic technologies and experiments" is tasked to develop a publicly available web-based document that will provide key information for all significant completed, ongoing, and upcoming seafloor geodetic experiments, and its enabling technologies. This living document will be available as a resource for all individuals interested in seafloor geodesy and the technologies and projects that have, or will, use this geodetic technique.

Objectives

- To provide a publicly accessible catalog of GNSS-Acoustic experiments and technologies;
- To encourage the voluntary listing of relevant technologies and experiments by the PIs and/or companies that are developing/deploying them.

Program of Activities

- Define the form & structure of the web page that will provide key summary information concerning seafloor techniques, applications, experiments and links to relevant PIs, and companies.
- Establish the categories, and minimum necessary information fields and optional sections for inclusion in the web document.
- Solicit document listings from all known active parties in seafloor geodesy.
- Publish document for comments and ongoing contributions.

Members

James Foster (Germany); Chair
Shuqiang Xue (China)
Yusuke Yokota (Japan)
Mark Zumberge (USA)
Laura Wallace (Germany)
Benoit Taisne (Singapore)

JWG M.3: Seafloor pressure - an essential variable for monitoring vertical deformation as well as ocean dynamics

Chair: Matt Wei (USA)
Affiliation: Commission 3, ICCC

Terms of Reference

Seafloor pressure data is quite unique comparing to other commonly used seafloor geodetic methods because it can continuously measure seafloor deformation in the vertical direction. Pressure sensors can be connected to cabled networks or deployed as a temporal array for a couple of years. For the past decade, cabled networks with seafloor pressure sensors have been built in Japan, USA and Canada. Many temporal arrays have been deployed in New Zealand and USA. Most of the data have been used to monitor marine volcano deformation such as Axial Seamount in USA and detect slow slip events in subduction zones such as New Zealand. They provided the needed temporal and spatial resolution at a reasonable cost which are not possible using other methods. The main challenge of using seafloor pressure data is the large oceanic noise. In most places, the ocean noise is at about a few centimeters equivalent of water. It is small comparing to large deformation caused by major earthquakes and volcanic eruption. However, it is quite large comparing to the long-term tectonic loading and

slow slip events in subduction zones. On the other hand, the ocean noise for geophysicists is physical oceanographer's signal. Regional observations of bottom pressure are sensitive to mesoscale circulation effects such as eddies, current meanders, and coastal trapped waves. At basin scales, bottom pressure can provide constraints on circulation mass budgets. Therefore, seafloor pressure is an essential variable for monitoring ocean dynamics too. Reducing water noise to improve our ability to detect small tectonic vertical deformation requires collaborations with physical oceanographers, which is a main objective of this working group.

Another challenge of using seafloor pressure data is the instrumental drift. Most currently used pressure sensors have an uncertain instrumental drift of a few to 10ths of centimeters per year in the first few months or years. This prevented us to monitor long-term, steady tectonic loading. Significant progress has been made to calibrate the instrumental drift and commercial drift-free pressure sensors have been developed and are available now. However, the long-term performance of these drift-free sensors is still a question.

This working group is actively promoting collaborations to solve these challenges so the scientific community can use seafloor pressure data to solve important questions. Seafloor pressure should be combined with GNSS-A and/or direct ranging to provide a 3D view of seafloor deformation.

Objectives

- To reduce ocean noise in seafloor pressure data for better measurements of vertical tectonic deformation;
- To better understand tectonic processes and assess related ocean hazards;
- To encourage collaborations between geophysicists and physical oceanographers;
- To promote international collaborations.

Program of Activities

- Organize workshops between geophysicists and physical oceanographers.
- Create a website for easy access of existing seafloor pressure data.
- Organize sessions in international conferences such as AGU Fall Meeting, Ocean Sciences Meeting, and IUGG meeting.

Members

Matt Wei (USA); Chair
Erik Fredrickson (USA)
Karina Ramos Musalem (Mexico)
Randy Watts (USA)
Heidrun Kopp (Germany)
Valérie Ballu (France)

JWG M.4: Realtime and post-processed kinematic GNSS positioning: status and perspectives for seafloor and sea-surface positioning

Chair: Tianhe Xu (China)
Vice-Chair: Zhiguo Deng (Germany)
Affiliation: Commission 4

Terms of Reference

Global Navigation Satellite System (GNSS) is widely applied in seafloor and sea-surface positioning. For instance, GNSS installed in a buoy can be used to facilitate the measurement of sea surface wave and tidal height, calibration of satellite altimeters, estimation of precipitable water vapor, and even monitoring of tsunamis. Additionally, GNSS/Acoustic (GPS-A) techniques are commonly employed for hydrophone position during seismic exploration, seafloor geodetic positioning, monitoring oceanic plate motion, and studying earthquake cycle deformation, etc.

Precise Point Positioning (PPP) is able to provide decimeter to centimeter-level kinematic positioning accuracy worldwide by using precise GNSS ephemeris. This makes PPP a preferred GNSS positioning technology in ocean environments. International GNSS Service (IGS) has substantially generated precise products with certain delays. These products can be freely accessed for users to carry out post-processed PPP. In response to the real-time application demands, IGS introduced an open-access real-time service (RTS) in 2013, which includes orbit, clock, and other corrections. The advent of RTS allows users to carry out real-time PPP without paying any fees. However, challenges arise in receiving RTS corrections due to the lack of internet-based infrastructures in oceanic regions. Several commercial companies have developed real-time PPP systems, such as OmniStar, StarFire of NavCom, and StarFix of Fugro. In recent years, navigation satellite systems, such as QZSS, Beidou, and Galileo, have also been broadcasting PPP services. In addition, the applications of observable-specific signal bias and atmospheric correction for augmented PPP via Short Message Communication (SMC) or other methods have great potential.

Nevertheless, the lower positioning accuracy and longer convergence time have always been a persistent issue for PPP, as compared to Real-time kinematic (RTK) positioning, particularly in the open ocean where there is no reference station network used to generate regional augmentation corrections. With the increasing deployment of unmanned intelligent systems in marine domains, in addition to high precision, high credibility has also been a key concern. The integrity monitoring server is the tool to ensure the positioning reliability and to obtain the protection level. However, methods, techniques, models, and algorithms for PPP integrity monitoring necessitate further development. This is the reason why it is worth focusing on the seafloor and sea-surface kinematic GNSS positioning within the ICCM.

Objectives

- To investigate the ocean environment influence on the kinematic GNSS PPP positioning and to work out solutions to decrease environment influence;

- To encourage the development of methodology to accelerate PPP convergence in the open ocean;
- To develop PPP integrity monitoring techniques to meet the increasing demands of unmanned intelligent systems;
- To promote international collaborations in seafloor and sea-surface kinematic GNSS positioning.

Program of Activities

- To encourage the seafloor and sea-surface kinematic GNSS data share among scholars and academic societies.
- Organization of real-time and post-processed kinematic GNSS positioning for seafloor and sea-surface positioning symposia, and publication of special issues of international journals such as Marine Geodesy and GPS Solutions.

Members

Tianhe Xu (China); Chair
Zhiguo Deng (Germany); Vice-Chair
Zhixi Nie (China)
Zhetao Zhang (China)

JWG M.5: Acoustic Delay Corrections for Submarine Geodesy

Chair: Shuqiang Xue (China)
Affiliations: Commission 4, IERS

Terms of Reference

The Global Navigation Satellite System-Acoustic (GNSS-A) technique has provided key observations for submarine geodetic positioning and has become the most potential tool for seafloor geodetic network establishment to extend the terrestrial network into the ocean. Nowadays, low-cost GNSS-A systems based on unmanned platforms are revolutionizing the traditional, costly technique based on the survey ship conducting seafloor geodetic observation and in-field sound speed measurement. This offers the possibility of achieving large-scale and even global, nearly real-time seafloor geodetic applications to shorten the gap between terrestrial geodesy and submarine geodesy. However, GNSS-A measurements encounter challenges in achieving precise ranging due to spatio-temporal variations of sound speed. It is feasible to obtain the sound speed profile (SSP) in the field to achieve centimeter-level precision of seafloor geodetic positioning, but the process remains costly and restricts the application of unmanned systems due to their limitations in equipping the SSP profiler.

Drawing on GNSS atmospheric delay estimation, efforts focusing on sound speed variation effects and mitigating these effects have been devoted to improving positioning precision. The acoustic delay relative to the reference SSP has been investigated in the past, and GNSS-A acoustic observation models appended with acoustic delay parameters have been developed. Facilitated by Marine Environment Monitoring

Services (MEMS), the marine environment datasets (MEDs), such as the monthly or daily ocean temperature and salinity profiles, are available for public access, e.g., the World Ocean Atlas (WOA) datasets from the National Centers for Environmental Information (NCEI), the datasets released by the Met Office Hadley Centre, and the datasets released by Mercator Ocean International. With the improvement of spatio-temporal resolution of MEDs, datasets offer a new way to conduct precise seafloor geodetic positioning in the absence of in-filed SSP.

Nevertheless, most of the current studies are to correct the time observations based on the reference SSP, which results in a theoretical gap between well-developed space geodesy and developing submarine geodesy. To reduce the cost of seafloor geodetic measurement and enhance the real-time capability of GNSS-A applications, the acoustic ranging observation corrections, which are implemented by a conventionally defined sound speed and MEDs to produce a priori acoustic delay corrections, need to be further developed, just like GNSS's tropospheric delay corrections. This is of significant importance for conducting submarine geodetic measurements without relying on in-field SSP measurements, especially utilizing unmanned platforms, as well as for future, promising real-time services of submarine geodesy.

Objectives

- To develop a ranging-based seafloor geodetic positioning theory and relevant models and algorithms compatible with the space geodetic positioning technique, e.g., GNSS;
- To contribute to developing future geodetic products and services for remoting ocean environmental changes, refer to a well-selected public global oceanic environmental grid dataset.

Program of Activities

- Working together with ocean physicists to establish a well-defined conventional sound speed serving as a reference for developing acoustic delay products based on one or more well-selected oceanic environmental grid datasets.
- Closely collaborating with the JWG M.1 "Data and tools exchange" to establish the data formats for the acoustic delay correction products and to create models and algorithms that process the oceanic environment re-analysis or forecast product to produce correction product data, which is then used to produce the acoustic delay corrections.
- Interacting with the JWG M.1, actively taking part in GNSS-A experimental trials with correction products, and then making the experimental results available to the public and posting them online.

Members

Shuqiang Xue (China); Chair
James Foster (Germany)
Erik Fredrickson (USA)
Pierre Sakic (France)

Surui Xie (USA)
Cheng Yang (China); contact to Commission 4
Shuang Zhao (China); contact to IERS

JWG M.6: How marine geodesy can better contribute to coastal hazards assessment and mitigation

Chair: Morelia Urlaub (Germany)
Vice-Chair: Lifeng Bao (China)
Affiliation: Commission 3

Terms of Reference

Seafloor deformation over long and short time scales can cause hazards to human life, marine ecosystems, and maritime activities. They can be subdivided into those that act on long time scales (e.g. sea level rise or ocean tidal changes) and those that act on short time scales (e.g. tsunami sources such as earthquakes and landslides or submarine volcanic activity). Monitoring is possible with remote sensing techniques from satellites and ships as well as with instrumentation on the ground (the seafloor).

Objectives

This group aims to explore how seafloor geodesy can help to better understand and detect hazardous seafloor movements. We aim to collate studies that characterise hazardous seafloor movements and to provide a platform for scientific and practical exchange for applications of seafloor geodesy to marine geohazards.

Program of Activities

We collate current publications. Regular meetings and attracting more members are the key activities for the upcoming period.

Members

Morelia Urlaub (Germany); Chair
Lifeng Bao (China); Vice-Chair

IAG Project - Novel Sensors and Quantum Technology for Geodesy (QuGe)

https://doi.org/10.82507/iag-gh2024_quge

President: Jürgen Müller (Germany)
Vice President: Marcelo Santos (Canada)

QuGe website - www.quge.iag-aig.org

1 Terms of Reference

The advancements in quantum physics over the past decade have ushered in a new era of possibilities, particularly in satellite geodesy and terrestrial gravity sensing. The IAG Project Novel Sensors and Quantum Technology for Geodesy (QuGe) harnesses these breakthroughs alongside innovative measurement concepts. It is a collaborative project between physics and geodesy, which aims to leverage quantum technology's potential for a myriad of groundbreaking applications in geodesy. Changes in the Earth system manifest in mass variations, spanning the hydrosphere, geosphere, and atmosphere. These changes are intricately linked to gravitational data, necessitating higher resolution and accuracy, the highest are achievable only through quantum technology. Stable reference systems, crucial for monitoring Earth's dynamic processes, rely heavily on precise timekeeping, marking clocks as pivotal components in future endeavors. The QuGe project stands as a unique platform for developing and testing novel concepts and observation systems, with potential applications extending to exploration and navigation.

Synergies of technology development with geodetic and geophysical modeling are imperative. Optical ranging, atom-interferometric accelerometry, and chronometric levelling are proposed methods to overcome limitations in traditional geodesy [1]. These innovative techniques promise unparalleled accuracy in observing mass variations across various spatial and temporal scales, thus, facilitating applications ranging from groundwater basin monitoring to understanding global mass transport in oceans.

QuGe, with its fusion of quantum physics and geodesy expertise, bridges engineering prowess with fundamental research, propelling the boundaries of gravimetric Earth observation and reference system realization.

1.1 Objectives

The objectives are grouped into three primary areas, reflecting its working groups:

1. Atom interferometry for ground-based and space-based gravimetry (quantum gravimetry) will offer a wide range of applications. This includes rapid local gravimetric surveys, exploration activities, and the monitoring of gravimetric Earth system processes with exceptional spatial and temporal resolution. In space, atom interferometry will revolutionize accelerometry and inertial sensing. Combining atom

interferometry with electrostatic accelerometers in hybrid systems could broaden the spectral range for future inertial sensing and navigation endeavors. Its impact will extend to satellite navigation enhancement and the development of next-generation gradiometer missions (such as GOCE follow-on).

2. Laser-interferometric ranging between test masses in space, with nanometer precision, represents another groundbreaking development. This technology, originally designed for gravitational wave detection and validated in missions like LISA/Pathfinder, is being adapted for geodetic measurements, as demonstrated by GRACE-FO. Further refinements, such as tracking satellite swarms, may become feasible in the coming years. Optical techniques may also find application in future accelerometers for test mass sensing and advanced space-based gradiometry.
3. Frequency comparisons of highly precise optical clocks interconnected via optical links offer insights into differences in gravity potential over significant distances (relativistic geodesy). In the future, relativistic geodesy employing clocks will reassess how height systems are defined and realized, both locally and globally. Clock measurements will also furnish long-wavelength gravity field data and enhance the accuracy of the International Atomic Time standard (TAI). They are crucial for all space geodetic techniques and for establishing and connecting reference systems. Additionally, high-performance clock networks could support Global Navigation Satellite Systems (GNSS).

In all three research domains, alongside with the advancements in measurement systems and techniques, it is imperative to establish robust theoretical foundations for analysis models. This necessitates dedicated geodetic and relativistic modeling of the various gravity field parameters and measurement concepts involved.

1.2 Program of Activities

The IAG project QuGe fosters and encourages research in the areas of its working groups by facilitating the exchange of information and organizing workshops and sessions, either independently or at major inter-disciplinary conferences such as EGU, AGU, COSPAR, IAG Scientific Assembly and Symposia, and IUGG General Assembly. QuGe will endeavour to improve its visibility and demonstrate the benefit of the new technologies in geodesy and beyond.

Within its scope, QuGe will continue contributing to related research activities and missions studied and pushed forward by NASA, ESA, EU and national programs on the use of quantum technology. Examples are the missions MAGIC, CARIOQA, ACES. QuGe will strengthen the contacts to industry, enabling good exchange with science, while the major focus of QuGe will remain on research.

The activities of its working groups, as described below, constitute the activities of the Project, which will be coordinated by the Steering Committee and summarized in annual reports to the IAG Bureau.

Project QuGe and its WGs will closely collaborate with other components of IAG such as specific Joint Study/Working Groups of the IAG commissions, ICCC and ICCT as well as with related services like IERS. Moreover, representatives of external bodies (e.g., from industry or research institutions) will collaborate in the WGs.

1.3 Structure

Working Groups

WG Q.1 Quantum gravimetry in space and on ground
Chair: Franck Pereira (France)
WG Q.2 Laser interferometry for gravity field missions
Chair: Samuel Francis (USA)
WG Q.3 Relativistic geodesy with clocks
Chair: Jakob Flury (Germany)

1.4 Steering Committee

The steering committee will meet at least twice per year.

- President: Jürgen Müller (Germany)
- Vice President: Marcelo Santos (Canada)
- Chairs of WG Q.1: Franck Pereira (France), Marvin Reich (Germany)
- Chairs of WG Q.2: Samuel Francis (USA), Kirk McKenzie (Australia)
- Chairs of WG Q.3: Jakob Flury (Germany), Pacôme Delva (France)
- Representative of IAG Comm. 1: Urs Hugentobler (Germany)
- Representative of IAG Comm. 2: Srinivas Bettadpur (USA)
- Representative of IAG Comm. 3: Rebekka Steffen (Sweden)
- Representative of IAG Comm. 4: Allison Kealy (Australia)
- Representative of Early Career Scientists: Öykü Koç (Italy)
- Representative of IGFS: Sylvain Bonvalot (France)
- Representative of GGOS: George Vergos (Greece)
- Representative of IHRF: Laura Sánchez (Germany)
- Member at large: Wenbin Shen (China)
- Member at large: Claudia Tocho (Argentina)

2 Working Groups

WG Q.1: Quantum gravimetry in space and on ground

Chair: Franck Pereira (France)
Vice-Chair: Marvin Reich (Germany)

Terms of Reference

On ground, quantum sensors based on matter wave interferometry with cold atoms are very well suited for rapid and very precise gravity sensing. They can be used as registration instruments and as absolute gravimeters with sub-µGal accuracy. Mobile devices are developed for field campaigns and large-scale stationary devices for achieving extreme precision. While the former enable new strategies for local and regional gravity surveys, the latter will provide a new gravity standard in the future. In space, the long-term stability and low noise level of quantum sensors will allow improving the spatial gravity field models in GOCE-type gradiometer missions. The determination of mass transport processes on Earth at low and medium degrees in GRACE-type missions will benefit from quantum accelerometers providing measurement of the specific non-conservative forces. In addition, hybrid systems (i.e. a combination of electrostatic and atom-interferometric accelerometers) can cover a wider spectral range, which will greatly support navigation and inertial sensing on ground and in space. The goal of this WG is to elaborate the major benefits and most promising applications of atom interferometry for gravimetry and inertial sensing in space and on ground.

Objectives

- Terrestrial quantum gravimeters and applications scenarios (including airborne and marine instruments);
- (Hybrid) accelerometers for space missions and spacecraft navigation;
- Atom interferometric gradiometry;
- Elaboration of further applications (like atmosphere research, relativity tests, etc.) and corresponding space demonstrators (e.g., pathfinder missions);
- Elaboration of synergies among different science topics in a single mission (Earth observation and fundamental physics, navigation and space exploration, several scenarios for Earth observation, e.g. gravimetry, atmospheric research and magnetometry).

Members

Franck Pereira (France); Chair
Marvin (Reich); Vice-Chair
Roland Pail (Germany)
Ernst Maria Rasel (Germany)
Thomas Lévèque (France)
Oliver Carraz (Netherlands)
Steffen Schön (Germany)

Yuichi Imanishi (Japan)
Jeffrey Kennedy (USA)
Shuqing Wu (China)
Nan Yu (USA)
Andre Gebauer (Germny)
Markus Krutzik (Germany)
Bastian Leykauf (Germany)
Ashton Flinders (USA)
Rainer Dumke (Singapore)
Nassim Zahzam (France)
Przemyslaw Dykowski (Poland)
Brynle Barrett (Canada)
Federica Migliaccio (Italy)

WG Q.2: Laser interferometry for gravity field missions

Chair: Samuel Francis (USA)
Vice-Chair: Kirk McKenzie (Australia)

Terms of Reference

GRACE has excellently demonstrated the great potential of inter-satellite tracking to determine time-variable gravitational signals which are related to mass transport processes in the Earth system. Examples are ice mass loss in Greenland and Antarctica, ground water loss in Asia, droughts in USA, quantification of the global water cycle, mass contribution to sea level rise, mass variation due to land uplift in North America and Scandinavia, or mass changes related to earthquakes. To increase the resolution and to extend the time series, GRACE Follow-On (GRACE-FO) was launched in May 2018, carrying as demonstrator a Laser Ranging Interferometer (LRI) which is able to approach an accuracy of tens of nm for inter-satellite ranging.

The GRACE-FO LRI continues to operate in-orbit with performance well below requirements. No signs of optical contamination or degradation have been seen after 5 years of operation and there have been few unplanned interruptions to tracking. Gravity fields derived from LRI are consistent with those derived from primary microwave instrument, while offering improved performance at high frequencies. The LRI will be the primary instrument on the NASA/ DLR GRACE Continuity (GRACE-C) mission. Optical sensing of the motion of test masses in the gravitational field with nanometer accuracy and beyond can be realized in various measurement concepts such as in ranging between satellites like in GRACE-FO or future swarms of satellites. Further concepts apply LRI for sensing single test-mass motion (accelerometry) or multiple test-mass constellations within one satellite (GOCE-type gradiometry). The overall goal of this WG is to study novel concepts including optical sensing for inter-satellite tracking, accelerometry and gradiometry, and its applications for next generation gravity field missions.

Objectives

- Interferometric Laser Ranging between swarms of satellites;
- Accelerometry with optical readout and application scenarios;
- Gradiometry with optical readout;
- Hybrid sensors and measurement concepts;
- New concepts for future satellite gravity missions.

Members

Samuel Francis (USA); Chair
Kirk McKenzie (Australia); Vice-Chair
Michael Murböck (Germany)
Robert Spero (USA)
Vitali Müller (Germany)
Gerhard Heinzel (Germany)
Jürgen Kusche (Germany)
Felix Landerer (USA)
David Wiese (USA)
Peter Bender (USA)
Gilles Metris (France)
Christophe Le Poncin-Lafitte (France)
Shuanggen Jin (China)
Christopher Woodruff (USA)
Brent Ware (USA)
Frank Flechtner (Germany)
Markus Hauk (Germany)
Thomas Papanikolaou (Denmark)
Andrew Wade (Australia)
Emily Rose Rees (Australia)
Clément Courde (France)
Julien Chabé (France)
Julie Rolla (USA)

WG Q.3: Relativistic geodesy with clocks

Chair: Jakob Flury (Germany)
Vice-Chair: Pacôme Delva (France)
Consultant from Physics: Christian Lisdat (Germany)

Terms of Reference

Optical clocks are sensitive to the gravity potential in which they are operated. The comparison of two clocks will reveal a frequency offset from the value expected from side-by-side comparisons, that can directly be related to the potential difference between both clocks. The best optical clocks now reach resolutions of better than 0.1 m^2/s^2, transportable ones about 1 m^2/s^2. They can be achieved already after few hours of averaging.

We will evaluate how this technique can be used to generate unified and long-term stable height networks and reference systems. This includes discussing the feasibility of realizing a datum by reference to e.g., a space-borne clock with ideally negligible gravitational interference. Future clock networks might also be used as ground-truth for space missions or even to bridge gaps in satellite observations.

Other aspects to be addressed are the application of observed time-variable signals in de-aliasing of satellite observations. Sensor fusion concepts will be discussed to utilize the different spatial integration characteristics of clocks and other gravity sensors so as to disentangle local and extended signal sources.

In summary, the goal of this WG is to use clock measurements for determining differences of physical heights and gravity potential for various geodetic applications.

Objectives

- Clock networks for unification of height systems;
- Gravity field recovery on ground;
- Application to realize reference systems, including dedicated space clocks;
- Further applications (height/potential variations);
- Potential satellite missions for long-wavelength gravity field recovery, including optical links for comparing the space clocks.

Members

Jakob Flury (Germany); Chair
Pacôme Delva (France); Vice-Chair
Christian Lisdat (Germany)
Claude Boucher (France)
Davide Calonico (Italy)
Pascale Defraigne (Belgium)
Ropesh Goyal (India)
Jochen Kronjäger (Germany)
Hua Guan (China)
Chris Hughes (UK)
Sergei Kopeikin (USA)
Jürgen Kusche (Germany)
Claus Lämmerzahl (Germany)
Marie-Françoise Lequentrec (France)
Guillaume Lion (France)
Andrew Ludlow (USA)
Helen Margolis (UK)
Elena Mazurova (Russia)
Nathan Newbury (USA)
Bijunath Patla (USA)
Nikos Pavlis (USA)
Paul-Eric Pottie (France)
Ulrich Schreiber (Germany)
WenBin Shen (China)

Simon Stellmer (Germany)
Yoshiyuki Tanaka (Japan)
Giulio Tagliaferro (France)
Pieter Visser (Netherlands)

Communication and Outreach Branch (COB)

https://doi.org/10.82507/iag-gh2024_cob

President: Szabolcs Rózsa (Hungary)
Secretary: Martin Sehnal (Austria)

Website - www.iag-aig.org

1 Developments

The Communication and Outreach Branch (COB) was created by the IAG Council at its special meeting in Budapest, 7 September 2001. A Call for Participation was issued by the IAG Central Bureau to fill this position.

The offer of the Hungarian Academy of Sciences (HAS)/Budapest University of Technology and Economics (BME) was elected by the Executive Committee at its meeting in Nice, 11 April, 2003. The IAG Council at the 23rd IUGG/IAG General Assembly (Sapporo, Japan, 30 June-11 July, 2003) has confirmed this election. Thus, the COB started its activities in July 2003, and the period of 2023-2027 will be the sixth term of the COB operated by the BME.

The COB is one of the components of the IAG. According to the IAG Statutes (Article 5), the COB is the office responsible for the promotional activities of the IAG and the communication with its members.

2 Terms of Reference

The responsibilities and tasks of the COB are defined by the Article 16 of the IAG By-laws. The fundamental role of the COB is to provide the IAG with communication, educational/public information and outreach links to the members, to other scientific organizations and to the world as a whole. The responsibilities of the COB include the following:

- Promote the recognition and usefulness of geodesy in general and the IAG in particular.
- Publications (such as newsletters) and social media platforms.
- Membership development
- General information service and outreach

The COB assists the IAG Secretary General in the following tasks, as required:

- Maintenance of the IAG website.
- Setting up IAG schools.
- Organizing meetings and conferences.

Major decisions related to the operations of the COB are made by a Steering Committee consisting of the following voting members:

- COB President.
- IAG Secretary General.
- Editor-in-Chief of the Journal of Geodesy.
- Editor-in-Chief of the IAG Symposia Series.
- Up to five other members appointed by the IAG Executive Committee on the recommendation of the President of the COB.

3 Program of Activities

According to the structure of the IAG, the individual membership has been introduced in addition to the traditional National Members. However, the individual membership requires a more commercial, member-oriented operation of the IAG. The main purpose of the COB is to promote communication and interaction among all its members and to facilitate the work of IAG in general. Therefore, the COB is a permanent office for publication, publicity and visibility of the IAG.

The activities of the COB are split into two main groups:

- communicational activities, and
- membership development and promotional activities which enable the growth of the IAG.

One of the major tasks of the COB is to create and maintain the communication channels within the IAG. Our intention is to provide a simple, structured way of communication using various information technologies. The communication of the IAG is done using the following channels:

- the official IAG website (see the chapter IAG on the Internet in this Handbook),
- publication of the IAG Newsletters and the Geodesist's Handbook in cooperation with the IAG Office.

The official IAG website acts, on one hand, as the most important interface to the outside community, and on the other hand, it is the first pillar of the communication infrastructure of the IAG. Therefore, the content of the website is defined to support both roles. The members receive the announcements and Newsletters via e-mail and through the website. The electronic version of the Newsletter is published monthly on the IAG website and is distributed to the members in WEB and PDF format via e-mail. A selection of the Newsletter articles is published in the Journal of Geodesy.

COB is active in the membership development and promotional activities. The major channel of promotional activities is the IAG website. Additionally, several brochures and leaflets are available for download and printing, which

- introduce the IAG to the global community,
- emphasize the mission statement of IAG, and
- describe the advantages of being an IAG member.

Our intention is that these brochures should be available at every conference organized and/or sponsored by IAG. Therefore the COB should also represent IAG at all

major meetings (including not only IUGG General Assemblies, IAG Scientific Assemblies, AGU and EGS meetings, but also at IAG-sponsored meetings) with different materials (brochures, etc). These brochures are also made available for download from the IAG website (https://www.iag-aig.orgwww.iag-aig.org).

Another important task of COB is to promote and support the outreach activities of IAG. We plan to collect the existing materials supporting primary and high-school education as well as promoting geodesy to students. Moreover, additional syllabus and exercises are to be developed.

The COB plans to contribute to the membership development of IAG by finding geodesy-related contacts in non-member countries and encourage these countries to become IUGG members, by establishing contacts with scientific/educational entities or governmental agencies.

4 Steering Committee

Ex officio voting members

- COB President: Szabolcs Rózsa (Hungary)
- IAG Secretary General: Daniela Thaller (Germany)
- Editor-in-Chief of the JoG: Peiliang Xu (Japan)
- Editor-in-Chief of the IAG Symposia Series: Jeff Freymueller (USA)
- Editor-in-Cheig of the IAG Symposia Series: Laura Sanchez (Germany)

Other voting members

- COB Secretary: Martin Sehnal (Austria)
- Newsletter Editor: Gyula Tóth (Hungary)
- Assistant IAG Secretary General: Christina Dimopoulou (Germany)
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5 COB Office

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Part IV

Global Geodetic Observing System (GGOS)

The Global Geodetic Observing System (GGOS)

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GGOS website - http://www.ggos.org

1 Terms of Reference

1.1 Preface

The proposal for the Global Geodetic Observing System (GGOS) was developed by the GGOS planning group between 2001 and 2003 according to the Bylaws of the IAG. The proposal was accepted by the IAG Executive Committee and the IAG Council at their meetings during the XXIII General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Sapporo in July 2003. GGOS was endorsed by the IUGG through Resolution No. 3 at the same General Assembly. Changes in the IAG Bylaws in 2007 resulted in GGOS being recognized as an integral component of IAG along with Services and Commissions. This transformed the status of GGOS from that of an IAG Project to an IAG component. Specific to GGOS are IAG Bylaw numbers 1(d) and 15. The Terms of Reference (ToR) of GGOS are regularly updated according to changes in the Statutes and Bylaws of the IAG, new strategic challenges for GGOS, achieved objectives, and organizational changes to meet new user needs or

to be in line with global initiatives in geodesy matters. Previous versions of the GGOS ToR are available in the Geodesist's Handbooks of 2008, 2012, 2016 and 2020.

The ToR presented in this document introduce some minor changes to be consistent with the recent changes to the IAG Statutes and Bylaws and to update the structure of GGOS. Changes to the GGOS structure include, among others, the merging of the former GGOS Consortium and GGOS Coordinating Board into the new GGOS Governing Board and the increasing of the number of voting members. This helps to streamline decision making within GGOS and enhances the involvement of all IAG components in the governance of GGOS. The new structure of GGOS was endorsed by the IAG Executive Committee on April 26, 2023 and approved by the former GGOS Coordinating Board on May 30, 2023. These ToR were approved by the former GGOS Coordinating Board on June 30, 2023 and by the IAG Executive Committee on September 5, 2023.

1.2 GGOS Background

GGOS, the Global Geodetic Observing System of the International Association of Geodesy

The parent organization of GGOS is the IAG. GGOS was established with the main objective of integrating and optimizing data analysis resources, procedures and dissemination of results performed by the different IAG components, namely the IAG Services, Commissions, Inter-Commission Committees (ICCs) and dedicated Projects. Motivation for the establishment of GGOS as well as its main goals and challenges were documented by the IAG science community in 2009 [2].

Essentially, GGOS works with the IAG Services to provide unique, mutually consistent, and easily accessible geodetic products (including the geodetic reference frames and the gravity field models) and the relevant geodetic constants for science and society. GGOS works in concert with Commissions, ICCs and dedicated projects concerning new developments, and it keeps all IAG components informed. This interaction is essential to understand the complexity of the Earth system, and advance geodetic knowledge as well as technology development. The societal benefit of integrated, consistent and high- quality geodetic products is wide reaching, including improved navigation systems, better understanding of climate and environmental change, reliable Earth surface deformation modelling, precise monitoring of mass transport within the Earth's system, accurately determining changes in the rotation of the Earth, etc.

In order for GGOS to interact effectively with the other IAG components, all IAG components have representatives in the various organizational elements of GGOS. Each IAG Service, Commission, ICC and Project has one representative on the GGOS Governing Board. The Commissions, ICCs and Projects have two representatives in the GGOS Science Panel. Each IAG Service has up to two representatives in each GGOS Bureau (Bureau of Products and Standards and Bureau of Networks and Observations). IAG Services, Commissions, ICCs and Projects participate in the various Focus Areas, Committees, Working Groups and Study Groups established within GGOS according to their areas of interest and objectives.

GGOS Vision

Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time.

GGOS Mission

We live on a dynamic planet in permanent motion that requires long-term continuous quantification of its changes in a truly stable frame of reference, everywhere on or close to the Earth surface, at any time, and at high spatial resolution. This ambitious program requires a strong cooperation among the geodetic, geodynamic and geophysical communities, and to external stakeholders. GGOS endeavours to provide this integration at the highest level, in service to the scientific community and society as a whole.

GGOS in International and Interdisciplinary Contexts

A key objective of GGOS is to increase the international and interdisciplinary visibility of the IAG and to engage with a diverse and growing range of stakeholders to raise awareness of the benefits of geodesy to science and society. In particular, GGOS contributes to two main initiatives: the scientific monitoring of global change, framed by the Group on Earth Observations (GEO), and to address global challenges related to the production and use of geospatial information, framed by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM).

In the context of GEO, GGOS is the IAG's contribution to the Global Earth Observation System of Systems (GEOSS). GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a wide range of users in both the public and private sectors. GGOS seeks the active participation of the geodesy community in current GEO flagships, programmes and initiatives. In the context of UN-GGIM, GGOS contributes to sustaining the UN Global Geodetic Reference Frame (GGRF) through science-policy networking in collaboration with the UN-GGIM's Subcommittee on Geodesy (SCoG) and the recently established UN Global Geodetic Centre of Excellence (UN-GGCE). The UN-SCoG provides an intergovernmental forum for cooperation and exchange of dialogue in support of the UN-GGCE, whose main task is to coordinate the development of a permanent, globally government-supported geodetic infrastructure as a cornerstone for the maintenance, sustainability and enhancement of the GGRF. GGOS seeks a symbiosis between the scientific expertise of the IAG and the political framework of the UN-GGCE in order to optimize resources for an effective improvement of the global geodetic infrastructure.

GGOS also represents the IAG on the Committee on Earth Observation Satellites (CEOS). CEOS is a consortium of 61 agencies operating 172 satellites worldwide working together to ensure international coordination of civil, space-based, Earth observation programs for the benefit of all.

1.3 GGOS Strategic Direction

Overarching Strategic Priorities of GGOS

GGOS Goals, Objectives, and Outcomes are built around four strategic priorities that were first communicated in 2011 and then reiterated in the 2014 Strategic Plan, and continue to be relevant to the activities and future efforts of GGOS. The strategic priorities of GGOS are:

- **Geodetic Information and Expertise**
  Development and maintenance of organizational intangible assets, including geodetic information, expertise, and capacity building.

- **Global Geodetic Infrastructure**
  Identification of gaps in the geodetic infrastructure and advocacy for modernization, extension and maintenance of the existing global geodetic infrastructure.

- **Standardization, Integration and Optimization**
  Interaction with all IAG components to provide unique standards and mutually consistent, highly reliable, and easily accessible geodetic products.

- **Communication, Education, and Outreach**
  Public relations, marketing, outreach, and engagement to ensure a long-term sustainable geodetic enterprise.

Long-Term Goals and Key Objectives of GGOS

GGOS aims to reinforce its role as a collaboration hub in the IAG, working as an observing system in support of sustainable geodesy by advocating and integrating diverse geodetic technologies and applications. In the focus of GGOS are:

- The observations needed to monitor, map, and understand changes in the Earth's shape, rotation, and mass distribution.
- The global geodetic frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.
- The benefit of science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

Strategic Plan of GGOS

GGOS revises and updates its strategic goals and supportive objectives regularly to meet emerging needs in geodetic matters. Based on extensive community surveys, GGOS designs updated versions of its Strategic Plan, highlighting cross cutting community needs that each strategic goal shall endeavour to address. Guided by the strategic goals, the community needs are elements of a holistic effort to support the geodetic community and advance the recognition and use of geodesy for public benefit through

innovation, advocacy, communication, and integration. The Strategic Plan is then complemented by an associated Implementation Plan containing the actions designed to achieve GGOS goals and objectives. The core of the Implementation Plan is to identify, assign, execute, and monitor the progress of these actions, which can be multi-year efforts depending on their nature. Detailed version of the current GGOS Strategic Plan and the associated Implementation Plan are available at https://ggos.org/.

1.4 GGOS Structure

Overview of Key GGOS Elements

The organizational structure of GGOS (Fig. 1) consists of the following key elements:

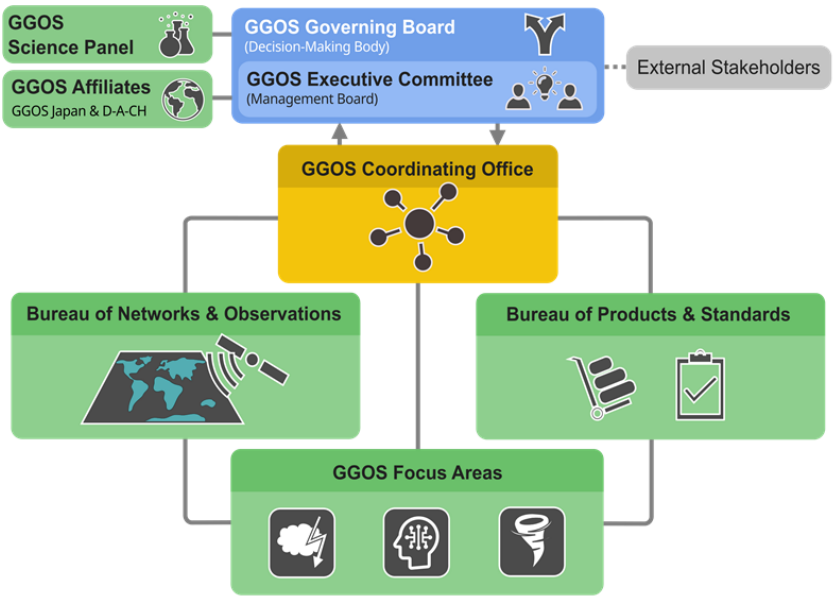

Fig. 1. GGOS organizational elements

- **GGOS Governing Board** is the central oversight and decision-making body of GGOS and the collective voice for all GGOS matters.
- **GGOS Executive Committee** serves under the direction of the GGOS Governing Board to accomplish day-to-day activities of GGOS.
- **GGOS Science Panel** provides advice and recommendations to the GGOS Governing Board and other GGOS elements on scientific aspects relevant to GGOS.
- **GGOS Coordinating Office** serves as the Secretariat of GGOS, coordinates the administrative work in support of the various GGOS structural elements, and is responsible for outreach and communications.

- **GGOS Bureau of Products and Standards** tracks, reviews, examines, evaluates all current standards, constants, resolutions and products adopted by IAG or its components and recommends their further use or proposes the necessary updates.
- **GGOS Bureau of Networks and Observations** develops a strategy to design, integrate and maintain the fundamental geodetic infrastructure including communication and data flow; monitors the status of the networks and advocates for implementation of core and other co-located network sites and improved network performance.
- **GGOS Affiliates** are national or regional organizations that coordinate geodetic activities in that country or region. GGOS Affiliates allow increased participation in GGOS, especially by organizations in under- represented areas of Africa, Asia-Pacific, and South and Central America.
- **GGOS Committees, Working Groups, Study Groups and Focus Areas** address overarching issues common to several or all IAG components, and are a mechanism to bring the various activities of the Services, Commissions, Inter-Commission Committees and Projects together, or to link GGOS to external organizations. Focus Areas are cross-disciplinary and address specific topics where GGOS contributors work together on broader and critical issues.

GGOS Governing Board

The Governing Board is responsible for governance, strategic policy and direction.

Membership: The membership of the GGOS Governing Board consists of delegates appointed by the other IAG components, the officers chairing the different GGOS components (see following sections), elected members-at-large and appointed members (Fig. 2). Each primary delegate may nominate an alternate to temporarily assume responsibilities (i.e. voting) if the primary delegate is unable to attend a meeting. One person may not hold two voting positions on the GGOS Governing Board. The membership of the GGOS Governing Board follows the four-year term used in the IAG. Renewal of this membership takes place during or shortly after the IUGG General Assemblies (see IAG Bylaws for more details).

Appointment and Election of Governing Board Members: Each IAG Service, Commission, ICC and Project is invited to nominate one delegate to the GGOS Governing Board. These appointed *representatives of the IAG Services, Commissions, ICCs or Projects* must be active members of those components. After a four-year term, it is at the discretion of each IAG component to renew its representation with the same delegate or to nominate a different colleague. In the event that a representative is unable to participate in the duties of the GGOS Governing Board (due to illness, retirement, change of affiliation, etc.), the GGOS President shall request a new appointment (replacement) from the respective IAG component.

Members-at-Large are invited to serve on the GGOS Governing Board to provide balanced representation of geographic regions or unique capabilities. The GGOS President, with the assistance of the GGOS Coordinating Office, shall appoint an Election Committee to organize the election process. This process includes issuing a call-for-participation to identify possible candidates, ensuring the availability of the nomi-

Voting Members	
GGOS President (ex-officio, votes in case of a tie)	1
GGOS Vice President (ex-officio)	1
Immediate Past President of GGOS (ex-officio)	1
IAG President or designated Representative (ex-officio)	1
IAG Service Representatives	12
IAG Commissions Representatives	4
IAG Inter-Commission-Committee Representatives	3
IAG Project Representatives	1
GGOS Science Panel Chair (ex-officio)	1
GGOS Bureau Directors (ex-officio)	2
GGOS Affiliate Representatives	2
GGOS Coordinating Office Director (ex-officio)	1
GGOS Manager of External Relations (ex-officio)	1
GGOS Focus Area Leads (ex-officio)	3
GGOS Committee Chairs (ex-officio)	6
Members-at-Large (elected by the GGOS Governing Board)	3
Appointed Members (appointed by the GGOS Executive Committee)	2
Total	*45*
Non-voting members	
GGOS Working Group Chairs (ex-officio)	9
GGOS Web and Social Media Manager (ex-officio)	1
Total	*10*
Total GGOS Governing Board membership	**55**

Fig. 2. Membership of the GGOS Governing Board (as of April 2024)

nated candidates, and consolidating a final slate of members-at-large candidates. The Election Committee shall then present this final slate to the GGOS Governing Board for a vote. In the event that a member-at-large is unable to participate in the duties of the GGOS Governing Board (due to illness, retirement, change of affiliation, etc.), the GGOS President, with the assistance of the GGOS Coordinating Office, shall submit a list of at least two candidates for replacement to the GGOS Governing Board.

Appointed Members are up to two additional members nominated by the GGOS Executive Committee to balance research areas or geographic regions not covered by the members-at- large. All candidates must then be approved by the Governing Board. In the event that an appointed member is unable to participate in the duties of the GGOS Governing Board (due to illness, retirement, change of affiliation, etc.),

the GGOS Executive Committee can nominate another colleague to serve in his/her place.

GGOS Officers: The GGOS President, Vice President, Immediate Past President, Coordinating Office Director, External Relations Manager, GGOS Bureau Directors, and Chairs of the Focus Areas, Committees and Working/Study Groups established within each GGOS component are ex- officio members of the GGOS Governing Board during their terms of office. See below for details.

Representatives of the GGOS Affiliates: Each GGOS Affiliate is invited to nominate one delegate to the GGOS Governing Board. Delegates appointed to the Governing Board as representatives of the GGOS Affiliates must be active members of the respective Affiliates. After a four-year term, it is at the discretion of each GGOS Affiliate to renew its representation with the same delegate or to nominate a different colleague. In the event that a representative is unable to participate in the duties of the GGOS Governing Board (due to illness, retirement, change of affiliation, etc.), the GGOS President shall request a new appointment (replacement) from the respective GGOS Affiliate.

Voting: Decisions shall be made by consensus whenever possible. Decisions requiring a vote shall be made by a simple majority of the votes cast. The quorum for valid vote is fifty percent of the voting Governing Board members. Voting may be conducted in person at meetings or by appropriate electronic means at the discretion of the GGOS Executive Committee.

Meetings: The Governing Board shall meet at least once a year, but twice a year is preferred. Observers may attend the Governing Board meetings at the discretion of the GGOS President. Governing Board meetings shall be convened by the GGOS President with the support of the GGOS Coordinating Office.

GGOS President

The GGOS President is elected by the IAG Executive Committee from a slate of nominations submitted and approved by the GGOS Governing Board. The President is appointed for a period of four years, renewable once. The President is the primary spokesperson and representative of GGOS to the IAG and external organizations. The President shall provide overall leadership for GGOS. The President shall preside at meetings of the GGOS Governing Board and GGOS Executive Committee and at the GGOS Days. Upon completion of his/her term as GGOS President, he/she shall serve Immediate Past President for the next term.

GGOS Vice President

The Vice President of GGOS is nominated by the GGOS President and then approved by the GGOS Governing Board. The Vice President shall assist the President and act as the President in the absence of the President or when a motion involving the President is under consideration.

GGOS Executive Committee

The GGOS Executive Committee is responsible for the administration of the affairs of GGOS in accordance with these ToR and the decisions of the GGOS Governing Board.

Membership: The GGOS Executive Committee consists of the members listed in Fig. 3.

Executive Committee Members	
GGOS President (ex-officio)	1
GGOS Vice President (ex-officio)	1
GGOS Bureau Directors (ex-officio)	2
GGOS Coordinating Office Director (ex-officio)	1
GGOS Manager of External Relations (ex-officio)	1
GGOS Governing Board Representatives	2
Total	*8*
Permanent guests	
Immediate Past President of GGOS (ex-officio)	1
IAG President or designated Representative (ex-officio)	1
GGOS Science Panel Chair (ex-officio)	1
Total	3

Fig. 3. Members of the GGOS Executive Committee

Appointment and Election of Executive Committee Members: The GGOS President, Vice President, Immediate Past President, Coordinating Office Director, External Relations Manager and the Directors of the GGOS Bureaus shall be members of the GGOS Executive Committees during their terms of office. The Governing Board members should elect two representatives to the GGOS Executive Committee. These representatives must be voting members of the GGOS Governing Board and shall serve on the GGOS Executive Committee for a term of four years.

Meetings: The GGOS Executive Committee shall hold monthly video or teleconferences and shall meet in person during the GGOS Governing Board meetings. GGOS Executive Committee meetings shall be convened by the GGOS President with the support of the GGOS Coordinating Office. The Immediate Past President of GGOS, the Chair of the GGOS Science Panel, and the President of the IAG or his/her designated representative shall be permanently invited guests at meetings of the GGOS Executive Committee. Other observers may be invited to attend these meetings (or teleconferences) as needed.

GGOS Science Panel

The GGOS Science Panel is an independent and multidisciplinary advisory board that provides scientific support and guidance to the GGOS steering and coordination entities as requested. This support includes in particular, assistance in revising and updating the content of the GGOS 2020 book and organizing relevant scientific sessions at conferences, workshops, and other events.

Membership: The members of the GGOS Science Panel are delegates from the IAG Commissions, ICCs and Projects and from the GGOS Focus Areas. Members-at-large may also be nominated when specific scientific topics not covered by the IAG are to be discussed. Membership of the GGOS Science Panel follows the usual four-year term. Renewal of this membership takes place during the IUGG General Assemblies.

Appointment and Election of the Science Panel Members: Each IAG Commission, ICC and Project is invited to nominate two delegates to the GGOS Science Panel. Each GGOS Focus Area is invited to nominate one delegate to the GGOS Science Panel. Delegates appointed to the GGOS Science Panel as representatives of the IAG Commissions, ICCs, Projects or GGOS Focus Areas must be internationally recognized scientists who are experts in the topics they represent. All nominated delegates must be approved by the GGOS Governing Board. The GGOS Governing Board may appoint additional at-large members to the GGOS Science Panel to cover scientific topics not covered by the IAG. After a four-year term, it is at the discretion of each IAG component and GGOS Focus Area to renew its representation with the same delegate(s) or to nominate a different colleague(s). In the event that a representative is unable to participate in the duties of the GGOS Science Panel (due to illness, retirement, change of affiliation, etc.), the GGOS President, with the support of the GGOS Coordinating Office, shall request a new appointment (replacement) from the respective IAG component or Focus Area. The immediate past Chair of the GGOS Science Panel is a Member of the GGOS Science Panel. The GGOS Science Panel elects its own Chair, who is approved by the GGOS Governing Board. The GGOS Science Panel Chair is appointed for a period of four years, renewable once.

GGOS Committees, Working/Study Groups and Focus Areas

The various GGOS structural elements may propose the establishment of Committees and Working or Study Groups as needed, in accordance with the IAG Bylaws. The proposed Committees and Working/Study Groups must be approved by the GGOS Governing Board. Working/Study Groups shall be established for a period of four years, Committees for a longer indefinite period. The GGOS Governing Board appoints their Chairs and prepare and approve their charters.

GGOS Focus Areas are cross-disciplinary and are intended to address gaps and needed future products. The GGOS Governing Board approves the Focus Areas and appoints their leaders. GGOS Focus Areas outline their charter and propose plans for the work they will undertake.

GGOS Coordinating Office

The GGOS Coordinating Office serves as the Secretariat of GGOS, coordinates the administrative work in support of the various GGOS structural elements, and is responsible for outreach and communications. The GGOS Coordinating Office ensures information flow, maintains documentation of the GGOS activities, and manages specific assistance functions that enhance the administrative coordination across all areas of GGOS, including inter-services coordination and support for meeting and workshops. The GGOS Coordinating Office, in its long-term coordination role, ensures that the GGOS components contribute to GGOS in a consistent and continuous manner. The GGOS Coordination Office also maintains, manages, and coordinates the GGOS web and social media presence.

The position of Manager of External Relations resides within the GGOS Coordinating Office. The Manager of External Relations coordinates, in consultation with the GGOS President, GGOS engagement with external organizations such as the GEO, the CEOS, the International Science Council (ISC) World Data System (WDS), the Federation of Surveyors (FIG), the UN-GGIM SCoG, and the UN-GGCE. The GGOS Governing Board elects the Manager of External Relations by vote.

GGOS Bureau of Products and Standards (BPS)

The GGOS BPS monitors the strict observance of adopted resolutions, geodetic standards, standardized units, fundamental physical constants and conventions in all official products provided by the geodetic community. It reviews, examines and evaluates all current standards, constants, resolutions and conventions related to geodesy adopted by international organizations such as ISO (International Organization for Standardization), IAU (International Astronomical Union), IUGG, IAG and their components, and recommends their further use or proposes the necessary updates. It identifies possible gaps in standards and products, and initiates steps to fill them with, e.g., through resolutions of the IUGG and/or IAG Councils.

GGOS Bureau of Networks and Observations (BNO)

The GGOS BNO develops a strategy to sustainably design, integrate, and maintain the fundamental geodetic infrastructure to meet the long-term (10–20 years) requirements identified by the GGOS Science Panel. The Bureau advocates for the implementation of core and other co-located network sites to satisfy GGOS requirements, monitors the present state of the networks and projects future states, and supports and encourages infrastructure critical for the development of data products essential to GGOS. Primary emphasis must be placed on sustaining the infrastructure needed to maintain the evolving global reference frames, while ensuring broader support for the scientific applications of the data collected. The coordination and implementation of the GGOS co-located station network is a major focus of the Bureau.

GGOS Affiliates

A GGOS Affiliate is a national or regional organization that coordinates geodetic activities in that country or region. GGOS Affiliates provide a forum for multi-technique, space geodetic discussions, work to improve the quality of space geodetic observations, and encourage cooperation among the various agencies in that country or region that own, operate, and maintain the space geodetic infrastructure there. To become a GGOS Affiliate, interested organizations submit an application to GGOS, which is approved by the GGOS Governing Board by vote.

1.5 ToR Modification and Approval of Revisions

Amendments to these Terms of Reference shall be approved by at least a simple majority of the votes cast by the GGOS Governing Board. The amended ToR shall then be submitted to the IAG Executive Committee for approval at its next meeting. Amendments shall take effect at the end of the IAG Executive Committee meeting. The rules contained in the current edition of Robert's Rules of Order Newly Revised (https://robertsrules.com/) shall govern GGOS in all cases to which they are applicable and in which they are not inconsistent with these Terms of Reference or any special rules that may be adopted by the GGOS Governing Board.

2 Members of GGOS

GGOS Executive Committee Members

Voting members

- Laura Sánchez (Germany); GGOS President
- Anna Riddell (Australia); GGOS Vice President
- Martin Sehnal (Austria); Director of GGOS Coordinating Office
- José Rodríguez (Spain); Director of BNO
- Detlef Angermann (Germany); Director of BPS
- Allison Craddock (USA); Manager of External Relations
- Georgios S. Vergos (Greece); GGOS Governing Board representative
- Claudia N. Tocho (Argentina); GGOS Governing Board representative

Permanent guests

- Basara Miyahara (Japan); Immediate Past President of GGOS
- Richard Gross (USA); IAG President
- José Ferrándiz (Spain); Chair of GGOS Science Panel

GGOS Governing Board Members (voting members)

Members within GGOS

- Laura Sánchez (Germany); GGOS President
- Anna Riddell (Australia); GGOS Vice President

- Martin Sehnal (Austria); Director of GGOS Coordinating Office
- Basara Miyahara (Japan); Immediate Past President of GGOS
- Richard Gross (USA); IAG President
- José Ferrándiz (Spain); Chair of GGOS Science Panel
- Allison Craddock (USA); Manager of External Relations
- José Rodríguez (Spain); Director of BNO
- Detlef Angermann (Germany); Director of BPS
- Michael Schmidt (Germany); Chair of Focus Area on Geodetic Space Weather Research
- Benedikt Soja (Switzerland); Chair of Focus Area on AI for Geodesy
- Timothy Melbourne (USA); Chair of Focus Area on Geohazards
- Alexander Kehm (Germany); Chair of Committee on PLATO (Performance Simulations and Architectural Trade-Offs)
- Elisabetta D'Anastasio (New Zeeland); Chair of Committee on DIS (Data and Information Systems)
- Roland Pail (Germany); Chair of Committee on SCM (Satellite and Space Missions)
- Maik Thomas (Germany); Chair of Committee on EM (Contribution to Earth System Modelling)
- Thomas Gruber (Germany); Chair of Committee on EGV (Essential Geodetic Variables)
- Kirsten Elger (Germany); Chair of Committee on DOI (DOI for Geodetic Data Sets)
- Yusuke Yokota (Japan); GGOS Japan representative
- Hansjörg Kutterer (Germany); GGOS D-A-CH representative

Members-at-Large and Appointed Members

- Aletha de Witt (Sout Africa); Member-at-Large
- Claudia N. Tocho (Argentina); Member-at-Large
- Ropesh Goyal (India); Member-at-Large
- Julia Azumi Koch (Switzerland); Appointed Member
- Yamin Dang (China); Appointed Member

Representatives of IAG Services, Commissions, ICCs and Project

- Daniela Thaller (Germany); IERS representative
- Ryan Ruddick (Australia); IGS representative
- Toshimichi Otsubo (Japan); ILRS representative
- Lucia McCallum (Australia); IVS representative
- Karine Le Bail (Sweden); IDS representative
- Elizabeth Bradshaw (UK); PSMSL representative
- Georgios S. Vergos (Greece); IGFS representative
- E. Sinem Ince (Germany); ICGEM representative
- Kevin Kelly (USA); IDEMS representative
- Christoph Förste (Germany); IGETS representative
- Urs Marti (Switzerland); ISG representative
- Sylvain Bonvalot (France); BGI representative

- Christopher Kotsakis (Greece); IAG Commission 1 representative
- Derek van Westrum (USA); IAG Commission 2 representative
- Rebekka Steffen (Sweden); IAG Commission 3 representative
- Krzysztof Sośnica (Poland); IAG Commission 4 representative
- Pavel Novák (Cezch Republic); ICCT representative
- Annette Eicker (Germany); ICCC representative
- Pierre Sakic (France); ICCM representative
- Jürgen Müller (Germany); QuGe representative

GGOS Science Panel Members

- Jose Ferrandiz (Spain); Chair of GGOS Science Panel
- Xavier Collileux (France); IAG Commission 1 representative
- Zinovy Malkin (Russia); IAG Commission 1 representative
- Kosuke Heki (Japan); IAG Commission 2 representative
- Thomas Gruber (Germany); IAG Commission 2 representative
- Jianli Chen (USA); IAG Commission 3 representative
- Jose Ferrandiz (Spain); IAG Commission 3 representative
- Jens Wickert (Germany); IAG Commission 4 representative
- Pawel Wielgosz (Poland); IAG Commission 4 representative
- Yoshiyuki Tanaka (Japan); ICCT representative
- Mattia Crespi (Italy); ICCT representative
- Pierre Sakic (Germany); ICCM representative
- Keiichi Tadokoro (Japan); ICCM representative
- Anna Klos (Poland); ICCC representative
- Carmen Blackwood (USA); ICCC representative
- Jürgen Müller (Germany); IAG Project QuGE representative
- Marvin Reich (Germany); IAG Project QuGE representative
- Ehsan Forootan (Denmark); Repr. of GGOS FA Geodetic Space Weather Research
- Lucie Rolland (France); Representative of GGOS FA Geohazards
- Maria Kaselimi (Greece); Representative of GGOS FA AI for Geodesy
- Kosuke Heki (Japan); Immediate past Chair of the GGOS Science Panel

3 GGOS Coordinating Office

Director: Martin Sehnal (Austria)
Manager of External Relations: Allison Craddock (USA)
GGOS Web and Social Media Manager: Helmut Klima (Austria)
Assistant: Lucas Triebenbacher (Austria)

Objectives

GGOS internal tasks:

- Supporting the GGOS President, Executive Committee, Governing Board and Science Panel in administrative issues;

- Facilitates the coordination of activities among the different GGOS components;
- Ensures information flow;
- Maintain documentation of the GGOS activities.

GGOS external tasks:

- Managing and maintaining of the GGOS web and social media presence;
- Organization and support of GGOS meetings, conferences and workshops;
- Enhance inter-services coordination;
- Managing of external relations.

The GGOS Committee on DOI for Geodetic Data Sets is associated to the GGOS Coordinating Office.

GGOS Committee on DOI (Digital Object Identifier) for Geodetic Data Sets

Chair: Kirsten Elger (Germany)

Introduction/ Motivation

Data publications with digital object identifiers (DOI) are key supporting elements for FAIR (Findable, Accessible, Interoperable, and Reusable) sharing data. Originally developed with the purpose of providing permanent access to (static) datasets described in scholarly literature, DOI today are more and more assigned to dynamic data. These DOI are providing a citable and traceable reference of various types of sources (data, software, samples, equipment) and means of rewarding the originators and institutions. As a result of international groups, like the Coalition on Publishing Data in the Earth, Space and Environmental Sciences (COPDESS) and the Enabling FAIR Data project, data with assigned DOI are fully citable in scholarly literature and many journals require the data underlying a publication to be available – even before accepting an article. Initial metrics for data citation allows data providers to demonstrate the value of the data collected by institutes and individual scientists.

This is particularly relevant for geodesy, where researchers base their studies on observational data and rely on operational aspects to collect the necessary input data. Consequently, geodetic equipment, observational data, and data results require a structured and well-documented mechanism that allows for citation, scientific recognition and reward that can be provided by assigning DOI to data and data products.

To address these challenges and to identify opportunities for improved coordination and advocacy within the geodetic community, GGOS has established a Working Group on "Digital Object Identifiers (DOI) for Geodetic Data Sets" in 2019 which was transformed to a GGOS Committee in 2023. This Committee is designated to establish best practices and advocate for the consistent implementation of DOI across all IAG Services and in the greater geodetic community.

Objectives

The main objectives and activities of this committee are:

- to identify what the community needs from consistent usage of DOI for data in terms of being able to discover data, permanently cite data, and acknowledge the data providers;
- to develop recommendations for DOI minting strategies for different geodetic data types and granularity across IAG Services (static, dynamic, observational data, data products, combination products, networks);
- to develop recommendations for a consistent method for data citation across all IAG Services, to support data providers, and to provide quantitative support detailing the use of geodetic datasets and other resources;
- to develop recommendations for connecting metadata standards for data discovery (e.g. DataCite, ISO19115) with community metadata standards (GeodesyML, Station Logs).

Members

Kirsten Elger (Germany); Chair
Detlef Angermann (Germany)
Yehuda Bock (USA)
Sylvain Bonvalot (France)
Roelf Botha (South Africa)
Markus Bradke (Germany)
Elizabeth Bradshaw (UK)
Carine Bruyninx (Belgium)
Daniela Carrion (Italy)
Glenda Coetzer (South Africa)
Pierre Fridez (Switzerland)
Elmas Sinem Ince (Germany)
Philippe Lamothe (Canada)
Vicente Navarro (Spain)
Mirko Reguzzoni (Italy)
Jim Riley (USA)
Dan Roman (USA)
Christian Schwatke (Germany)
Laurent Soudarin (France)
Daniela Thaller (Germany)
Yusuke Yokota (Japan)

Associated Members

Godfred Amponsah (USA)
Sandra Blevins (USA)
Francine Coloma (USA)
Allison Craddock (USA)
Christoph Förste (Germany)

John Galetzka (USA)
Ryan Hippenstiel (USA)
Patrick Michael (USA)
Anna Miglio (Belgium)
Basara Miyahara (Japan)
Mike Pearlman (USA)
Ryan Ruddick (Australia)
Martin Sehnal (Austria)
Ira Sellars (USA)
Lori Tyahla (USA)

4 GGOS - Point of Contact

GGOS Coordinating Office
BEV - Federal Office of Metrology and Surveying
(Bundesamt für Eich- und Vermessugnswesen)
Schiffamtsgasse 1-3
1020 Vienna, AUSTRIA
Email: co@ggos.org
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5 The GGOS Bureau of Networks and Observations (GGOS-BNO)

Director: José Rodríguez (Spain)
Deputy Director: Martin Lidberg (Sweden)
IERS Representative: Ryan Hippenstiel (USA)

GGOS-BNO website - https://ggos.org/about/org/bureau/bno

5.1 Introduction

The Bureau of Networks and Observations (GGOS-BNO) develops a strategy to design, integrate and maintain the fundamental infrastructure in a sustainable way to satisfy the long-term (10-20 years) requirements identified by the GGOS Science Panel. Primary emphasis must be on sustaining the infrastructure needed to maintain the evolving global reference frames, while at the same time ensuring the broader support of the scientific applications of the collected data. Advocating for the implemention of the GGOS co-located station network is a key focus for the Bureau. This activity should be done in concert with the UN-GGIM and its UN-GGCE, providing a centralised access to the expertise available from the IAG Services and Committees of the Bureau.

5.2 Structure

Three GGOS committees are associated to the GGOS-BNO. The GGOS-BNO works closely with the IAG Services, which have their own chapters in this Handbook. In addition, the GGOS-BNO contributes to the initiatives lead by the IAG Sub-Commissions 1.1 and 1.2, respectively:

- JWG 1.1.1 GENESIS (joint with IAG Commission 1, IERS);
- JWG 1.2.2 Metrology of space geodetic infrastructure (joint with IAG Commission 1, IERS).

These JWG are presented in the IAG Commission 1 chapter.

5.3 Members

- José Rodríguez (Spain); Director
- Martin Lidberg (Sweden); Deputy Director
- PLATO Committee: Alexander Kehm (Germany), Benjamin Männel (Germany)
- Missions Committee: Roland Pail (Germany), C.K. Shum (USA)
- Data and Information Systems: Roger Fraser (Australia), Taylor Yates (USA)
- Johannes Böhm (Austria)
- Cornelia Eschelbach (Germany)
- Ryan Hippenstiel (USA); IERS Representative
- IGFS: Riccardo Barzaghi (Italy), George Vergos (Greece)
- IVS: Hayo Hase (Germany), Dirk Behrend (USA)

- ILRS: Toshimichi Otsubo (Japan), Clément Courde (France)
- IGS: Allison Craddock (USA), Markus Bradke (Germany)
- IDS: Jérôme Saunier (France), Guilhem Moreaux (France)
- PSMSL: Elizabeth Bradshaw (UK), Lesley Rickards (UK)
- Richard Gross (USA)

5.4 Objectives

The GGOS-BNO supports the networks capability available to the IAG in its goal to provide geodetic data products of sufficient quantity, quality and temporal and spatial resolution to improve our understanding of the dynamic Earth for both scientific understanding and societal needs. Fundamental to achieving this goal is the maintenance and further development of the globally available terrestrial and celestial reference frames, which are the basis for our metric measurements over space, time, and evolving technology. The GGOS-BNO advocates for implementation of the global space geodesy network of sufficient capability and geographic coverage to achieve data products essential for GGOS and serves as a coordinating point for the Services to meet, discuss status and plans, and examine common paths for meeting GGOS requirements. Committees and Working Groups are included in the Bureau in recognition of their synergies with Bureau activities.

The role of the GGOS-BNO is to:

- Advocating and encouraging expansion and upgrade of the global geodetic network of reference for the maintenance and improvement of the International Terrestrial Reference Frame (ITRF), the International Terrestrial Gravity Reference Frame (ITGRF) and the International Height Reference Frame (IHRF);
- Encouraging formation of partnerships to build and upgrade the network infrastructure, in particular the installation of new geodetic core sites in regions with poor coverage;
- Organize and expand the GGOS affiliated network by promoting broad participation of geometric and non-geometric Services in GGOS;
- Scoping of the required network and project the network status into the future (5 and 10 years ahead) based on input from the stations and Services to anticipate data product quality for the ITRF, ITGRF and IHRF;
- Working with the UN Global Geodetic Centre of Excellence (UN-GGCE) as well as the UN Committee of Experts on Global Geospatial Information Management (UN GGIM) and its affiliates to develop a plan for the improvement of the global geodetic reference networks to satisfy the accuracy requirements for the monitoring of the Earth System: an accuracy of 1 mm and a stability at a level of 0.1 mm/year;
- Conduct simulation studies and analyses to assess impact on geodetic key products related to reference frames and the Earth's rotation of: network configuration, system performance, technique and technology mix, treatment of co-locations on ground and in space, and network trade-off options (PLATO);
- Advocate for the uptake and development of systems to effectively share geodetic metadata across a wide range of users including GGOS; engage across the geodetic techniques to develop integrated solutions for geodetic metadata sharing and dissemination (Committee on Data and Information Systems);

- Providing the opportunity for representatives of the IAG Services and associated GGOS-BNO Committees and Working Groups to meet and share progress and plans and discuss issues of common interest through the organisation of GGOS-BNO virtual meetings and at major international conferences such as EGU, AGU and the GGOS Days;
- Presenting talks and posters about the GGOS-BNO at major international conferences such as AGU, EGU, IAG, JpGU-AGU, AOGS, etc. with the aim of promoting awareness of GGOS amongst the scientific community;
- Letters/ documentation to support stations, current/ new missions, and analysis centers.

5.5 Tasks

- Continue recruiting station membership in the GGOS Network through the Call for Participation; issue membership certificates;
- Continue monitoring network status and plans; develop next network projection status for 5 and 10 years ahead;
- Provide next update of the "Guideline for GGOS Core Sites and Co-locations Sites" document;
- Work with the IGFS, the PSMSL and the other Services to integrate relevant parameters from other ground networks (gravity field, tide gauges, etc.) into the GGOS network to support GGOS requirements including the reference frame, a unified height system, etc.; advocate for installation of GNSS receivers at appropriate tide gauges;
- Support the technique Services on the promotion of recommended technologies, configurations and procedures in the establishment of new sites and the upgrading of current sites, and in the evaluation of performance of new stations and new capabilities after they become operational;
- Continue simulation and trade-off studies for network options (PLATO Committee);
- Work with IGS and other groups to finalize GeodesyML and advocate for its uptake; continue metadata systems development across different geodetic techniques (Committee on Data and Information Systems);
- Improve communication and information exchange and coordination with the space missions (Committee on Satellite Missions);
- Contribute to IAG JWG 1.2.2 to improve the quality of site ties and instrument reference points;
- Continue GGOS-BNO meetings to meet, discuss status and plans, and examine common interests and requirements;
- Continue presentation at international meetings in GGOS-BNO activities and plans;
- Continue providing letters and documentation support;
- Update the Bureau web pages for public use (to be compatible with the new GGOS website in process).

6 Committees of the GGOS-BNO

GGOS-BNO C1: Committee on "Performance Simulations and Architectural Trade-Offs" (PLATO)

(joint with IAG Sub-Commission 1.1)
Chair: Alexander Kehm (Germany)
Vice-Chair: Benjamin Männel (Germany)

Objectives

The PLATO Committee has various individual members and groups working on simulations and data analysis covering the full range of existing ground and space assets, including VLBI, SLR, GNSS, and DORIS. The main focus is on how to optimally exploit existing observation capabilities (stations, observation concepts, tracking performance, etc.) including co-location in space with existing and new dedicated satellites to best support GGOS planning and implementation.

- Use simulation techniques to assess the impact of network configuration, system performance, technique and technology mix, co-location conditions, site ties, space ties (added spacecraft, etc.), analysis and modeling techniques, etc., on geodetic key parameters related to reference frames or the Earth's orientation;
- Use and develop improved analysis methods for geodetic parameters by including all existing data and available co-locations (i.e., include all satellites and use all data types on all satellites);
- Make recommendations on network configuration and inter-technique combination strategies based on the simulation and trade-off studies.

Studies within the PLATO framework put focus on future space-geodetic network capabilities and examine trade-off options for station deployment, technology upgrades, the impact of measured local ties and their potential replacement by common target/common clock-based approaches (for example in conjunction with the new DFG Research Unit 5456 "Clock Metrology: A Novel Approach to TIME in Geodesy"), additional space missions (one focus being studies related to ESA's next GENESIS mission), with the goal to maximize the utility of the GGOS assets.

Investigations covered by the PLATO activities include:

- Exploiting the full range of existing ground and space assets:
  - GNSS assets (ground and space);
  - SLR (beyond Lageos-1 and -2) including ranging to GNSS satellites;
  - LLR assets;
  - VLBI assets including tracking of GNSS satellites;
  - Co-located assets in space (e.g. GRACE-FO, Sentinel, GENESIS);
  - Hybrid networks of legacy stations and simulated next-generation stations;
  - Improved GNSS antenna calibrations and clock estimation strategies (GNSS only or combined with SLR, VLBI, and DORIS).
- Improving the performance of current systems and networks:
  - Simulate the impact of upgrading existing stations and their procedures;

  - Simulate the impact of additional ground surveys at colocation sites (site ties).
- Potential future space assets: Co-locate all four space-geodetic techniques in space on a dedicated satellite.

Tasks

- Examine trade-off options for station deployment, technology upgrades, the future treatment of co-locations, etc. and project future network capability based on network configurations projected by the GGOS-BNO or relevant IAG services (IGS, ILRS, IVS, IDS);
- Investigate the impact of improved SLR tracking scenarios including spherical satellites, LEOs, GNSS satellites and VLBI satellite tracking on reference frame products;
- Identify technique-specific systematics by analyzing short baselines, data from new observation concepts, and available co-locations (e.g., consistent processing of LEO and ground-based observations);
- Investigate the best-practice methods for co-location in space and assess the impact of co-location in space on reference frame products based on existing satellites and by simulation studies for proposed missions.

GGOS-BNO C2: Committee on Data and Information Systems

Chair: Roger Fraser (Australia)
Vice-Chair: Taylor Yates (USA)

Objectives and Tasks

The Committee on Data and Information Systems is invested in the following objectives:

- Support the development and implementation of a GGOS portal;
- Assessment and implementation of FAIR principles for geodetic data;
- Development and implementation of a metadata scheme (GeodesyML);
- Ongoing enhancements to GeodesyML;
- Engagement across different geodetic techniques for the uptake of GeodesyML.

Work to develop and promote a Geodesy Markup Language (GeodesyML) standard for metadata sharing within the GNSS community was done by Nicholas Brown (Geoscience Australia) and others. After the initial release of version 0.5 of GeodesyML by Geoscience Australia, the International GNSS Service (IGS) Infrastructure Committee established a taskforce to extend and finalize the GeodesyML schema to support its uptake and use within the GNSS community. The taskforce is composed by the GFZ German Research Centre for Geosciences, the Royal Observatory of Belgium, Geoscience Australia, NASA Crustal Dynamics Data Information System, EarthScope Consortium (formerly Unavco, USA) and GNS Science New Zealand.

A proposal to enrich GeodesyML with new functionalities was developed to include metadata to enhance Findability, Accessibility and Reusability of metadata information. The proposal suggests including elements that ensure backward compatibility

and share information about data licensing, searchable keywords, metadata provenance; modification timestamp and geodetic network attribution. A controlled vocabulary for terminology used in GeodesyML was also developed. The proposal has been submitted to the IGS Infrastructure Committee and is under review.

Once finalized by IGS, there is potential for expansion to the other space geodesy techniques and GGOS. If other techniques will further develop and uptake GeodesyML, this can become a standard mechanism to share metadata information across GGOS and provide the foundational elements for standardized and machine-to-machine metadata communication, archiving, and retrieval. In the long term, it is expected that GeodesyML will be expanded to the other Services to help manage site related metadata and to other data related products and information.

Alongside the development of GeodesyML, Curtin University, Geoscience Australia and collaborators have conducted extensive studies to assess if metadata defined in generic geospatial and geodetic standards support FAIR use of modern GNSS data and seamless communication between GNSS data and service providers and their users. These activities have included a user survey to understand the perspectives of current geodetic data users and identify gaps in the current standards that could inhibit the uptake. Results confirm that offering FAIR GNSS data and services is fundamental, but for a confident use of them, detailed and relevant metadata need to be offered to the community. These findings were published in Ivanova et al., 2023 (http://doi.org/10.1162/dint_a_00185). The same group also developed a proposal for an ISO 19100 series compliant GNSS Metadata profile which links to GeodesyML.

In addition, the Crustal Dynamics Data Information System (CDDIS) is also continuing to work to address the need to meet FAIR standards through ensuing the creation of DOI and collection-level metadata for new data and derived product collections, most recently, the GUARDIAN GDGPS. As a NASA Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC), the CDDIS utilizes the EOSDIS infrastructure of the Common Metadata Repository (CMR) to manage collection and granule-level metadata describing CDDIS archive holdings; these metadata include 171 published DOI representing DORIS, GNSS, SLR, and VLBI data and derived product collections archived at CDDIS. CMR is accessible through APIs and can be used by GGOS to find geodetic data and products available through CDDIS. The CDDIS also actively participates in the GGOS DOI Committee, sharing NASA EOSDIS DOI methods and best practices with the greater Geodesy community. In addition, as changes are made to metadata standards, the proper adjustments will be implemented.

The Committee on Data and Information Systems over the last few years has continued its work to improve GeodesyML and metadata FAIRness. Justine Woo and Taylor Yates have stepped in to continue to support the development of a GGOS data portal. Following change in leadership, the committee is currently working on refining its objectives and outcomes, and aligning those with the GGOS 2024-2034 Strategic Plan. These activities have started in June 2024.

GGOS-BNO C3: Committee on Satellite Missions

Chair: Roland Pail (Germany)
Vice-Chair: C.K. Shum (USA)

Objectives

- Advocate, coordinate, and exchange information with satellite missions as part of the GGOS space infrastructure, for a better ground-based network response to mission requirements and space-segment adequacy for the realization of the GGOS goals;
- Support proposals for new mission concepts and advocate for needed missions;
- Interfacing and outreach with other components of the Bureau; especially the ground networks component, the simulation activity (PLATO), as well as the Bureau of Standards and Products;
- Contributions to the development of Global Geodetic Variables.

Tasks

- Continue the regular activities, i.e. updating the two central lists, supporting future satellite missions, etc.;
- Evaluate the contribution of current and short-term satellite missions to GGOS goals;
- Work with GGOS Executive Committee, Focus Areas, and data product development activities (e.g., ITRF) to advocate for new missions to support GGOS goals;
- Support the Executive Committee and the Science Panel in the GGOS Interface with space agencies;
- Increase the exchange and collaboration with PLATO; set up a more formal procedure of collaboration; discuss needs and run simulations to study the impact of future satellite missions, identify gaps for fulfilling the GGOS goals, etc;
- Contribute to the discussion on Essential Geodetic Variables;
- Communicate with Chinese IAG colleagues to seek advice and collaborations to advocate for possible availability of Chinese gravity mission data to the scientific community.

7 The GGOS Bureau of Products and Standards (GGOS-BPS)

Director: Detlef Angermann (Germany)
Deputy Director: Thomas Gruber (Germany)

GGOS-BPS website - https://ggos.org/about/org/bureau/bps/

7.1 Objectives

The Bureau of Products and Standards (GGOS-BPS) supports GGOS in its goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth. A key objective of the GGOS-BPS is to keep track of adopted geodetic standards and conventions across all IAG components as a fundamental basis for the generation of consistent geometric and gravimetric products. Another key objective is the work towards the definition of Essential Geodetic Variables (EGVs), which shall be performed in close cooperation among the Committee on EGVs, the GGOS Science Panel and representatives of the other IAG components. In collaboration with the GGOS Coordination Office, the other IAG components and the United Nations Global Geodetic Centre of Excellence (UN-GGCE), the GGOS-BPS also contributes to outreach activities in the form of user-friendly descriptions for geodetic science data products, social media posts and the creation of videos about geodesy in non-specialist language. The objectives of the GGOS-BPS may be divided into two major parts:

Standards and conventions

A long-term objective is to keep track and to foster homogenization of adopted geodetic standards and conventions across all components of IAG to ensure consistent geodetic results. Towards reaching these goals, the GGOS-BPS has compiled an inventory of standards and conventions used for the generation of IAG products which needs to be regularly updated to keep its content up-to-date and to reflect the latest developments regarding standards and conventions. The GGOS-BPS inventory presents the current status, identifies gaps and inconsistencies, and highlights open issues, providing recommendations regarding the consistent application of standards and conventions. To accomplish these tasks, the GGOS-BPS interacts with the IAG Services, the IERS Conventions Centre and external stakeholders involved in standards and conventions such as the International Astronomical Union (IAU) Commission A3 "Fundamental Standards", the International Organization for Standardization (ISO) and its Technical Committee (ISO/TC 211), the Open Geospatial Consortium (OGC), the Committee on Data for Science and Technology (CODATA), the United Nations Global Geospatial Information Management (UN-GGIM) and its Subcommittee on Geodesy (SCoG), and the UN-GGCE. The GGOS-BPS shall propagate standards and conventions to the wider scientific community and promote their use, proposing new standards when necessary. In this context, the GGOS-BPS promotes the development of a new geodetic reference system (GRS) based on the best estimates available for the major parameters

of a geocentric level ellipsoid and contributes to the Working Group "Consolidation of a best estimate GRS based on the adopted W_0 of the IHRF".

Geodetic products

The IAG strives to provide geodetic products at the highest level of accuracy and consistency which fundamentally requires that common standards, conventions and (geo)physical models are used for the data analysis. The GGOS-BPS contributes to this goal by evaluating the adopted standards and conventions across all IAG components and by regularly updating the GGOS-BPS inventory. In collaboration with other IAG and GGOS components, the GGOS-BPS focuses on the classification of geodetic products and on the generation of user-friendly descriptions, which have been implemented at the GGOS website (www.ggos.org). The GGOS-BPS also supports the GGOS Coordination Office in the development of the GGOS Portal. The GGOS Portal will serve as a unique search and access point (one-stop shop) for geodetic data and products to ensure a better discoverability, user-friendly interfaces, easy-to-understand descriptions, a comprehensive overview of data sources, and interoperability with IAG Service data products and external portals (e.g., GEOSS, EOSDIS, EPOS, GFZ Data Services). In close collaboration with the UN-GGCE and the IAG Services, the GGOS-BPS takes part in the mapping of the global geodesy supply chain for the generation of geodetic products, focusing on the five areas: Evidence, resources, governance, capacity, and awareness. This work includes the assessment of costs, users and societal benefits of geodetic products. Furthermore, the GGOS-BPS shall initiate steps to identify user needs, gaps and requirements, and shall contribute to the development of new products, required to address important geophysical questions and societal needs.

7.2 Tasks

The tasks of the GGOS-BPS are to:

- act as contact and coordinating point for homogenization of IAG standards and products;
- keep track of adopted geodetic standards and conventions across all IAG components, initiate steps to close gaps and deficiencies, and provide recommendations to resolve inconsistencies;
- regularly update the inventory of standards and conventions used for the generation of IAG products to incorporate the latest developments;
- interact with IAG Services, the IERS Conventions Centre and external stakeholders in the field of standards and conventions (e.g., IAU, ISO, OGC, CODATA, UN-GGIM);
- act as IAG representative to the ISO Technical Committee (ISO/TC 211);
- propagate standards and conventions to the wider community; promote their use;
- foster the development of advanced methodologies for the combination of geometric and gravimetric observations and the generation of integrated products required for Earth sciences and societal needs, in collaboration with IAG Services and GGOS Focus Areas;

- contribute to the definition of EGVs, which are observed variables that are crucial to characterize the geodetic properties of the Earth and that are needed to understand the dynamics of the Earth system in all components and their interactions, in close collaboration with the Committee on the definition of EGVs, the GGOS Science Panel and representatives of the other IAG components;
- contribute to promote geodetic products to other disciplines and to society by creating user-friendly product descriptions and videos, in collaboration with the GGOS Coordinating Office, the IAG Services and the UN-GGCE;
- contribute to the mapping of the global geodesy supply chain for the generation of geodetic products, in collaboration with the UN-GGCE and the IAG Services;
- contribute to GGOS outreach activities (e.g., social media posts, videos about geodesy and geodetic products), in collaboration with the GGOS Coordinating Office;
- support the GGOS Coordinating Office in the development of the GGOS portal as a unique search and access point (one-stop shop) for geodetic data and products;
- organize internal GGOS-BPS meetings (every two months) and external Bureau meetings (twice per year);
- contribute to organizational GGOS business and coordination activities within IAG and with external stakeholders;
- represent GGOS-BPS activities and outcomes at conferences and workshops, and publish GGOS-BPS results in scientific and other journals.

In addition, the GGOS-BPS contributes to the IAG JWG 1.1.1 GENESIS (joint with IAG Commission 1, IERS). Description and objectives of this JWG are given in the IAG Commission 1 chapter.

7.3 Members

- D. Angermann (Germany); Director
- T. Gruber (Germany); Deputy Director
- M. Gerstl (Germany)
- R. Heinkelmann (Germany)
- U. Hugentobler (Germany)
- L. Sánchez (Germany)
- P. Steigenberger (Germany)

Associated Members (IAG Service representatives and others)

- R. Barzaghi (Italy)
- M. Bloßfeld (Germany)
- S. Bonvalot (France)
- M. Craymer (Canada)
- J. Ferrandiz (Spain)
- J. Gipson (USA)
- L. Hothem (USA)
- E. S. Ince (Germany)
- K. M. Kelly (USA)

- J. Kusche (Germany)
- M. Reguzzoni (USA)
- S. Rózsa (Hungary)
- M. Sehnal (Austria)
- N. Stamatakos (USA)
- P. Štěpánek (Czech Republic)
- H. Wziontek (Germany)

8 Components Associated to the GGOS-BPS

GGOS Committee on Earth System Modeling

Chair: Maik Thomas (Germany)

The GGOS Committee on Earth System Modeling tends to promote the development of physically consistent modular Earth system modeling tools that are simultaneously applicable to all geodetic parameter types (i.e., Earth rotation, gravity field and surface geometry) and observation techniques. Hereby, the committee contributes to:

- the interpretation of geodetic monitoring data and, thus, to a deeper understanding of dynamical and complex interacting processes in the Earth system responsible for the observed variations;
- the establishment of a link between geodetic products and numerical process models;
- a consistent combination and integration of observed geodetic parameters derived from various monitoring systems and techniques;
- the utilization of geodetic products for the interdisciplinary scientific community.

Objectives

The overall long-term goal is the development of a physically consistent modular numerical Earth system model for homogeneous processing, interpretation and prediction of geodetic parameters with interfaces allowing the introduction of constraints provided by geodetic time series of global surface processes, rotation parameters and gravity variations. This ultimate goal implicates the following objectives:

- development of Earth system model components considering interactions and relationships between surface deformation, Earth rotation and gravity field variations as well as interactions and physical fluxes between relevant compartments of the Earth system;
- promotion of homogeneous processing of geodetic monitoring data (de-aliasing, reduction) by process modeling to improve analyses of geodetic parameter sets;
- contributions to the interpretation of geodetic parameters derived from different observation techniques by developing strategies to separate underlying physical processes;
- contributions to the integration of geodetic observations based on different techniques in order to promote validation and consistency tests of various geodetic products.

Activities

Major current activities focus on:

- the consideration of three-dimensional structures of the Earth's crust and mantle as well as of anelastic effects in surface mass loading models;
- implementation of interfaces to geodetic monitoring data based on Kalman and particle filter approaches in order to constrain and improve stand-alone model approaches and to prove consistency of various geodetic monitoring products;
- feasibility studies regarding the coupling of neural networks with traditional data assimilation techniques and application of the combined approach in stand-alone models.

Important in-progress activities and future efforts focus on:

- estimation of consequences of upcoming hardware developments for CPU intensive model simulations (high-performance computing vs. exascale modeling);
- application of forward modeling and inversion methods in order to improve model-based predictions of geodetic quantities and to invert geodetic observations for the underlying causative processes.

GGOS Committee on Essential Geodetic Variables (EGVs)

Chair: Thomas Gruber (Germany)

The GGOS Committee on Essential Geodetic Variables (EGVs) was established in 2018 in order to define a catalogue of EGVs and to assign requirements to them. This Committee consists of representatives of the IAG Services, Commissions, Inter-Commission Committees, and the GGOS Focus Areas. EGVs are observed variables that are crucial (essential) to characterizing the geodetic properties of the Earth and that are key to sustainable geodetic observations. Examples of EGVs might be the positions of reference objects (ground stations, radio sources), Earth orientation parameters, ground- and space-based gravity measurements, etc. Once a list of EGVs has been determined, requirements can be assigned to them. Examples of requirements might be accuracy, spatial and temporal resolution, latency, etc. These requirements on the EGVs can then be used to assign requirements to EGV-dependent products like the terrestrial and celestial reference frames. The EGV requirements can also be used to derive requirements on the observing systems that are used to observe the EGVs. The EGVs can also serve as the basis for a gap analysis to identify observations needed to fully characterize the geodetic properties of the Earth.

Activities

The sequence of tasks to be performed by the Committee on EGVs are to:

- identify the purpose of EGVs in context with Earth observation;
- develop a concept and criteria on how to define EGVs;
- prepare a roadmap document towards the definition of EGVs and initiate discussion among the Committee and the broader geodetic community;

- define high level EGVs and prepare a classification scheme (matrix) linking them with geodetic products;
- assign requirements for high level EGVs and analyze if existing geodetic products meet these requirements or identify needs;
- discuss the purpose of and needs for lower level EGVs, e.g., as a tool to assess deployed and needed geodetic infrastructure.

GGOS Working Group on Consolidation of a best estimate GRS based on the adopted W_0 of the IHRF

Chair: Urs Marti (Switzerland)

The Geodetic Reference System 1980 (GRS80) is still the IAG conventional system for most applications in Geodesy and other Earth sciences. It was defined through the four parameters a (semi-major axis), J_2 (Dynamical Form Factor), GM (geocentric Gravitational Constant) and ω (Angular Rotation Velocity). It represents the scientific status of the 1970ies and in its concept, the tidal systems and relativistic theories are not considered. Since its adoption, various inconsistencies have been introduced into geodetic standards and applications, with respect to new values for GM or to the IERS conventions. In addition, this ellipsoid is not recognized by some communities outside the IAG. For example, the satellite altimetry and gravity field communities typically use different ellipsoid parameters, causing confusion for external users of geodetic data or products, and requiring them to implement transformations to make the data compatible when referenced to different ellipsoids. Moreover, in 2015, a conventional value for the gravity potential at sea level W_0 was adopted by the IAG, which also contradicts the definition of GRS80. In a previous GGOS Working Group (WG) in 2019-2023, several sets of parameters of a new best estimate GRS have been calculated by different groups. These calculations used different defining parameters and calculation methods. A consolidated and broadly accepted new GRS that could replace GRS80 is not yet ready to be published. In this present WG, a consolidated set of parameters and formulas for a new GRS should be worked out and presented. This WG will study the necessity to work towards an IAG resolution to replace GRS80 as the conventional system and provide transformation procedures between the two systems. It will study as well the necessity to define and adopt a conventional global gravity field model for standard applications in geodesy, navigation and related topics. This WG is assigned to the GGOS-BPS and works together with representatives of IAG Commissions 1 and 2, the ICCT, the IGFS, the IERS and the GGOS Committee on Essential Geodetic Variables. This WG will focus its activities on the coordination of the geometric reference frame (ITRF), the global height reference frame (IHRF), the global terrestrial gravity reference frame (ITGRF) and their temporal changes. The application of Earth orientation parameters and tidal models and the underlying standard and reference models has to be brought into consistency.

Objectives and Activities

The main objectives and activities of this working group are to:

- give an overview of already published work and compare the results;
- develop the mathematical apparatus for computing all derived quantities based on the defining constants;
- derive improved formulas for computations and transformations in a suitable coordinate system, as well as the creation of relevant software tools for implementation;
- calculate consistent parameters of a new mean Earth ellipsoid and derived quantities based on recent values of GM, W_0, J_2 and ω;
- study the influence of long-term changes of the defining parameters;
- present a new, consolidated "best estimate" GRS with all the derived quantities;
- study the necessity to replace the GRS80 as the conventional system;
- advance the realization of a conventional global reference gravity field model (combined and satellite only);
- study the influence of Earth orientation parameters, tidal models and relativistic effects on the realization of a consistent global reference frame in geometry, height and gravity.

Members

Urs Marti (Switzerland); Chair
Jonas Ågren (Sweden)
Detlef Angermann (Germany)
Riccardo Barzaghi (Italy)
Ropesh Goyal (India)
Sergei Kopeikin (USA)
Christopher Kotsakis (Greece)
Jaakko Mäkinen (Finland)
Pavel Novák (Czech Republic)
Ilya Oshchepkov (Russia)
Georgios Panou (Greece)
Erricos Pavlis (USA)
Laura Sánchez (Germany)
Hartmut Wziontek (Germany)

9 GGOS Focus Areas

GGOS FA website - https://ggos.org/about/org/fa/

9.1 Focus Area on Geohazards Monitoring (FA-GM)

Chair: Timothy Melbourne (USA)

Introduction

The GGOS Focus Area Geohazards Monitoring seeks to accelerate global implementation of emerging geodetic capabilities that improve resilience to environmental hazards. The FA-GM establishes working groups comprising GGOS members and responsible agencies of participating nations. The FA-GM encourages the sharing of intellectual, financial and physical resources as recommended by the UN-GGIM.

GNSS for Tsunami Early Warning

The FA-GM is currently focused on implementing global real-time GNSS observations to enhance existing earthquake and tsunami early warning systems. Following Resolutions 4, 6 and 7 of the 2015 IUGG General Assembly (https://iugg.org/wp-content/uploads/2022/04/Combined_Sendai_Partnerships.pdf) that collectively emphasize international cooperation in reducing risk, the FA-GM is coordinating GNSS data sharing and real-time analyses for GNSS-enhanced Tsunami Early Warning Systems (GeTEWS). This builds upon the GGOS vision document recommendation 5.8 (https://www.springer.com/gp/book/9783642026867) that calls upon us to "promote the development of GNSS seismology particularly for early warning and disaster assessment".

The importance of GeTEWS was amply defined in the powerful 2011 Tohoku-Oki earthquake and tsunami recorded by one of the world's most advanced GNSS ground networks, the Japanese GEONET (https://pubs.usgs.gov/of/2005/1131/UJNR_Wed/Yamagiwa/UJNR_Yamagiwa.pdf). The Geodetic and Geohazards community studied the data extensively and concluded that the GNSS could have provided an accurate early warning within five minutes of the Tohoku oki earthquake's onset. The same GNSS capability could have provided verification of the tsunami scale and begin to track its propagation before the inundation of the nearest coastal community. GeTEWS could provide authorities significant time to warn the local communities with far fewer false alarms. This information was provided by the GGOS co-sponsored GeTEWS 2017. The GeTEWS 2017 workshop reports are published by the Association of Pacific Rim Universities (APRU, https://apru.org/) and following peer review by the UN Office for Disaster Risk Reduction (UNDRR) as a contributing paper to the Global Assessment Report for 2019 (GAR19), see https://www.preventionweb.net/files/66779_flabrequeglobalnavigationsatellites.pdf.

GATEW Working Group

As its first initiative, the GGOS Geohazards Focus Area initiated and established a working group for the "GNSS Augmentation of Tsunami Early Warning" (GATEW) for the implementation of the GeTEWS initiative in 2016. The GATEW Working Group (https://www.dropbox.com/s/h4whbdqnnn4qquz/GATEWMembership17__11_2019.pdf?dl=0) remains open to all agencies and institutions that can provide resources and knowledge for the advancement of its GeTEWS initiative. The GATEW Working Group currently numbers 18 exceptional institutions from 12 nations. The GATEW members were central to the success of the GeTEWS 2017 meeting its report and the unfolding implementation of GeTEWS.

Further Steps

The FA-GM is currently working to establish a consortium to oversee the development and operation of a GNSS-enhanced Tsunami Early Warning capability for the Pacific Rim. IUGG has provided seed funds to support the planning and meeting of a "GeTEWS Consortium" to facilitate shared access to real time multi-GNSS data and processing. This meeting, currently scheduled for November 2024, has also been endorsed by the GGOS Coordinating Board, the IAG President, the IUGG Commission on Geophysical Risk and Sustainability (GRC). The FA-GM is working with the GRC and the Geodesy4Sendai activity of the Group on Earth Observations (GEO) to develop support and resources to assemble a consortium of principal organizations for the formation of the GeTEWS Consortium. We believe that the members of the GATEW working group will play an essential role within the GeTEWS Consortium. During the coming months, the GATEW working group is conducting virtual meetings to develop support for GeTEWS goals, strategies and timelines and membership composition including those government agencies responsible for the disaster risk management. The FA-GM will recommend that the findings and recommendations of the GeTEWS 2017 workshop serve as the foundation for the GeTEWS Consortium. Furthermore, the GeTEWS Consortium will likely require:

- National government participation for access to real time data;
- Participation of national emergency response agencies to insure proper interface and support;
- Broadband communications secure during disaster response;
- Cloud computing support;
- Science and technology readiness.

In addition, FA-GM interacts with the ICCT hosting JSG T.49 "High-resolution probing of the troposphere and ionosphere". In particular, the contribution of horizontal and altitude-wise profiles of electron content to the analysis of natural and man hazard-related ionospheric perturbations will be investigated as a potential tool to enhance early warning systems.

9.2 Focus Area on Geodetic Space Weather Research (FA-GSWR)

Chair: Michael Schmidt (Germany)
Vice-Chair: Ehsan Forootan (Denmark)

Introduction

Space weather is an up-to-date interdisciplinary field of research, which describes physical processes in space mainly caused by the Sun's radiation of energy. The manifestations of space weather are multiple, for instance, the variations of the Earth's magnetic field or the changing states of the upper atmosphere, in particular the ionosphere, the plasmasphere, and the thermosphere. The most extreme known space weather event happened at September 1, 1859 – the Carrington storm. Other prominent recent, but much weaker events have been the Halloween storm on October 28 – 30, 2003, or the St. Patrick's storm at March 17, 2015. In early February 2022, the poor understanding of thermospheric neutral density changes, caused by unexpected magnetic storms, resulted in the accidental re-entry of 38 Starlink satellites with the cost of more than 10 million EUR. More than 900,000 small debris objects with a radius of at least 1 cm are currently orbiting uncontrolled in the upper atmosphere, which are potential treats to operational satellites. The strength of atmospheric events, their impacts on modern society and the possibility of much stronger future events have brought several countries such as US, UK, Japan, Canada, and China to recognize the necessity of studying these impacts scientifically, of developing protection strategies and procedures and to establish space weather data centres and space weather services. Because of these activities the FA-GSWR was initiated and installed in 2017. The following statements summarize the necessity of geodesy to cover scientific research on the coupled processes within the magnetosphere, ionosphere/plasmasphere, and thermosphere (MIT): Geodesy has

- to deal with the ionosphere and the plasmasphere, since the measurements of almost all space-geodetic observation techniques are depending on the charging state of the upper atmosphere, i.e. the ionosphere and plasmasphere;
- to deal with the thermosphere, since the thermospheric drag is the most important deceleration effect on Low-Earth Orbiting (LEO) satellites and objects in the re-entry stage;
- to deal with the magnetosphere as it comprises the ionosphere, plasmasphere and thermosphere;
- a long history and extensive experience in the development and application of sophisticated analytical techniques and modeling approaches.

Objectives

From the statements above we define the main objectives of the FA-GSWR as:

- development of improved ionosphere models;
- development of improved thermosphere density models;
- study of the coupling processes within the MIT system;

- improved understanding of space weather events and their monitoring by geodetic and non-geodetic space missions and techniques.

The first objective is related to the electron density of the ionosphere, the second objective to the neutral density within the thermosphere.

Planned activities

In the following years the FA-GSWR will continue working on the following aspects:

- extensive simulation studies must be performed to assess the impact of space weather events on technical systems and to define necessary actions in case of severe space weather events;
- development of ionosphere and thermosphere models (maps) as stated above as IAG products for direct applications;
- establishment of recommendations for the applications of relevant models, e.g., in precise satellite orbit determination, for collision avoidance, in space debris analysis, and for re-entry computations.

In the following years the FA-GSWR will also work on following new aspects:

- We plan to extend the investigation area within the FA-GSWR from the upper atmosphere to the lower atmosphere. This leads to an integrated analysis of the MIT coupling processes and the vertical coupling processes (co-operations with the new proposed Focus Area on Combined Tropospheric Products);
- In connection to the vertical coupling processes, we will investigate the projection of climate change effects from the lower to the upper atmosphere (co-operations with the ICCC).

Other planned activities are:

- Special Issue to disseminate the results of the FA-GSWR;
- Planning focused workshops to promote the contribution of geodetic techniques for better understanding the atmosphere, for example, a workshop on geodesy and space weather to force the cooperation with the International Association of Geomagnetism and Aeronomy (IAGA);
- Producing a GGOS film on the contribution of Geodesy to Space Weather Monitoring and Forecasting.

In order to achieve the objectives of the FA-GSWR described above, the following four Joint Study Groups (JSG) are set up. These groups are titled as

- GGOS.GSWR.JSG 1: Understanding ionospheric and plasmaspheric processes
- GGOS.GSWR.JSG 2: Thermosphere modelling improvements and applications
- GGOS.GSWR.JSG 3: Space weather monitoring and prediction
- JSG T.44: Atmospheric coupling studies

The first three are led by GGOS FA-GSWR and are joint with IAG Commission 4, Sub-Commission 4.3. Since JSG T.44 is covering the coupling processes, i.e. it has to deal with many physical problems, it is led by IAG ICCT and is joint with GGOS and

Commission 4. There will be a strong connection and cooperation between the four groups.

Other implemented IAG Working/Study Groups within the current programme will provide valuable input for the FA-GSWR, in particular from the Commission 4, Sub-commission 4.3. Finally, it should be mentioned that the work within the FA-GSWR will be carried out in close relation to IAGA, since this organization is also concerned with the understanding of properties related, e.g. to the ionosphere and magnetosphere as well as the Sun and the solar wind. In this context, we want to mention the Interdivisional Commission on Space Weather (ICSW). Partly, the work in the FA-GSWR will be related to the International Association of Meteorology and Atmospheric Sciences (IAMAS).

GGOS.GSWR.JSG 1: Understanding Ionospheric and Plasmaspheric Processes

(Led by GGOS; joint with IAG Comm. 4)
Chair: Fabricio S. Prol (Finland)
Vice-Chair: David R. Themens (United Kingdom)

Introduction

The need for improved global-scale electron density models has been widely acknowledged in the past years, particularly with the rise in space activity. Over the decades, numerous studies have been conducted with particular interest on ionospheric and plasmaspheric models for geodetic positioning, space weather monitoring, aeronomy, and telecommunications. JSG 1 aims to advance three-dimensional (3D) ionospheric and plasmaspheric models specifically developed for geodetic applications. The reason for this initiative arises from the demand for highly precise electron density models of the ionosphere and plasmasphere, essential for satellite-based navigation and precise orbit determination of artificial satellites. We are targeting both empirical- and physics-based models. However, accomplishing this task presents inherent challenges, including the need for comprehensive data coverage, accurate model inversions, reliable measurements on a global scale, and an accurate initial guess of the modelling system. To promote solutions to overcome these challenges, the group has outlined the following objectives.

Objectives

- Promote developments of instruments to observe the ionosphere and plasmasphere;
- Evaluation of established methods of 3D imaging of the ionosphere to determine their accuracy in forecasting parameters relevant to space weather and geodesy. These include, in particular, the parameters of a vertical electron density profile, namely the maximum value of the electron density, the height of the maximum value, the scale height and vertical total electron content (VTEC), i.e. the integration of the electron density along the vertical;
- Improve the coupling and interaction between the ionosphere and plasmasphere;

- Enhance the feasibility of using 3D ionospheric maps for Precise Point Positioning (PPP) and RTK-PPP;
- Propose perspectives and recommendations for future developments of 3D electron density estimations with particular interest in geodetic positioning.

Members

Marcio Muella (Brazil)
Artem Smirnov (Germany)
Alessio Pignalberi (Italy)
Zhe Yang (China)
Yan Xiang (China)
Tatjana Gerzen (Germany)
Ehsan Forootan (Denmark)
Min-Yang Chou (United States)
Chris Watson (Canada)
Sean Elvidge (United Kingdom)
Paulo Sérgio de Oliveira Jr (Brazil)
Timothy Kodikara (Germany)
Ana Lucia Christovam (Brazil)

GGOS.GSWR.JSG 2: Thermosphere modelling improvements and applications

(Led by GGOS; joint with IAG Comm. 4 and ICCC)
Chair: Günther March (Netherlands)
Vice-Chair: Armin Corbin (Germany)

Introduction

In the last decades, accelerometer observations allowed to estimate thermosphere density and wind products. Such observations highly improved our understanding of the thermosphere. The generated datasets also provided detailed information on the forcing by Solar Extreme Ultraviolet radiation and charged particles and demonstrated for the first time the extent of forcing processes in lower layers of the atmosphere. Space Weather has a great influence on thermosphere dynamics. Neutral mass density, temperature, composition, and winds are important parameters which need to be carefully modelled to estimate acting forces on satellites. This is especially the case for LEO satellites which are heavily affected by atmospheric drag. The accurate characterization of the thermosphere is important for applications such as orbit prediction, collision avoidance, space debris, and mission lifetime predictions. Aerodynamic forces can be retrieved from accelerometer observations, which can be complemented using positioning techniques such as GNSS, SLR or radar tracking of space objects. The objective of this study group is to work on thermosphere modelling improvements aiming a better consistency between available datasets and investigate new applications from a modelling perspective including novel data exploitations. Broadening the observational data and applications, will also benefit climatological studies

of the thermosphere and the definition of next generation gravity missions. Within the study group the theoretical impact of novel applications for space weather monitoring and new science opportunities for the next generation gravity missions will be also investigated.

Objectives

- Update review on space geodetic observations and state-of-the-art processing methods including an overview of novel thermosphere datasets, e.g., very low Earth orbiting satellites, and model applications;
- Advance thermosphere modelling to increase consistency between observational datasets and to enable new applications;
- Assess accuracy level of available space geodetic observations;
- Study the impact of improved observational datasets and advanced processing methods on orbit determination and prediction;
- Use of improved thermosphere models and observational data sets to forward the investigation of thermosphere variations in the context of climate change and space weather monitoring.

Members

Michael Schmidt (Germany)
Günther March (Netherlands)
Armin Corbin (Germany)
Ehsan Forootan (Denmark)
Christian Siemes (Netherlands)
Kristin Vielberg (Germany)
Jose van den IJssel (Netherlands)
Mona Kosary (Iran)
Sandro Kraus (Austria)
Andreas Strasser (Austria)
Saniya Behzadpour (Switzerland)
Timothy Kodikara (Germany)
Peter Nagel (USA)
Andres Calabia (Spain)
Federico Gasperini (USA)
Florian Woeske (Germany
Chuntao Chang (China)
Sabin Anton (Netherlands)
Jack Wang (USA)

GGOS.GSWR.JSG 3: Space Weather Monitoring and Prediction

(Led by GGOS; joint with IAG Comm. 4)
Chair: Haixia Lyu (China)
Vice-Chair: Benedikt Soja (Switzerland)

Introduction

Space weather refers to the dynamic conditions in the Earth's outer space environment as influenced by the sun and the solar wind. It can affect different systems with increasing human activity reliance, such as satellite navigation systems, communication systems, power grids, etc. In the 25th solar cycle, characterized by heightened solar activity, the occurrence of intense coronal mass ejections (CMEs) and solar flares in 2023 underscores the critical importance of space weather monitoring and prediction. It is still challenging to monitor space weather in real time due to the inherent complexity and unpredictability of solar-terrestrial interactions, limitations in observational capabilities, and the computational demands of processing vast amounts of data in a timely manner. JSG 3 will focus on combining spaceborne observation systems and ground-based observations to better understand the process of space weather events and their effect on the near-Earth environment, developing space weather forecasting methods or models, trying to give more accurate predictions for ionospheric variations. Synergy with GGOS.GSWR.JSG 1, JSG T.44 and GGOS.AI4G.JSG 1 "AI for GNSS Remote Sensing" is promoted by identifying connected key questions to achieve a comprehensive understanding of the impact of space weather events.

Objectives

- Comparison and inter-validation among different space-based and ground-based observations of space weather events;
- Investigate in detail the impact of different space weather information on ionosphere, e.g., TEC predictions;
- Study the impact of selected geomagnetic storms on the ionospheric modeling and GNSS positioning performance;
- Development of AI and Data Fusion techniques for improving real-time space weather prediction capabilities.

Members

Anna Belehaki (Greece)
Jens Berdermann (Germany)
Yao Chen (China)
Yanhong Chen (China)
Jinsil Lee (Republic of Korea)
Anthony J. Mannucci (USA)
Enric Monte-Monero (Spain)
Xiaoqing Pi (USA)
Rami Qahwaji (UK)
Jean-Pierre Raulin (Brazil)
Pietro Zucca (Netherlands)
Louise Harra (Switzerland)

JSG T.44: Atmospheric Coupling Studies

(Led by ICCT; joint with IAG Comm. 4 and GGOS FA-GSWR)
Chair: Andres Calabia Aibar (Spain)
Vice-Chair: Binod Adhikari (Nepal)
The descrition of JSG T.44 is given in the ICCT chapter.

9.3 Focus Area on Artificial Intelligence for Geodesy (FA-AI4G)

Chair: Benedikt Soja (Switzerland)
Vice-Chair: Maria Kaselimi (Greece)

Introduction

The Focus Area will utilize methods from the field of Artificial Intelligence (AI), including machine learning (ML) techniques, to improve geodetic observations and products. The field of artificial intelligence has seen rapid progress in recent years, with breakthroughs in areas such as natural language processing, computer vision, and deep learning. This progress has led to the development of new AI applications and technologies and has the potential to transform a wide range of industries and fields. AI has become increasingly important in science, with applications in fields such as physics, biology, chemistry, and astronomy. It has become well-established in the neighboring disciplines of geodesy, including climate and weather prediction, space sciences, and remote sensing, helping to improve our understanding and prediction of complex natural phenomena. In general, AI can help scientists analyze complex data, identify patterns and relationships, and develop new hypotheses, ultimately accelerating the pace of scientific discovery. Geodesy has seen a significant increase in observational data in recent years, for example in the case of GNSS and InSAR missions. Furthermore, auxiliary data used in the analysis of space-geodetic data such as meteorological or environmental models have seen a significant increase in spatio-temporal resolution. Traditional data processing and analysis techniques that rely largely on human input are not well suited to harvest such rich data sets to their full potential. Recent advances in the development of ML algorithms, in particular efficient implementations of deep neural networks, together with a significant increase in computing power, have the potential to facilitate:

- the automation of data processing,
- the detection of anomalies in time series and image data,
- their classification into different categories,
- modeling complex spatio-temporal data,
- and creating enhanced derivate products in geodesy.

For these reasons, there has been a strong increase in research related to AI and ML in geodesy, covering various problems, including those mentioned above in relation to geometric space-geodetic techniques, gravity field, and earth orientation parameters, among other topics.

Objectives

- *Develop improved geodetic products based on AI and ML:* The FA-AI4G aims to explore the potential of AI and ML methods in improving the quality and accuracy of geodetic observations and products. The objective is to develop new approaches and methods that can help extract valuable information from large and complex geodetic datasets and use this information to create more accurate and reliable products. Depending on the application, improved geodetic products could have a higher accuracy, resolution, as well as better performance in in real-time or prediction scenarios. This will often involve assimilating data from different sources. To achieve the above objective, it is important to identify the most relevant and suitable geodetic and auxiliary datasets that can be used for training and validating ML algorithms. This will involve selecting datasets that have the right spatio-temporal resolution, accuracy, and other relevant characteristics that can help improve geodetic products. The FA-AI4G will also work on designing appropriate ML methods that can effectively improve the quality of geodetic data. This will involve exploring different ML algorithms, such as deep neural networks, and developing new techniques that can be used to analyze geodetic data.
- *Evaluate improved geodetic products based on AI and ML:* Thorough quality assessment is essential for increasing trust in the products produced with the use of AI, especially considering the "black box" nature of deep learning algorithms. The FA-AI4G will compare the performance of different ML methods with traditional data analysis approaches. This will involve identifying the strengths and limitations of each approach and determining the most appropriate method for a given application. AI4G will pay particular attention to the accuracy, precision, and reliability of the results produced by ML algorithms. This will involve developing new techniques for error assessment and uncertainty quantification, and identifying potential sources of errors in the results.

Implementation and overview of the Joint Study Groups (JSG)

To achieve the objectives mentioned above, FA-AI4G has implemented four joint study groups, described below, to tackle specific topics related to the use of AI in geodetic observations and products.

In addition to organizing JSG, FA-AI4G also aims to facilitate collaboration beyond these study groups. The goal is to ensure that the methodological progress achieved in these study groups benefits the wider geodetic community. To this end, we plan to organize events such as workshops or summer schools in addition to sessions at scientific conferences to disseminate the findings of the joint study groups. An example is the successful organization of the EGU General Assembly 2024 session on "Data Science and Machine Learning in Geodesy" with 22 submitted abstracts. The progress of the FA-AI4G will be documented on a dedicated website (https://space.igp.ethz.ch/services/services-to-iag/ggos/ai4g.html) and advertised on social media.

AI4G will collaborate closely with existing components of the IAG, in particular with the ICCT hosting JSG T.48 "Theoretical Foundations of Machine & Deep Learning in Geodesy" and other Working/Study groups under the IAG commissions

and committees, as well as other relevant organizations, including the International Telecommunication Union (ITU) and its Focus Group on AI for Natural Disaster Management (FG-AI4NDM) and the IERS JWG on the Prediction of Earth Orientation Parameters (PEOP).

GGOS.AI4G.JSG 1: AI for GNSS Remote Sensing

(joint with IAG Sub-Commission 4.3, ICCC and GGOS FA-GSWR)
Chair: Milad Asgarimehr (Germany)
Vice-Chair: Lei Liu (USA)

Introduction

GNSS remote sensing exploits the signals transmitted by positioning and navigation systems. GNSS provides visibility to multiple GNSS satellites at any point on the globe, enabling Earth observations with high spatial coverage and sampling frequency. GNSS remote sensing techniques, such as GNSS Reflectometry (GNSS-R), Radio Occultation (GNSS-RO), and ground-based sounding approaches, require only a receiver component as they exploit GNSS signals of opportunity. Consequently, the use of GNSS receivers for remote sensing purposes has rapidly grown in regional and global ground networks, as well as in small satellites and CubeSat constellations. These receivers generate large datasets that offer significant potential for data-driven algorithm development and "learning" by AI models.

However, the full potential of AI in GNSS remote sensing has not yet been realised. In contrast, ML techniques are well established in other remote sensing domains, particularly in the processing of optical Earth observations. AI can enhance retrieval and modelling capabilities, which is particularly valuable in GNSS remote sensing, especially where theoretical models lack validation under different field conditions, or when the associated physics cannot be easily formulated using theoretical knowledge. This study group aims to use AI approaches to drive innovative and interdisciplinary developments in GNSS Earth observations and Earth system modelling, including land/ocean surface parameters, atmospheric, ionospheric, and space weather processes.

Objectives

- Explore the potential of advanced AI techniques for retrieving Earth's surface, atmospheric, climate, ionospheric, and space weather parameters from GNSS remote sensing data as a sole source of information or in fusion with data from other sensors/techniques. The studies may include quantification of model uncertainty.
- Study physics-informed AI to embed theoretical knowledge in the learning process and to mutually improve physical understanding and domain knowledge through explainable modelling, inverse knowledge extraction, pattern recognition, and simulation.
- Explore the potential for prediction of surface, atmospheric, and ionospheric patterns and climate-driven changes by training AI on historical data and incorporating real-time information.

- Leverage AI models for Earth system modelling and forecasting using GNSS data to support risk assessment, early warning systems, and decision making for climate change mitigation and adaptation.

Members

Fikri Bamahry (Belgium)
Mohammad Sharifi (Iran)
Grzegorz Nykiel (Poland)
Randa Natras (Germany)
Manuel Martin-Neira (Netherlands)
Zorheh Adavai (Austria)
Artem Smirnov (Germany)
Jonathan Jones (UK)
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Shuyin Mao (Switzerland)
Gregor Möller (Austria)
Timothy Kodikara (Germany)
Stylianos Kossieris (Greece)
Jens Wickert (Germany)
Caroline Arnold (Germany)
Matthias Aichinger-Rosenberger (Switzerland)
Tianqi Xiao (Germany)
Mario Moreno (Germany)
Laura Crocetti (Switzerland)
Cansu Beşel (Türkiye)
Ole Roggenbuck (Germany)
Cheng Wang (China)
Witold Rohm (Poland)
Jihye Park (USA)
Alireza Amiri-Simkooei (Netherlands)
Saeid Haji-Aghajany (Poland)

GGOS.AI4G.JSG 2: AI for Gravity Field and Mass Change

(joint with IAG Comm. 2 and ICCC)
Chair: Vacant
Vice-Chair: Saniya Behzadpour (Switzerland)

Introduction

Gravity field data provide invaluable insights into various aspects of Earth's dynamics, ranging from monitoring changes in water storage to understanding mass redistribution and geophysical phenomena. These data play a crucial role in fields such as hydrology, geophysics, and climate science. However, traditional methods of gravity field determination and analysis often face challenges in terms of data processing, spatial resolution, and filling temporal gaps.

JSG 2 seeks to address these challenges by leveraging the power of AI and ML techniques. AI/ML algorithms have demonstrated remarkable capabilities in extracting patterns from large-scale datasets, automating data processing tasks, and quantifying uncertainties. Recent generative AI algorithms have further pushed the envelope of learning from foundation models. Moreover, ML techniques offer the potential to address the issue of spatial resolution in gravity field analysis. The exploration of downscaling techniques will contribute to improving the spatial resolution of gravity field data, allowing for more detailed analyses of water dynamics at localized levels.

Additionally, ML models can fill the temporal gaps in gravity field datasets by learning from existing data and predicting missing values. By training these models on historical data from missions such as GRACE, we can generate reliable estimates during periods when data collection is unavailable. This capability ensures a more complete and continuous understanding of gravity field variations and facilitates more accurate analyses of temporal trends and anomalies.

Objectives

- Investigate and integrate AI algorithms and techniques in gravity field determination and its related applications;
- Evaluate the potential of gravity field data in enhancing the accuracy of hydrological models by providing additional information on water storage variations;
- Explore the downscaling techniques and methodologies that can effectively integrate gravity data with hydrological models to improve spatial resolution;
- Assess the performance of ML models in terms of accuracy, precision, and robustness in filling the temporal and spatial gaps between the GRACE and GRACE-FO datasets;
- Investigate physics-informed AI/ML for fusing GRACE data into global hydrological models.

Members

Junyang Gou (Switzerland)
Tao Jiang China)
Zizhan Zhang (China)
Emel Zeray Öztürk (Türkiye)
Ashraf Rateb (USA)
Himanshu Save (USA)
Metehan Uz (Türkiye)
Keiko Yamamoto (Japan)
Roland Hohensinn (Switzerland)
Betty Heller (Germany)
Filip Gałdyn (Poland)

GGOS.AI4G.JSG 3: AI for Earth Orientation Parameter Prediction

(joint with IAG Comm. 3)
Chair: Sadegh Modiri (Germany)

Vice-Chair: Justyna Śliwińska-Bronowicz (Poland)
Vice-Chair: Prof. Santiago Belda (Spain)

Introduction

The JSG 3 will explore the use of AI for predicting Earth Orientation Parameter (EOP). This group will build on the successful Second EOP Prediction Comparison Campaign (2nd EOP PCC) organized by the IERS and will continue to investigate ML for the prediction of EOP and effective angular momentum.

The JSG 3 recognizes the pivotal significance of accurate EOP prediction and the transformative potential of AI in advancing our understanding of these parameters. EOP, encompassing nutation offsets, pole coordinates, and dUT1, serve as a crucial link between the terrestrial and celestial reference frames, playing a vital role in many operational activities. Navigation of deep-space satellite missions, the precise pointing of astronomical instruments, and satellite-based positioning on Earth heavily rely on precise EOP predictions. Timely and reliable estimates of these parameters are essential for ensuring the success and accuracy of such endeavours. Recognizing this need, numerous agencies and institutions worldwide diligently process space geodetic observations to obtain rapid estimates, forming the foundation for subsequent EOP predictions. The advent of AI presents an unparalleled opportunity to revolutionize EOP prediction by leveraging the remarkable progress made in AI methodologies. AI techniques, including natural language processing, computer vision, and deep learning, have demonstrated their prowess in various fields, enabling breakthroughs in data analysis, pattern recognition, and hypothesis generation. By harnessing these AI capabilities, scientists can delve deeper into complex EOP theories, enhance our understanding of Earth's orientation, and refine prediction models. AI empowers researchers to analyze vast and intricate datasets with remarkable efficiency, unravelling hidden patterns and relationships that might have eluded traditional methods. These AI-driven insights accelerate scientific discovery and contribute to the development of robust EOP prediction models. The ability to process and interpret complex data, coupled with AI's capacity for adaptive learning, opens new avenues for refining existing theories and exploring novel hypotheses related to Earth's orientation. Through the collaborative efforts of the group, AI methodologies are deployed to enhance the accuracy, reliability, and timeliness of EOP predictions. By integrating AI into the existing prediction processes, scientists can harness the power of ML algorithms to improve prediction models based on observed EOP data continually. This iterative feedback loop strengthens the foundations of EOP theories, enabling a more comprehensive understanding of Earth's orientation dynamics. The group's primary objective is to foster innovation, collaboration, and knowledge exchange among experts in AI and geodesy. By bringing together interdisciplinary expertise, the group aims to push the boundaries of AI research, uncovering novel insights into EOP theories and further refining prediction methodologies. This collective effort enhances our understanding of Earth's orientation and advances the accuracy of navigation, positioning, and astronomical endeavours that rely heavily on EOP predictions. In summary, JSG 3 recognizes the critical importance of accurate EOP predictions and embraces the transformative potential of AI. By synergistically merging AI methodologies with the

rich field of geodesy, the group aims to unlock new frontiers in EOP research, thereby advancing our understanding of Earth's orientation and improving the precision and reliability of EOP predictions. Through collaboration, exploration, and innovation, the study group strives to shape the future of EOP prediction and its applications in various operational activities, paving the way for significant advancements in navigation, positioning, and astronomical sciences.

Objectives

- Investigate the results of the 2nd EOP PCC, analyzing the accuracy, consistency, and reliability of the obtained parameters. By evaluating the performance of the EOP PCC method, the group aims to identify areas for improvement and propose refinements to enhance the quality of EOP predictions.
- Study the impact of geophysical and meteorological parameters on EOP prediction: investigate the influence of various geophysical and meteorological parameters on the EOP prediction. By analyzing their correlations and dependencies, the study group aims to enhance the understanding of how these parameters affect EOP predictions, enabling more accurate and robust forecasting models.
- Explore effective angular momentum prediction: focus on studying and improving the prediction of effective angular momentum, which plays a critical role in Earth's orientation dynamics. By developing advanced prediction models and leveraging ML techniques, the group aims to enhance the accuracy and reliability of effective angular momentum predictions, contributing to improved EOP forecasts.
- Study ML methods to derive the physical meaning and dependency structure between EOP and other parameters: investigate ML methods specifically designed to extract the physical meaning and underlying dependency structure between EOP and other geophysical and meteorological parameters. By applying these methods, the group seeks to uncover valuable insights and enhance the interpretability of AI-driven models, facilitating a deeper understanding of EOP dynamics.
- Develop hybrid models to improve EOP prediction: develop hybrid prediction models that combine traditional methods with AI techniques. By integrating the strengths of different approaches, such as data-driven ML algorithms and physical models, the group seeks to enhance the accuracy, robustness, and reliability of EOP predictions, providing more comprehensive forecasting capabilities.
- Improve EOP theory using AI: By leveraging AI methodologies, the group aims to advance the theoretical understanding of Earth orientation parameters. Through the analysis of complex datasets and the application of AI-driven techniques, the group seeks to refine and expand EOP theories, enabling a deeper comprehension of the underlying dynamics and factors influencing Earth's orientation.
- Conduct sensitivity analysis of EOP prediction models: perform sensitivity analyses to evaluate the stability and robustness of EOP prediction models. By systematically assessing the impact of various input parameters and assumptions, the group aims to identify critical factors that influence the accuracy and reliability of predictions, providing insights for model refinement and validation.
- Explore commercial applications, such as satellite orbit determination and real-time applications: investigate the commercial applications of improved EOP predictions, particularly in areas such as satellite orbit determination and real-time

applications. By understanding the impact of accurate EOP predictions on these domains, the group seeks to contribute to the development of innovative solutions and technologies that can enhance satellite operations and realtime positioning systems.

- Identify the best prediction model for each EOP by evaluating and comparing different prediction models. By conducting comprehensive assessments and benchmarking exercises, the group seeks to identify the most accurate and reliable prediction methods for specific parameters, allowing for tailored approaches and optimized EOP predictions.
- Foster knowledge sharing and collaboration: actively promote knowledge sharing and exchange of ideas among researchers, industry professionals, and policymakers. Through workshops, conferences, and publications, the group aims to facilitate discussions and interactions that accelerate advancements in EOP prediction, promoting the adoption of AI techniques and fostering innovation in the field.

Members

Alireza A. Ardalan (Iran)
Dimitrios Ampatzidis (Greece)
Esther Azcue (Spain)
Jan Becker (Germany)
Liliane Biskupek (Germany)
Santiago Belda (Spain)
Sharyl Byram (USA)
Maria Davis (USA)
Robert Dill (Germany)
Sujata Dhar (Germany)
Sonia Guessoum (Spain)
Robert Galatiya Suya (UK)
Dzana Halilovic (Germany)
Maria Karbon (Spain)
Mostafa Kiani Shahvandi (Switzerland)
Qiaoli Kong (China)
Tomasz Kur (Poland)
Yan Kailing (China)
Arnab Laha (India)
Marcin Ligas (Poland)
Zhao Li (China)
Sadegh Modiri (Germany)
Mariana Santos Moreira (Portugal)
Maciej Milchalczak (Poland)
Wei Miao (China)
Ibnu Nurul Huda (Indonesia)
Haibo Que (China)
Jihye Park (USA)
Xanthos Papanikolaou (Greece)

Aleksander Partyka (Poland)
Victor Puente (Spain)
Ole Roggenbuck (Germany)
Shrishail Raut (Germany)
Justyna Śliwińska-Bronowicz (Poland)
Harald Schuh (Germany)
David Schunck (Australia)
Sahayan Shirafkan (Iran)
Lin Wang (Germany)
Na Wei (China)
Xueqing Xu (China)
Yuanwei Wu (China)
Dongshan Yin (China)

GGOS.AI4G.JSG 4: AI for Geodetic Deformation Monitoring

(joint with IAG Comm. 3)
Chair: Mohammad Ali Sharifi (Iran)
Vice-Chair: Mohammad Omidalizarandi (Germany)

Introduction

Monitoring the system Earth and man-made structures, and their deformation induced by natural or anthropogenic forces is recognized as a key role of modern geodesy. Different space and terrestrial geodetic technologies have been employed for precise measurement and identification of spatio-temporal deformation of the Earth surface. The geodetic measurement techniques are getting even more precise with unprecedented temporal and spatial resolutions. For example, Dense GNSS Continuously Operating Reference Stations (CORS) and the Interferometric Synthetic Aperture Radar (InSAR) with complementary abilities successfully monitor the Earth system dynamics. Nonlinearity and complexity of deformation patterns on the one hand and the need for knowledge mining in the steadily growing big geodetic data on the other hand make use of ML and AI-assisted approaches vital to the geodetic community.

Objectives

- Automatic recognition and identification of spatio-temporal patterns associated to various deformation mechanisms such as tectonics, volcanism, land subsidence, ice and glacier motion, and landslides in InSAR data.
- Detection of abnormalities and sinkhole-precursors signals in deformation time series acquired by different geodetic techniques (e.g., InSAR, GPS, Levelling, etc).
- AI potential for mitigation of atmospheric effects on InSAR and GNSS data through AI training on meteorological models.
- ML-based classification of deformation time series based on different kinematic patterns.
- Estimation and calibration of civil structure dynamic models by exploiting AI learning capabilities.

- Deep-learning-based structural health monitoring of civil infrastructures and buildings using satellite or ground-based geodetic measurements.
- Automatic detection of offsets, probable slow slip events, and abnormal earthquake patterns in GNSS time series.
- Identification of complex multi-fault ruptures and triggering mechanisms using local CORS networks.
- Development of ML methodologies to forecast how deformations might evolve in the future.

Members

Mohammad Ali Sharifi (Iran)
Mohammad Omidalizarandi (Germany)
Ingo Neumann (Germany)
Alireza Amiri Simkooei (Netherlands)
Andrew Hooper (UK)
Amir M. Abolghasem (Germany)
Sami Samiei Esfahany (Iran)
Zhiping Chen (China)
Xiaoxing He (China)
Roland Hohensinn (Switzerland)
Yao Yevenyo Ziggah (Ghana)
Dimitrios Anastasiou (Greece)
Stylianos Bitharis Greece)
Liming Jiang (China)
Shunqiang Hu (China)

Part V

IAG Scientific Services

International Earth Rotation and Reference Systems Service (IERS)

https://doi.org/10.82507/iag-gh2024_iers

Chair of Directing Board: Tonie van Dam (USA)
Central Bureau Director: Daniela Thaller (Germany)

IERS website - https://www.iers.org

1 Introduction

The IERS was established as the "International Earth Rotation Service" in 1987 by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), and it began operation on 1 January 1988. Since 2001, the IERS works in a new organizational structure.

In 2003, the new name "International Earth Rotation and Reference Systems Service" was adopted, without changing its abbreviation. The IERS is a regular member of the ISC World Data System (WDS) and an Associate Member of the International Committee on Global Navigation Satellite Systems (ICG). The latest Terms of Reference (ToR) of IERS can be found on its website: https://www.iers.org/IERS/EN/Organization/About/ToR/ToR.html.

2 Objectives

The primary objectives of the IERS are to serve the astronomical, geodetic and geophysical communities by providing the following:

- The International Celestial Reference System (ICRS) and its realization, the International Celestial Reference Frame (ICRF);
- The International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF);
- Earth orientation parameters (EOP) required to study Earth orientation variations and to transform between the ICRF and the ITRF;
- Geophysical data to interpret time/space variations in the ICRF, ITRF or EOP, and model such variations;
- Standards, constants and models (i.e., conventions) encouraging international adherence.

3 Products

IERS collects, archives and distributes products to satisfy the objectives of a wide range of applications, research and experimentation. These products include:

- International Celestial Reference Frame;
- International Terrestrial Reference Frame;
- Final daily Earth orientation data updated monthly;
- Rapid service estimates of near real-time Earth orientation data and their predictions updated four times per day;
- Announcements of the differences between astronomical and civil time for time distribution by radio stations;
- Leap second announcements;
- Products related to global geophysical fluids such as mass and angular momentum distribution;
- Annual reports and technical notes on conventions and other topics;
- Long-term Earth orientation information.

The accuracies of these products are sufficient to support current scientific and technical objectives including:

- Fundamental astronomical and geodetic reference systems;
- Monitoring and modeling Earth rotation/orientation;
- Monitoring and modeling deformations of the solid Earth;
- Monitoring mass variations in the geophysical fluids, including the atmosphere and the hydrosphere;
- Artificial satellite orbit determination;
- Geophysical and atmospheric research, studies of dynamical interactions between geophysical fluids and the solid Earth;
- Space navigation.

4 Structure

The IERS accomplishes its mission through the following components:

- Technique Centers: International GNSS Service (IGS), International Laser Ranging Service (ILRS), International VLBI Service (IVS), International DORIS Service (IDS);
- Product Centers: Earth Orientation Center, Rapid Service/Prediction Center, Conventions Center, ICRS Center, ITRS Center, and Global Geophysical Fluids Center (GGFC) with Special Bureaus for the Atmosphere, for the Oceans, for Hydrology, and for Combination;
- ITRS Combination Centers at Deutsches Geodätisches Forschungsinstitut at TU München (DGFI-TUM), Institut Géographique National (IGN), Jet Propulsion Laboratory (JPL);
- Analysis Coordinator;
- Central Bureau;
- Directing Board;
- Working Groups: WG on Metrology of Space Geodetic Infrastructure, WG on SINEX Format, WG on the Consistent Realization of TRF, CRF, and EOP, WG on GENESIS, WG on Evaluation of the Terrestrial Reference Frames.

Some of these components (e.g., Technique Centers) may be autonomous, structurally independent from IERS, but which cooperate with the IERS. A participating organization may also function as one or several of these components.

IERS Directing Board

- Tonie van Dam (USA); Chair of the IERS Directing Board
- Daniela Thaller (Germany); Director of the Central Bureau
- Robert Heinkelmann (Germany); Analysis Coordinator
- Christian Bizouard (France); Earth Orientation & Conventions Center Repr.
- Nick Stamatakos (USA); Rapid Service/Prediction Center Repr.
- Claire E. Cramer (USA); ICRS Center Representative
- Zuheir Altamimi (France); ITRS Center Representative
- Jean-Paul Boy (France); GGFC Representative
- Jérôme Saunier (France); IDS Representative
- Petr Štěpánek (Czech Republic); IDS Representative
- Rolf Dach (Switzerland); IGS Representative
- Elisabetta D'Anastasio (New Zealand); IGS Representative
- Clément Courde (France); ILRS Representative
- Mathis Bloßfeld (Germany); ILRS Representative
- Rüdiger Haas (Sweden); IVS Representative
- Sigrid Böhm (Austria); IVS Representative
- Thomas Herring (USA); IAG/IUGG Representative
- Aleksander Brzezinski (Poland); IAU Representative
- Detlef Angermann (Germany); GGOS Representative

International DORIS Service (IDS)

https://doi.org/10.82507/iag-gh2024_ids

Chair of the Governing Board: Frank Lemoine (USA)
Central Bureau Director: Laurent Soudarin (France)

IDS website - https://ids-doris.org/

1 Introduction

The DORIS (Doppler Orbit determination and Radio-positioning Integrated on Satellite) system for satellite orbit determination and precise positioning was developed by the Centre National d'Etudes Spatiales (CNES) in conjunction with the Institut Géographique National (IGN) and the Groupe de Recherche de Géodesie Spatiale (GRGS).

A proof of concept for the International DORIS Service (IDS) was conducted through a pilot phase prior to the establishment of the International DORIS Experiment in 1999 by the IAG. The IDS formally began on July 1, 2003 after official approval by the IAG at the IUGG General Assembly in Sapporo, Japan. The IDS [3] is an IAG Service and operates in close cooperation with the International Earth rotation and Reference systems Service (IERS). The latest Terms of Reference (ToR) of IDS can be found on its website: https://ids-doris.org/ids/organization/terms-of-reference.html.

2 Mission, Objectives, Products

The primary objective of the IDS is to provide a service to support geodetic and geophysical research activities through DORIS data and derived products. The IDS collects, archives and distributes DORIS observation datasets of sufficient accuracy

to satisfy the objectives of a wide range of applications and experiments. From these datasets the following products are derived:

- Coordinates and velocities of the IDS tracking stations;
- Geocenter and scale of the Terrestrial Reference Frame;
- High accuracy ephemerides of the DORIS satellites;
- Earth orientation parameters (EOPs).

The accuracies of these products are sufficient to support current scientific objectives including:

- Realization of global accessibility to and the improvement of the International Terrestrial Reference Frame (ITRF);
- Monitoring deformations of the solid Earth;
- Monitoring crustal deformation at tide gauges;
- Monitoring variations in the hydrosphere (sea level, ice-sheets, etc.);
- Orbit determination for scientific satellites.

3 Structure

The IDS accomplishes its mission through the following components:

- Satellites carrying a DORIS receiver
- Network of tracking stations
- Data Centers
- Analysis Centers, Associate Analysis Centers and Analysis Coordinator
- Combination Center
- Working Groups
- Central Bureau (CB)
- Governing Board (GB)

Satellites carrying a DORIS receiver

Since July 2003, the CNES and the European Space Agency (ESA) have provided DORIS data to the IDS. Data from additional agencies are expected and welcome. DORIS receivers are flown on LEO satellites for precise orbit determination as well as for geodetic applications. Satellites with DORIS receivers are listed in Table 1 and on the IDS website.

Network of tracking stations

The IDS network is composed of DORIS permanent tracking stations located at host institutions and maintained by the IGN. A list of the sites (past and present) is included on the IDS website. The network also includes additional DORIS stations proposed by the IDS to observe during specific campaigns of scientific interest.

Table 1. DORIS data from satellites, available at IDS Data Centers (March 2024)

Satellite	Start	End	Type
SPOT-2	31-MAR-90	04-JUL-90	Remote sensing
	04-NOV-92	15-JUL-09	
TOPEX/Poseidon	25-SEP-92	01-NOV-94	Remote sensing
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	24-JUN-13	Remote sensing
Jason-1	15-JAN-02	21-JUN-13	Altimetry
SPOT-5	11-JUN-02	1-DEC-15	Remote sensing
ENVISAT	13-JUN-02	08-APR-12	Altimetry, Environment
Jason-2	12-JUL-08	03-OCT-19	Altimetry
Cryosat-2	30-MAY-10	-	Altimetry
HY-2A	1-OCT-11	11-SEP-20	Altimetry
SARAL	14-MAR-13	-	Altimetry
Jason-3	19-JUN-16	-	Altimetry
SENTINEL-3A	23-FEB-16	-	Altimetry
CSENTINEL-3B	25-APR-18	-	Altimetry
HY-2C	24-SEP-20	-	Altimetry
SENTINEL-6A	17-DEC-20	-	Altimetry
HY-2D	04-AUG-21	-	Altimetry
SWOT	12-JAN-23	-	Altimetry

Data Centers

The Data Centers are in direct contact with the CNES, which provides the DORIS data. They archive the DORIS data, derived products, and ancillary information required to process these data.

Analysis Centers, Associate Analysis Centers and Analysis Coordinator

The Analysis Centers (ACs) are committed to provide at least one of the above IDS products on a regular basis. They adhere to IDS recommendations for the creation of high-quality products and their timely archiving and distribution. Expertise in DORIS data analysis and operational capability are essential factors in the selection of ACs. Currently, only groups providing IDS products routinely may be considered as ACs.

The Analysis Coordinator assists the ACs and monitors their activities to ensure that the IDS objectives are carried out. The Coordinator, working with the ACs, is expected to provide quality control, performance evaluation, and continued development of appropriate analysis standards. The Analysis Coordinator, with the support of the Combination Center, is also responsible for the appropriate combination of ACs' products into a single set of prescribed data products.

Associate Analysis Centers (AACs) provide specialized or derived products, not necessarily at regular intervals (such as precise orbits, station positions, Earth Orientation Parameters, ionospheric products, tropospheric delays, or any scientific data

products of a mission-specific nature). They are recognized as such by the GB, upon recommendation of the Analysis Coordinator. The AACs are encouraged to present their results at IDS meetings and to submit their final results in IDS Data Centers for dissemination to researchers and other users. An AAC may become an AC after demonstrating its expertise and operational capability during a test period.

A current list of ACs and AACs is given in Table 2.

Table 2. IDS Analysis Centers and Associate Analysis Centers (March 2024)

Analysis Center	**Country**	**Software**
ESA/ESOC	Germany	NAPEOS
Geod. Observatory Pecny	Czech Rep.	Bernese
NASA/GSFC	USA	GEODYN
IGN	France	GIPSY/OASIS
INASAN	Russia	GIPSY/OASIS
CNES/CLS	France	GINS/DYNAMO
Associate An. Center	**Country**	**Software**
GFZ	Germany	EPOS-OC
CNES/POD	France	Zoom
TU Delft	Netherlands	
DGFI-TUM	Germany	DOGS

Combination Center

The IDS appoints a Combination Center (CC) to combine individual AC solutions and to generate IDS data products for submission to the IERS for the formulation of the periodic update of the ITRF and other geodetic products. The CC is selected by the GB every four years through a call for participation initiated six months prior to the end of the current CC term. Interested institutions submit proposals outlining their plan for operation of the CC and the resources that they will commit.

Working Groups

IDS Working Groups provide expertise on particular topics related to the IDS components and on development of particular IDS product(s) or service(s) relying on the IDS infrastructure. They are created when needed, and are dissolved by the GB when their work has been completed or they are no longer needed. Each Working Group must develop a charter that includes a mandate, a list of specific tasks, a schedule, and an identified Chair.

Central Bureau

The CB is the executive arm of the IDS GB and is responsible for the general management of the Service, according to the directives, policies and priorities set by the GB. The CB, within available resources, coordinates IDS activities, facilitates communications, maintains the documentation, and organizes reports, meetings and workshops. The CB responds to external inquiries about the IDS, promotes the use of IDS data and products, and coordinates interactions with other services, including the IERS.

The CB supports the CC in combining the various ACs' products and providing all information necessary to validate the final combined products.

The CB operates the information system for the IDS and produces the IDS Annual Reports and the IDS Associates directory. The CB coordinates the publication of other documents required for the satisfactory planning and day-to-day operation of the Service, including standards and specifications regarding the performance, functionality and configuration requirements of all Service elements.

Although the Chair of the GB is the official representative of the IDS to external organizations, the CB is responsible for the day-to-day liaison with such organizations, consistent with the directives established by the GB.

The long-term function of the IDS is assured through redundancy and emergency contingency plan for all of its components except for the CB. The CB serves for a term of four years. One year prior to the end of the term, the GB formally reviews the performance of the CB, and may then request the CB to re-confirm its commitment for another four years. If the CB declines, or if the GB chooses to change the CB, then the GB announces a call for proposal for a new IDS CB to take the responsibility including a six-month transition phase.

In summary, the CB performs primarily a long-term coordination role to ensure that IDS participants contribute to the Service in a consistent and harmonious manner and adhere to IDS standards.

Governing Board

The principal role of the GB is to set the policy and to exercise broad oversight of all IDS functions and components. It also controls the general activities of the Service, including restructuring, when appropriate, to maintain the efficiency and reliability of the Service.

The GB elects a Chair from its members to serve a term of four years with the possibility of re-election for one additional term. The Chair is the official representative of the IDS to external organizations.

The GB consists of eleven voting and a number of non-voting members. The membership is chosen trying to strike the right balance between project specialists and the general community. The composition of the IDS Governing Board (voting members, March 2024) is as follows:

- Frank Lemoine (USA); Chair of IDS; Analysis Center Representative
- Laurent Soudarin (France); Director of the Central Bureau
- Jérôme Saunier (France); Network Representative
- Cécile Manfredi (France); DORIS System Representative

- Patrick Michael (USA); Data Flow Coordinator
- Petr Štěpánek (Czech Republic); Analysis Coordinator
- Guilhem Moreaux (France); Combination Center Representative
- Ernst Schrama (Netherlands); IAG Representative
- Tonie van Dam (USA); IERS Representative
- Laura Sanchez (Germany); Member-at-Large
- Karine Le Bail (Sweden); Member-at-Large

During their mandate, the Working Group Chairs are GB members with voice but without vote.

IDS Associates (see below) elect the following GB members: Analysis Center representative, Data Center representative, Analysis Coordinator and two Members-at-Large. The elected members have staggered four-year terms, with elections every two years. There is no limit to the number of terms that a person may serve, however he or she may serve only two terms consecutively as an elected member. The Analysis Center representative, the Data Center representative, and one Member-at-Large are elected during the first two-year election. The Analysis Coordinator and the other Member-at-Large are elected in the second two-year election. Although no formula is prescribed, efforts should be made to keep the GB membership properly balanced with regard to supporting organizations and geographic distribution.

The Director of the CB and the Combination Center representative are appointed GB members. The DORIS System representative and the Network representative are appointed by CNES and IGN, respectively, for four-year terms without limitation. The IAG and IERS representatives to the IDS GB are appointed by the IAG Executive Committee and by the IERS DB, respectively, for a maximum of two four-year terms. In case of a resignation from the GB, the CB, after consulting with the appropriate IDS components, nominates a replacement candidate for election by the GB. The replacement will serve until the end of the term of the resigned member.

Most decisions at GB meetings are to be made by consensus or by a simple majority vote of the voting members present, provided that there is a quorum consisting of at least six voting members of the GB. GB decisions can be made through email or other correspondence by a majority vote of the GB voting membership. Changing the ToR and the Chair of the GB can only be made by a 2/3 majority of the members of the GB, i.e., by seven or more votes.

The GB meets at least annually. The CB provides the secretariat of the GB.

Members of the GB become IAG Fellows with the appropriate rights and privileges, after an initial two-year period.

4 Members

IDS Associates

IDS Associates are persons representing organizations that participate in any of the IDS components. A participating institution can submit a person's name, and primary IDS function in its organization to the CB for application to become an IDS Associate, with a limit of ten persons. The GB approves all memberships. The GB reserves the

right to appoint additional associates who do not participate in any IDS components but who contribute significantly to the IDS or whose activities rely on DORIS data and products. Such persons are nominated directly by the GB. The CB maintains the current list of IDS Associates.

IDS Associate Members take part in the election of five incoming members of the GB, as explained above. The GB must approve the list of IDS Associates eligible for voting in the elections at least three months prior to the election process. For the election, current and former GB members are also considered as IDS Associates. A nominating committee of three persons conducts the elections. The Chair of the nominating committee is appointed by the GB Chair, and must be a GB member not currently up for re-election. The GB chooses the remaining two members of the nominating committee from the list of IDS Associates. The nominating committee solicits nominations from the IDS Associates for each position to be filled; at least two candidates are required for each position. The CB runs the election. Election is by a simple majority of votes for each position. The two Member-at-Large positions are filled by the candidates receiving the most votes; a vote by the GB will resolve any situation of a tie.

IDS Associates are considered IAG Affiliates.

IDS representatives to the IERS and the IAG

Through the existing reciprocity agreement between the IDS and the IERS, the IDS Analysis Coordinator serves as the DORIS Technique Center representative to IERS, and as such, subject to GB approval, is a member of the IERS DB (together with another person selected by the IDS GB). This arrangement ensures full cooperation between the two Services.

5 Contacts, Outreach, Publications

IDS and DORIS quick reference list:

1. IDS website: https://ids-doris.org/
2. Contacts
   Central Bureau: ids.central.bureau@ids-doris.org
   Governing Board: ids.governing.board@ids-doris.org
3. Data Centers
   CDDIS: https://cddis.nasa.gov/archive/doris/
   IGN: ftp://doris.ensg.eu and ftp://doris.ign.fr
4. Tables of Data and Products:
   https://ids-doris.org/ids/data-products/tables-of-data-products.html
5. IDS web service: https://ids-doris.org/webservice
   DOR-O-T for DORis Online Tools (pronounced in French like the given name Dorothée) is the web service developed to promote the use of the DORIS products. The current version of the service provides tools to browse time series in an interactive and intuitive way, and a network viewer.

6. Citation: The article in [3] is suggested for citation in papers and presentations that rely on DORIS data and results.
7. DORISmail: dorismail@ids-doris.org
   It is used to send information of general interest to the DORIS community.
8. Documentation: https://ids-doris.org/ids/reports-mails/documentation.html
   Table compiling links to various pages with documents, grouped in 4 categories: DORIS system components, IDS information system, Publications, Presentations, Documents.
9. List of presentations given at DORIS or IDS meetings with access links: https://ids-doris.org/ids/reports-mails/meeting-presentations.html
10. List of documents and links to discover the DORIS system: https://ids-doris.org/analysis-coordination/documents-related-to-data-analysis.html
11. List of DORIS publications in international peer-reviewed journals: https://ids-doris.org/ids/reports-mails/doris-bibliography/peer-reviewed-journals.html
12. Overview of the DORIS system (technique): https://www.aviso.altimetry.fr/en/techniques/doris.html
13. Overview of the DORIS satellite constellation: https://ids-doris.org/doris-system/satellites.html
14. Site logs: https://ids-doris.org/doris-system/tracking-network/site-logs.html
    DORIS stations description forms and pictures from the DORIS installation and maintenance department.
15. Virtual tour of the DORIS network all around the world with Google Earth: https://ids-doris.org/doris-system/tracking-network/network-on-google-earth.html
16. IDS video channel: https://www.youtube.com/@internationaldorisservice-7170
    Videos of the DORIS-equipped satellites in orbit.
17. IDS Newsletters: https://ids-doris.org/ids/reports-mails/newsletter.html
    Find all the issues published in color with live links on the IDS website.
18. Photo Gallery: https://ids-doris.org/ids/gallery.html

International GNSS Service (IGS)

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Governing Board Chair: Rolf Dach (Switzerland)
Central Bureau Director: Allison B. Craddock (USA)

IGS website - https://www.igs.org

1 Introduction

In 2024, the International GNSS Service (IGS) will have been fulfilling its voluntary mission for thirty years. Still today, the Service and all of its members continue to provide and advocate for freely and openly available high-precision GNSS data and products. The delivery of the IGS core products (terrestrial reference frame, satellite orbits, satellite and receiver clock corrections, atmospheric products, and associated standards) continues to drive the Service's activities. As part of its multi-GNSS excellence objective, the IGS also continues its steady transformation into a multi-GNSS service, by adding more and more multi-GNSS stations into the core IGS network and extending the legacy products provided by the analysis centers to more constellations.

The IGS operates as a Service of the IAG, and its contribution is fundamental to generating and accessing the International Terrestrial Reference Frame (ITRF). The IGS also aims to enhance the sustainability of the global/regional geodetic reference frames through intergovernmental advocacy for geodesy. To this goal, it continues to engage with our international user community as well as several partner organizations that have an interest in geodetic applications of GNSS, such as:

- the Global Geodetic Observing System (GGOS) and International Earth Rotation and Reference Systems Service (IERS), where it facilitates cost-effective geometrical linkages with and among other precise geodetic observing techniques;
- the UN Office for Outer Space Affairs International Committee on GNSS (UN OOSA ICG), where it co-chairs the working group on "Timing, Reference Frames, and Applications", the International GNSS Monitoring and Assessment (IGMA) task force, and the Disaster Risk Reduction task force;

- the UN Committee of Experts on Global Geospatial Information Management (UN-GGIM), its Subcommittee on Geodesy and the recently established UN Global Geodetic Centre of Excellence (UN-GGCE). In this context, IGS has namely supported the development of the Global Geodetic Reference Frame (GGRF) resolution.

Additionally, IGS Governing Board (GB) members participate in the governance of IAG and GGOS Bureaux, Commissions, and Working Groups, ensuring that the IGS retains its strong level of international interconnectivity, significance, and sustainability.

IGS Terms of Reference (ToR) have been deeply reviewed within the last few years and finally approved by the GB in 2023. A number of policies and guidelines of IGS components and services have been implemented in order to improve the sustainability of the Service in future and minimize potential risks. The new ToR are now closer to the structure recommended by the IAG.

2 Structure

The IGS accomplishes its mission through membership, several components and entities for governance. As of early 2024, we count over 350+ Associate Members (AMs), representing 100+ countries/regions, and 150+ contributing organizations within the IGS. Among the latter, we count 100+ agencies operating GNSS Network Tracking Stations, 6 Global Data Centers, 13 Analysis Centers, 5 Product Coordinators, 21 Associate Analysis Centers, 24 Regional/Operational & Project Data Centers, 13 Technical Working Groups, and 2 Active Pilot Projects (Fig. 1).

AMs represent the people contributing across all IGS components, ensuring balanced organizational and geographical representation. Leading the IGS, the Governing Board (GB) is composed of elected or appointed AMs who represent the core of IGS components. The GB exercises broad oversight of IGS functions and components, discusses their activities, sets policies and monitors the progress with respect to the agreed strategic plan and annual implementation plan.

Gary Johnston (Geoscience Australia) completed his service as GB Chair in May 2020. Felix Perosanz (CNES, France) then served as GB Chair until April 2023, followed by Rolf Dach (AIUB, Switzerland) up to present. For the current composition of the GB, see https://igs.org/governance-management/#governing-board.

The Central Bureau (CB) functions as the executive office of the Service, supporting all the IGS components in their day-to-day work by providing continuous management and technology. It is steered by the GB's decisions, funded by the United States National Aeronautics and Space Administration (NASA), and hosted at the Jet Propulsion Laboratory (JPL) in Pasadena, California, USA. The CB serves as the command-and-control center for tracking network operations, manages the primary IGS Information System, and supports the ongoing update of the Service's institutional structures (ToR, GB elections, internal meetings, etc.). It also represents the outward face of the Service through public outreach to the global user community and general public.

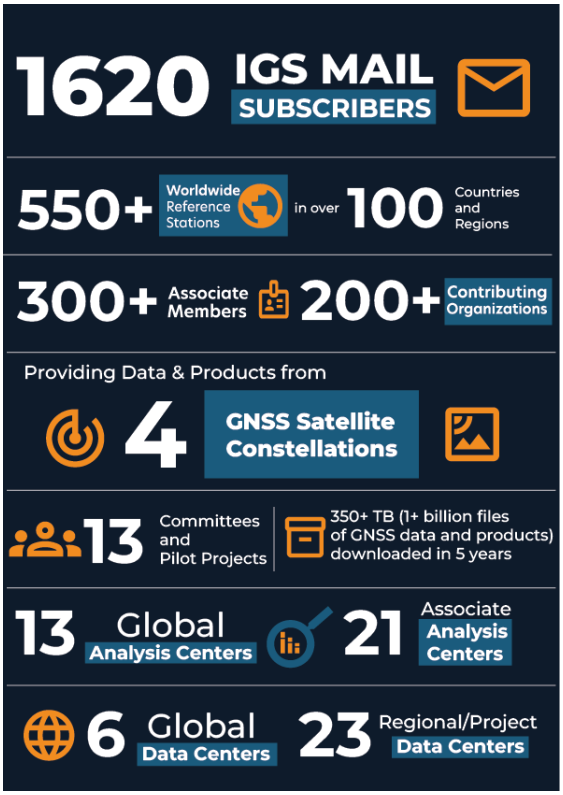

Fig. 1. "IGS at a Glance", showcasing the key numbers describing the IGS, as of April 2024. See also the IGS website https://igs.org

Allison Craddock has been the CB Director over the above mentioned period and up to present. For the current composition of the CB, see https://igs.org/governance-management/#central-bureau.

The IGS' active members are continuously and voluntarily contributing towards the IGS goals: advocacy for, development of, use of, and consistent provision of high-precision GNSS data and products.

3 IGS Network, Data and Products

The basis of the IGS is a global network of over 500 permanent and continuously operating GNSS ground stations of geodetic quality and well established monumentations. All stations track signals from GPS, and in a trend that is becoming more widespread year after year, most of them also track signals from one or more other GNSS/RNSS constellations, such as GLONASS, Galileo, BDS, QZSS, or NavIC (IRNSS). Some stations also track space-based augmentation systems (SBAS).

The IGS Network Maps at https://network.igs.org/ gives information about the current state of the IGS Network; as of April 2024, the network comprises 515 stations. Alongside the Network Map, the IGS Site Log Manager (SLM) allows station operators to securely manage and share their stations' metadata, ensuring that comprehensive and up-to-date details are available for researchers, users, and the scientific community.

The IGS Network Coordinator ensures appropriate and timely addition and decommissioning of stations in collaboration with the Infrastructure Committee, as well as regular changes to station antennas and rcvr_ant.tab file in collaboration with the Antenna Committee. The rcvr_ant.tab file contains essential information about GNSS receiver and antenna combinations utilized by IGS stations, enabling precise positioning and data interpretation, leading to enhanced compatibility, consistency, and standardization within the network for a diverse range of scientific investigations and geodetic applications.The expansion of the IGS network significantly contributed to improved coverage and geographical diversity, ensuring the availability of tracking data and products to a global user base. In particular, the continued growth and development of the network around the globe owes a lot to the numerous collaborations between the IGS and regional reference frames.

IGS data (RINEX from IGS stations) are available at the various IGS Global Data Centres (GDCs), listed at https://igs.org/data-access/#global-dcs. IGS products (terrestrial reference frames, satellite orbits, satellite and receiver clock corrections, ionospheric maps, tropospheric products, and various GNSS biases) are described and accessible at https://igs.org/products/. Some Analysis Centres started producing satellite attitude quaternions and phase biases, enabling undifferenced ambiguity resolution on a global scale. Real-Time IGS data and products are accessible through the University Corporation for Atmospheric Research (UCAR, USA) real-time caster, operational since January 2021.

There exist three lines of legacy post-processing IGS products, named as a function of the latency of their deliveries: "Final" may be released up to a week after real-time, "Rapid" is intended for daily updates, and "Ultra-rapid" products are broadcast every 6 hours. The IGS products file names follow the format described in the guidelines (https://files.igs.org/pub/resource/guidelines/Guidelines_For_Long_Product_Filenames_in_the_IGS_v2.0.pdf). In addition to post-processed products, the IGS maintains a line of real-time data and products accessible through various real-time casters.

IGS Analysis Centres are in charge of processing GNSS data and computing individual products. Some of these products are made available in the GDCs. These individual products are also merged into IGS combined products under the responsibility of the IGS Analysis Center Coordinator. The products and combined products were historically GPS-only, but are now transitioning to be fully multi-GNSS. Collectively, the IGS produces more than 700 different types of IGS Final, Rapid, and Ultra-Rapid products.

Contribution to the ITRF

The IGS' reprocessing campaigns play a pivotal role in establishing the terrestrial reference frame with utmost precision. By reanalyzing GNSS data over an extended

period, these campaigns achieve unparalleled accuracy and consistency. The results of these campaigns provide inputs to the ITRF. In turn, the IGS provides its users with the IGS realization of the ITRF, alongside updates to the associated ground and satellite antenna calibrations. This process ensures complete and reliable consistency for geodesic applications across all fields of science and society.

The Repro3 reprocessing campaign (http://acc.igs.org/repro3/repro3.html) was carried out after a decision taken at the 2018 IGS Workshop, using GPS data collected since 1994 and up to 2020. The processing standards and models have been discussed during a dedicated Analysis Center Workshop held in April 2019. The final Repro3 combined terrestrial frame solutions were provided to the IERS in April 2021 and contributed to the establishment of the 2020 release of the ITRF (ITRF2020). Subsequently, the IGS released its 2020 realization (IGS20) and the corresponding antenna calibrations (igs20.atx), which included revised values for the radial phase center offsets (PCOs) of GPS, GLONASS, and Galileo satellites, all consistent with the scale of ITRF2020.

The IGS20 is essentially an extract of ITRF2020 coordinates for a set of 332 current and historical IGS stations selected for their long-term and stable position time series. Within the IGS20 station network, a subset of 55 clusters of stations was designated as the IGS20 core network. This subset offers a homogeneous global coverage and the best possible temporal stability, and is hence recommended for the alignment of global solutions to the IGS20 reference frame.

4 Objectives and Activities (2021+)

The IGS 2021+ Strategic Plan, developed over 2020-2021 with inputs from the GB, CB, and community feedback, delineates the organization's forward-looking strategy. Released in October 2021, it encapsulates goals of achieving multi-GNSS technical excellence, strengthening outreach and engagement, and fostering sustainability and resilience. Embracing its role as a facilitator, coordinator, incubator, and advocate, the plan emphasizes the importance of maintaining leadership within the GNSS community, especially amidst growing societal demands. It strives to balance research and operational roles, promoting inclusivity, collaboration, and standardization. Its intention is to identify barriers to multi-GNSS success and to advocate for open access data through proactive measures, examples of which are detailed below. The Plan underscores a commitment to serving an expanding user base with high-quality multi-GNSS products, reflecting the collective efforts of a diverse and dedicated community. Fig. 2 summarizes the Plan.

The first Goal of the IGS 2021+ Strategic Plan is to achieve multi-GNSS technical excellence. In recent years, the IGS has made significant strides towards advancing the accuracy and reliability of multi-GNSS infrastructure, processing schemes, and product lines, paving the way for complete exploitation of new signals and constellations in navigation, surveying, geodesy, and remote sensing. The Service continually improves on that front. An example of this is the transition of the IGS raw data products to the RINEX 4 format, released in 2021 in collaboration with the Radio Technical Commission for Maritime Services - Special committee 104 (RTCM-SC104). Since then,

the IGS is actively coordinating the transition to the new format that allows a full representation of all GNSS constellations, signals and observations. The effort is supported by the CB, which advocates for the inclusion or conversion of receivers capable of multi-GNSS tracking and real-time casting.

IGS also looks outward to other techniques through its participation in the GGOS, which has illuminated how SLR observations of GNSS satellites, as well as GNSS observation of non-GNSS satellites, can play a key role in improving our understanding of observational errors and thus drive further improvement of IGS products.

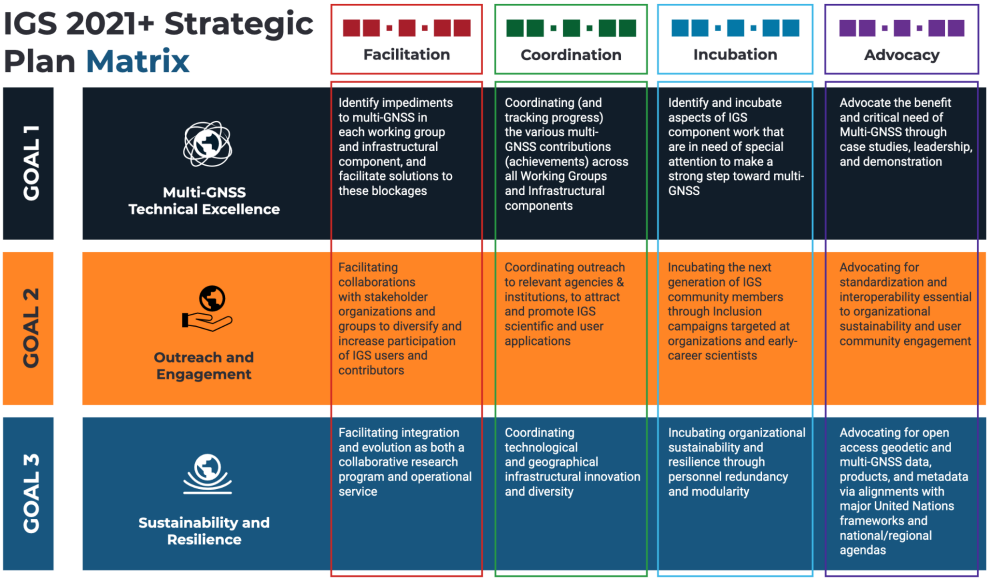

Fig. 2. Matrix summarizing the IGS 2021+ Strategic Plan, available in the Plan's main document at https://igs.org/strategic-planning/

Goal 2 of the Strategic Plan is to strengthen outreach and engagement activities. The IGS seeks to expand the IGS Network and user base through constant outreach endeavors. It maintains a particular focus on underrepresented regions and areas with sparse coverage in order to curate the long-term sustainability of the Service.

Goal 3 is to build a sustainable and resilient organization. In 2021-2023, under the leadership of Ryan Ruddick (Geoscience Australia), a Committee on Sustainable Working Group Governance identified ways in which the IGS Components could be invigorated, in order to ensure they are in the best position to support the IGS in successfully achieving its mission. After delivering its recommendations, the Committee was disbanded in early 2024.

The third goal also aims to develop diverse contributions to the IGS, in order to work towards a well-managed and supported organization with a diverse user base. In pursuit of that objective, a Working Group on Equity, Diversity, and Inclusion

(EDI) was created in 2024, co-led by Elisabetta d'Anastasio (GNS Science Te Pū Ao, New Zealand) and Léo Martire (NASA JPL, USA). It is operational, tasked with the definition objectives to support EDI, and with their ongoing evaluation.

5 Point of Contact

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6 Outreach, Meetings, Publications

Community engagement stands as a cornerstone of the IGS, recognising its voluntary nature and the diverse interests of its stakeholders. In pursuit of this goal, the CB spearheads efforts to foster ongoing dialogue and collaboration among users, experts, and stakeholders worldwide. The CB not only prepares, organizes, and leads numerous meetings annually, but also sustains a steady online presence to consistently be accessible to and approachable by the IGS community.

Introduced in 2021 as both a community outreach and capacity development initiative, the Tour de l'IGS (https://igs.org/tour-de-ligs) is a series of virtual 2-hour-long mini-workshops, each delving into a specific topic of interest. To this day, these events covered issues as broad as reprocessing campaigns, space-borne and ground-based instrumentation, constellation spotlights, or applications to natural hazards. They foster close, frequent, and inclusive engagement within the greater IGS community.

The CB also makes sure to represent the IGS at various large-scale scientific conferences (such as EGU and AGU), as well as gatherings of the IGS' parent/sibling organizations (such as GGOS, various UN bodies, and the IUGG). Notably, the IGS has maintained sessions at AGU every year since 2015, focusing on the value of IGS

products, sometimes in collaboration with GGOS. This consistent presence allows the IGS to regularly broadcast its crucial importance and latest results, while also capturing the attention and interest of a vast spectrum of geodesy and geodesy-adjacent scientists, in an effort to increase robustness and inclusivity within the Service.

IGS Workshops, held every two years since 2004, provide week-long platforms for the IGS community to convene and delve into focused discussions. Due to the COVID-19 pandemic, the 2020 Workshop was held virtually. These gatherings facilitate both open discussions and closed meetings among IGS components, allowing for in-depth exploration of a wide variety of key issues. Recent workshops have seen an increased focus on advancing towards a multi-GNSS IGS.

The CB is responsible for managing the IGS website (https://www.igs.org), which in the last four years has undergone a comprehensive overhaul aimed at improving user experience and enhancing security measures. This revamped website serves as a central online hub for the IGS community, consolidating its digital presence and providing easy access to a wide range of IGS components and products. Notably, the website features the IGS Network Map (see above).

The CB administers mailing lists on specific topics relevant to the global community. The primary mailing list, IGSMAIL, (https://lists.igs.org/mailman/listinfo/igsmail) covers general topics pertinent to the entire IGS community, fostering open communication and collaboration. Using other component-specific mailing lists, members can engage in discussions tailored to their interests and expertise.

The CB maintains an active social media presence. On these platforms, it disseminates important announcements, highlights sessions at conferences, shares new newsletter articles, or communicates other noteworthy updates. This social media engagement is a valuable tool for increasing visibility, fostering community engagement, and promoting the latest developments within the IGS ecosystem.

Since 2021, the CB has extended its outreach efforts through the publication of the IGS Newsletter (https://igs.org/newsletter/), which showcases a diverse range of topics and emphasizes the international nature of the Service. Each edition covers news pertinent to the GNSS community and its stakeholders, along with articles on specific subjects, such as the Hunga Tonga Hunga Ha'apai eruption, the release of ITRF2020, Galileo satellite metadata, or the application of GNSS for disaster risk reduction.

The work performed by the IGS should be acknowledged in scholarly research and other works by citing [4]. Other official publications are the IGS Technical Reports (see https://igs.org/news/igs-technical-report-2023/; similar links for 2022, 2021).

International Laser Ranging Service (ILRS)

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Chair of the Governing Board: Stephen Merkowitz (USA)
Director of the Central Bureau: Michael Pearlman (USA)

ILRS website - http://ilrs.gsfc.nasa.gov/

1 Introduction

The International Laser Ranging Service (ILRS) is an established space geodetic Service of the IAG and a key contributor to the GGOS. The primary objective of the ILRS is to support – through Satellite and Lunar Laser Ranging data and related products – geodetic, geophysical and other scientific research activities, as well as product development for the International Earth Rotation and Reference Systems Service (IERS), important for the maintenance of an accurate and stable International Terrestrial Reference Frame (ITRF). The Service also develops and maintains the necessary standards/specifications and encourages international adherence to its conventions.

Satellite Laser Ranging (SLR) was established in the mid-1960s, with early ground system developments by NASA, SAO, and CNES. Early US and French satellites provided laser targets that were used mainly for inter-comparison with other satellite tracking systems, refinement of orbit determination techniques, and as input to the development of ground station fiducial networks and global gravity field models. Early SLR brought the results of orbit determination and station positions to the meter level of accuracy. The SLR network was expanded in the 1970s and 1980s as other groups built and deployed systems, and technological improvements began the evolution toward the decimeter and centimeter accuracy. Since 1976, the main geodetic target has been LAGEOS, subsequently joined by LAGEOS-2 (as well as Etalon-1 and -2)

in 1992 and LARES in 2012, providing the backbone of the SLR technique's contribution to the realization of the ITRF. LARES-2 was later launched in 2022. Lunar Laser Ranging (LLR) tracking activity began in 1969 after the deployment of the first retroreflector array on the surface of the Moon by the Apollo 11 astronauts.

Tracking campaigns were initially organized through COSPAR (Committee on Space Research) and through the SLR/LLR Sub-commission on the Coordination of Space Techniques for Geodesy and Geodynamics (CSTG). With strong encouragement from the President of the CSTG, the Sub-commission Steering Committee undertook the formation of the ILRS in April 1998, following a similar initiative that had brought the GPS (now GNSS) community under the International Service IGS, in 1993.

The ILRS is a major component of GGOS, providing observations that contribute to the determination of the three fundamental geodetic observables and their variations, i.e., the Earth's shape, its gravity field and its rotational motion in space. The ILRS continues delivering fundamental inputs to the ITRF. Currently, more than 40 stations in the ILRS network track over 150 satellites in LEO, MEO, GNSS orbits. Some stations in the ILRS network support lunar ranging, with plans to extend ranging to interplanetary missions with optical transponders.

On the current path toward mm accuracy, SLR and LLR practitioners are now building new systems and upgrading old ones to improve the ground system performance using higher pulse repetition rates (0.1 – 100 kHz) for faster data acquisition. Smaller, faster slewing telescopes are being built for more rapid target acquisition and pass interleaving. Capabilities to ranging from Low Earth Orbiting (LEO) satellites to the Earth navigation satellites are being added. More accurate pointing allows for greater link efficiency; narrower laser pulse widths allow for greater precision. New detection systems permit greater ranging accuracy. Greater temporal, spatial, and spectral filtering improve signal to noise conditions. Increased automation should enhance operational economy (24/7) and greater temporal coverage. Modular construction and more off-the-shelf components should lead to reduced fabrication/operations/maintenance cost.

Over the next few years, considerable expansion to the ILRS network is anticipated (see Table 1). However, significant geographic gaps will still exist in Africa, South America, Oceania, and Antarctica.

2 Mission

The ILRS collects, merges, analyzes, archives and distributes SLR and LLR observation data sets of sufficient accuracy to satisfy the GGOS objectives of a wide range of scientific, engineering, and operational applications and experimentation. The basic observable is the precise time-of-flight of an ultra-short laser pulse to and from a retroreflector-equipped satellite (round-trip measurement). These data sets are used by the ILRS to generate a number of fundamental added value products, including but not limited to:

- Centimeter-accurate satellite ephemerides;
- Earth orientation parameters (polar motion and length of day);
- Three-dimensional coordinates and velocities of the ILRS tracking stations;

Table 1. Future ILRS network developments (*Status of the IPIE Stations uncertain due to political situation)

Site Name	**Type**	**Agency**	**Timeframe**
La Plata, Argentina	Upgraded core site	BKG, Germany	2024 – 2025
San Juan, Argentina	Upgraded SLR system	NAOC, China	2024 – 2025
Metsähovi, Finland	New SLR system	FGI, Finland	2024 – 2025
Greenbelt, MD, USA	Replacement core site	NASA, USA	2024 – 2024
Haleakala, HI, USA	Replacement core site	NASA, USA	2024 – 2026
McDonald, TX, USA	Replacement core site	NASA, USA	2024 – 2025
Ny Ålesund, Norway	New core site	NMA, Norway and NASA, USA	2024 – 2025
Ensenada, Mexico*	New SLR site	IPIE, Russia	2024 – 2026
Java, Indonesia*	New SLR site	IPIE, Russia	2024 – 2026
Gran Canaria, Spain*	New SLR in core site	IPIE, Russia	2024 – 2026
Tahiti, French Polynesia*	New SLR system	IPIE, Russia	2024 – 2026
Mt Abu, India	New SLR site	ISRO, India	2025 – 2026
Ponmundi, India	New SLR site	ISRO, India	2025 – 2026
Ishioka, Japan	New SLR site	Hitotsubashi U., NAOJ and U. Tokyo, Japan	2024
Yebes, Spain	New SLR site	IGS, Spain	2024
Irkutsk (Tochka)	New SLR site	VNIIFTRI, Russia	2025 – 2026
Mendeleevo (Tochka)	New SLR site	VNIIFTRI, Russia	2025 – 2026

- Time-varying geocenter coordinates;
- Static and time-varying coefficients of Earth's gravity field;
- Fundamental physical constants;
- Lunar ephemerides and librations;
- Lunar orientation parameters.

3 Products

The most important aspects of the SLR and LLR observations are the absolute accuracy as well as the long and stable time history at a number of sites. Accuracy approaches the level of a few mm for modern stations; time histories can be 40 years or more on some satellites (e.g., LAGEOS, Starlette, Beacon), and now 54 years on the Moon. Since the inception of the service, the ILRS has put the generation of official analysis products high on its agenda. Official submissions to the IERS include weekly solutions for station coordinates and Earth Orientation Parameters submitted daily. Additionally, some of the ILRS Analysis Centers submit estimates of GM and time-varying geocenter motion to the IERS Global Geophysical Fluids Center. Other user products include static and time-varying coefficients of Earth's gravity field, accurate satellite ephemerides for POD and validation of altimetry, relativity, and satellite dynamics, backup POD for other missions, and lunar ephemeris for relativity studies and lunar libration for lunar interior studies.

The products of the Analysis, Lunar Analysis, and Associate Analysis Centers are made available to the scientific community through the two Global Data Centers:

- Crustal Dynamics Data Information System (CDDIS) at NASA's Goddard Space Flight Center, Greenbelt, MD, USA;
- European Data Center (EDC), at DGFI-TUM, Munich, Germany.

The high accuracy of SLR/LLR data products supports many scientific, engineering, and operational applications including:

- Realization and maintenance of the ITRF;
- Access to Earth's center of mass relative to the global network and its time variations (geocenter);
- Monitoring three-dimensional deformations of the solid Earth;
- Monitoring Earth rotation variations and polar motion;
- Monitoring the long wavelength static and dynamic components of Earth's gravity field;
- Supporting, via precise ranging to altimeter satellites, the monitoring of variations in the topography of the liquid and solid Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, vegetation canopies, etc.);
- Calibration and validation of Global Navigation Satellite Systems (e.g., GPS, GLONASS, Galileo, Bei-Dou, and DORIS);
- Picosecond global time transfer experiments;
- Determination of non-conservative forces acting on satellites;
- Determination of satellite attitude;
- Astro-dynamic observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant;
- Gravitational and general relativistic tests, including Einstein's frame-dragging, Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant G;
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k2), and free librations and stimulating mechanisms;
- Solar System ties to the International Celestial Reference Frame (ICRF);
- Realization and maintenance of the Mean Earth and Principal Axis lunar reference frames;
- Tracking of space debris.

4 Structure

The ILRS structure includes the following permanent components:

- Tracking Station Network;
- Operations Centers;
- Global Data Centers;
- Analysis, Lunar Analysis, Associate Analysis, and Combination Centers;
- Governing Board;

- Central Bureau;
- Specialized Standing Committees: Analysis, Missions, Networks and Engineering, Data Formats and Procedures, and LLR and Transponders;
- Specialized Study Groups, including Space Debris Tracking.

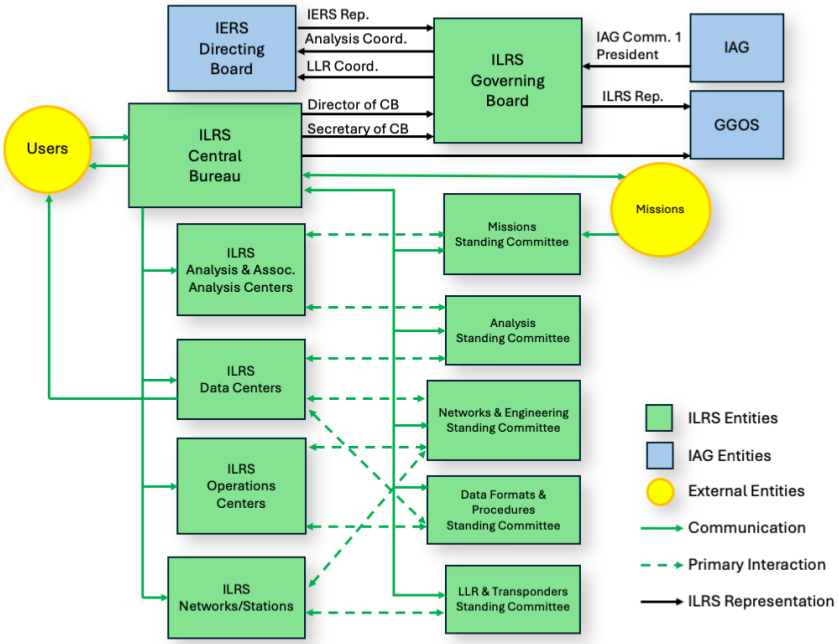

Fig. 1. ILRS Organization and relationship with IAG, IERS and GGOS

Governing Board (2023-2024)

The ILRS Governing Board (GB) is responsible for the general directions in which the ILRS is providing its services. It defines the official ILRS products, decides upon the satellites to be included in the ILRS tracking list, accepts standards and procedures prepared and proposed by the individual bodies of the ILRS, and ensures, through its Chair, contact with other services and organizations. The GB exercises general control over the activities of the ILRS including modifications to the organization that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and theory.

Most GB decisions are to be made by consensus or by a simple majority vote of the members, provided that there is a quorum consisting of at least ten GB members.

Changes in the ILRS ToR and the Chair can be made by a 2/3 majority of the GB members, i.e., by twelve or more votes.

- Stephen Merkowitz; appointed, NASA Network Repr.; Chair
- Michael Pearlman; ex-officio, Director Central Bureau
- Claudia Carabajal; ex-officio, Secretary Central Bureau
- Urs Hugentobler; ex-officio, President IAG Commission 1
- Daniela Thaller; appointed, IERS Repr.
- Sven Bauer; appointed, EUROLAS Network Repr.
- José Rodríguez; appointed, EUROLAS Network Repr.
- James Bennett; appointed, WPLTN Network Repr.
- Zhang Zhongping; appointed, WPLTN Network Repr.
- Evan Hoffman; appointed, NASA Network Repr.
- Vincenza Luceri; elected, Analysis Center Repr.
- Mathis Blossfeld; elected, Analysis Center Repr.
- Justine Woo; elected, Data Center Repr.
- Clément Courde; elected, LLR Repr.
- Christian Schwatke; elected, Member-at-Large
- Matthew Wilkinson; elected, Member-at-Large
- Takehiro Matsumoto; Board appointed member
- Randall Carman; Board appointed member

Central Bureau

The Central Bureau (CB) is responsible for the daily coordination and management of the ILRS in a manner consistent with the directives and policies established by the GB. The primary functions of the CB are to facilitate communications and information transfer within the Service and between the ILRS and the external scientific community, coordinate ILRS activities, maintain a list of satellites approved for tracking support and their priorities, promote compliance to ILRS network standards, monitor network operations and quality assurance of data, maintain ILRS documentation, website and databases, produce reports as required, and organize meetings and workshops. The responsibilities and activities of the CB may be distributed between different groups and organizations according to written agreements and charters.

Although the Chair of the GB is the official ILRS representative to external organizations, the CB, along with the directives, is responsible for the day-to-day liaison with such organizations.

The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, such as standards/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions. The CB operates the communication center for the ILRS. It produces and/or maintains a hierarchy of documents and reports, in both hard copy and electronic form, including network information, standards, newsletters, electronic bulletin board, directories, summaries of ILRS performance and products, and biannual reports summarizing the status of the Service.

The CB may propose to the GB names of individuals to be considered by the ILRS Associates for election as Members-at-Large on the GB to help ensure the proper representation of important contributing organizations.

In summary, the CB performs a long-term coordination and communication role to ensure that ILRS participants contribute to the Service in a consistent and continuous manner and that they adhere to ILRS standards.

The CB Director and Secretary are ex-officio members of the GB (see above).

Specialized Standing Committees

The ILRS now uses the IAG standard term "Committee" for entities that focus on particular areas within the Service. The GB, at its discretion, can create or disband Committees. A Committee may be either permanent (Standing Committee) or temporary (Ad-Hoc Committee) in nature. Standing Committees carry out business of the ILRS for indefinite periods (more than 4 years). Occasionally, Ad-Hoc Committees are appointed to carry out special investigations or tasks of a temporary or interdisciplinary nature.

Actual information on these permanent components can be found on the ILRS website (http://ilrs.gsfc.nasa.gov/). From time to time, the ILRS also establishes temporary Study Groups to address timely topics.

5 Contacts

- Michael Pearlman; Director ILRS CB; mpearlman@cfa.harvard.edu
- Claudia Carabajal; Secretary ILRS CB; Claudia.Carabajal@nasa.gov
- Stephen Merkowitz; Chair ILRS GB; Stephen.M.Merkowitz@nasa.gov
- Cinzia Luceri; ILRS Analysis Coordinator; cinzia.luceri@e-geos.it
- Mathis Bloßfeld; ILRS Analysis Coordinator; mathis.blossfeld@tum.de

6 Publications, Meetings

The CB maintains a comprehensive website (http://ilrs.gsfc.nasa.gov) as the primary vehicle for the distribution of information within the ILRS community. Many ILRS and related publications and reports are accessible online through this website including:

- ILRS Terms of Reference;
- ILRS Standing Committee charters, members, reports;
- ILRS network description and status;
- ILRS satellite descriptions and tracking information;
- ILRS workshop/meeting reports and presentations;
- ILRS service reports;
- ILRS associates directory;
- ILRS organization and technical contacts;
- Science and engineering references and reports.

The ILRS sponsors International Workshops on Laser Ranging (IWLR) which are typically held every two years. In addition, it organizes focused technical or specialized workshops in years between the IWLR. The ILRS has created guidelines to plan these workshops and for the community to propose future workshops.

When the ILRS was not able to hold in person workshops, it has held virtual workshops to keep the community engaged, and posted materials presented on the website. During 2021, the virtual workshop included scientific sessions along with virtual stations tours (https://ilrs.gsfc.nasa.gov/ILRS_Virtual_World_Tour_2021/). In 2023, the virtual IWLR held sessions on i) Scientific Analysis of SLR Observations: Past, Current and Future Challenges and Possibilities; ii) New Technologies and Operations; iii) Lunar Laser Ranging and Transponders; iv) Missions and Applications and Space Debris (https://ilrs.gsfc.nasa.gov/lw23/Program/index.html). In October 2024, the 23rd IWLR will be held in Kunming, China (https://23rdworkshop.casconf.cn/). We hope to hold a specialized workshop in Arequipa, Peru in 2025.

International VLBI Service for Geodesy and Astrometry (IVS)

https://doi.org/10.82507/iag-gh2024_ivs

Chair of Directing Board: Rüdiger Haas (Sweden)
Coordinating Center Director: Dirk Behrend (USA)

IVS website - https://ivscc.gsfc.nasa.gov/

1 Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) [5] is an international collaboration of organizations, which operate or support Very Long Baseline Interferometry (VLBI) components. IVS was established in 1999 as a Service of the IAG. In 2000, the IVS was recognized as a Service of the International Astronomical Union (IAU). In 2013 an agreement was signed between the IVS and the International Science Council (ISC, formerly ICSU) accepting the Service as a Network Member of ISC's World Data System (WDS). The IVS interacts closely with the International Earth Rotation and Reference Systems Service (IERS), which is tasked by IAU and IUGG/IAG with maintaining the international celestial and terrestrial reference frames (ICRF and ITRF). The latest Terms of Reference (ToR) of IVS can be found at the URL: https://ivscc.gsfc.nasa.gov/about/org/documents/ivsTOR.html.

2 Mission, Objectives

The objectives of IVS are:

- To provide a service to support geodetic, geophysical, and astrometric research and operational activities.
- To promote research and development activities in all aspects of the geodetic and astrometric VLBI technique.
- To interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

To meet these objectives, IVS coordinates VLBI observing programs, sets performance standards for VLBI stations, establishes conventions for VLBI data formats and data products, issues recommendations for VLBI data analysis software, sets standards for VLBI analysis documentation, and institutes appropriate VLBI product delivery methods to ensure suitable product quality and timeliness. IVS closely coordinates its activities with the astronomical community because of the dual use of many VLBI facilities and technologies for both astronomy and astrometry/geodesy.

3 Products

All VLBI data products are archived in IVS Data Centers and are publicly available. VLBI data products currently available are:

- All components of Earth orientation;
- Terrestrial reference frame;
- Celestial reference frame;
- Tropospheric parameters;
- Baseline lengths.

4 Structure

IVS accomplishes its goals through Permanent Components. As of 2024, the IVS has:

- 34 Network Stations, acquiring high performance VLBI data.
- 3 Operation Centers, coordinating activities of Network Stations.
- 7 Correlators, processing acquired data, providing feedback to stations and providing processed data to analysts.
- 4 Data Centers, distributing products to users, providing storage and archiving functions.
- 32 Analysis Centers, analyzing the data and producing results and products.
- 6 Technology Development Centers, developing new VLBI technology.
- 1 Office for Outreach and Communications, promoting knowledge of the VLBI technique and IVS activities.
- 1 Coordinating Center, coordinating daily and long-term activities of IVS.

All together there are 88 Permanent Components, representing 43 organizations in 22 countries, and ∼350 individuals who are Associate Members. The 43 organizations that support IVS components are IVS Member Organizations. There are also 6 Affiliated Organizations that cooperate with IVS on issues of common interest but do not support a IVS component.

Office for Outreach and Communications

The Office for Outreach and Communications was created in 2019 to establish and maintain an outreach program that would promote knowledge of the VLBI technique and the activities of the IVS and foster an understanding of the importance of its products for the scientific communities and the general public. The outreach website is availalbe under https://vlbi.org; the Office also maintains IVS accounts on X (formerly Twitter) and Instagram.

Directing Board (2023–2025)

The IVS has a Directing Board (DB) to determine policies, standards, and goals. The current DB consists of the following members:

- R. Haas (Sweden); Chair of Directing Board and IERS representative
- D. Behrend (USA); Coordinating Center Director
- A. Neidhardt (Germany); Network Coordinator
- B. Soja (Switzerland); Analysis Coordinator
- G. Tuccari (Italy); Technology Coordinator
- N. Kotary (USA); Office for Outreach and Communications
- L. McCallum (Australia); Network Stations Representative
- P. de Vicente (Spain); Network Stations Representative
- C. Ruszczyk (USA); Technology Development Centers Representative
- P. Haftings (USA); Correlators and Operation Centers Representative
- O. Titov (Australia); Analysis and Data Centers Representative
- A. Walenta (Germany); Analysis and Data Centers Representative
- A. de Witt (South Africa); IAG Representative
- P. Charlot (France); IAU Representative
- H. Hase (Argentina); Member-at-Large
- M. Ishigaki (Japan); Member-at-Large
- F. Shu (China); Member-at-Large

Central Bureau

The Central Bureau of the IVS, called Coordinating Center, is responsible for coordination of both the day-to-day and the long-term activities of IVS, consistent with the directives and policies established by the DB. Specifically, the Coordinating Center monitors, coordinates, and supports the activities of the Network Stations, Operation Centers, Correlators, Data Centers, Analysis Centers, and Technology Development Centers. The Coordinating Center works closely with the Technology Coordinator, the Network Coordinator, and the Analysis Coordinator to coordinate all IVS activities.

Committees and Working Groups

IVS currently has four committees and one active task force:

- Observing Program Committee (OPC);
- VGOS Technical Committee (VTC);

- Celestial Reference Frame Committee (CRF Committee);
- Committee on Training and Education (CTE);
- Task Force on VLBI Scale.

Recognizing the importance of the VLBI scale question, the ad-hoc Task Force will be converted into an IVS Working Group on VLBI Scale, giving it a more formal footing. Establishing other Working Groups (e.g., on station events, data documentation) is currently under discussion.

5 Publications, Meetings

IVS publishes a Biennial Report, a thrice-annual Newsletter, and Proceedings from its biennial General Meeting. All publications are available electronically on the website. IVS holds a General Meeting every two years, a Technical Operations Workshop every two years, and an Analysis Workshop every year. Information about all IVS activities is available on the websites https://vlbi.org and https://ivscc.gsfc.nasa.gov.

International Gravity Field Service (IGFS)

https://doi.org/10.82507/iag-gh2024_igfs

Chair: Riccardo Barzaghi (Italy)
Central Bureau Director: Georges Vergos (Greece)

IGFS website - http://igfs.topo.auth.gr/

1 Introduction

IGFS is a unified "umbrella" IAG Service, coordinating the following "Level-1" IAG Services:

- BGI (Bureau Gravimétrique International), Toulouse, France
- ICGEM (International Center for Global Earth Models), GFZ, Potsdam, Germany
- ISG (International Service for the Geoid), Politecnico di Milano, Milano, Italy
- IGETS (International Geodynamics and Earth Tides Service), EOST, Strasbourg, France
- IDEMS (International Digital Elevation Model Service), ESRI, Redlands, CA, USA

Furthermore, IGFS has two Product Centers, the COST-G (Combination Service for Time-variable Gravity Fields) at AIUB, Berne, Switzerland and the IHRF-CC (International Height Reference Frame Coordination Center) at AUTh, Thessaloniki, Greece.

2 Mission, Objectives

The overall goal of IGFS is to:

- Coordinate collection, validation, archiving and dissemination of gravity field related data;
- Organize courses, generate information materials and in general organize public outreach relating to the Earth's gravity field;
- Unify gravity products for the needs of GGOS.

IGFS then facilitates the servicing of the geodetic and geophysical community with gravity field related data, software and information. The combined data of the IGFS entities will include global geopotential models, terrestrial, airborne, satellite and marine gravity observations, Earth tide data, GPS/leveling data, digital models of terrain and bathymetry, as well as ocean gravity field and geoid from satellite altimetry. Both the static and the temporal variations of the gravity field will be covered by the IGFS. Physical heights and potential values for the IHRF core sites, as well as offsets to national and regional heights systems will be also provided by IGFS. In cooperation with the other Gravity Services IGFS will make a special effort in trying to secure release of data from national and international institutions, holding data on the spatial and temporal gravity variations, geoid and the surface heights of the Earth, to make them widely available to the scientific community. IGFS will coordinate regional conferences, tutorials and schools to train young scientists and members of national institutions in the various aspects of the gravity field science, computations, and data collection.

3 Products

COST-G, as Product Center, provides consolidated monthly global gravity field models in terms of spherical harmonic coefficients and derived grids by combining solutions from individual Analysis Centers. These global gravity field models are available on the ICGEM web site.

IHRF-CC, as the Coordination Center for the IHRF will deliver the coordinates (X, Y, Z, C) (where $C(P) = W_0 - W(P)$ and $W_0 = 62636853.4\,\mathrm{m^2 s^{-2}}$ is the conventional selected value for the gravity potential at the geoid) of the IHRF reference stations and a catalogue of the vertical datum parameters, i.e., the transformation parameters between the existing local height systems and the IHRF.

The activities of COST-G and IHRF-CC will be annually reviewed by the IAG Executive Committee.

4 Program/Activities (2023-2027)

IGFS activities in the next four years term mainly focus on:

- improving the connection and cooperation among the Gravity Services.
- increasing the contacts with GGOS, particularly with the Bureau of Network and Observations and Bureau of Products and Standards.

- keeping contacts with the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) via the Global Geodetic Centre of Excellence (UN-GGCE).
- organizing, every two years, together with Commission 2 and GGOS, the Gravity Geoid and Hight System (GGHS) Symposium: In 2024 it will take place in Thessaloniki, Greece, on September 4^{th}-6^{th}. Contacts have been also established to hold the next GGHS Symposium in India in 2026.
- organizing international schools on geoid computation and height systems: the last was in Buenos Aires and there are plans for holding the next in Kazakhstan.
- continuing and supporting the activities of the two IGFS Product Centers, namely COST-G and IHRF-CC.

5 Structure

The IGFS Service is organized by means of the following structure:

- Central Bureau
- Advisory Board
- Gravity Services
- IGFS Product Centers

Central Bureau

The Central Bureau acts as the central coordination and communication center of the IGFS. It provides i) a link between the IGFS entities, IAG, and external projects, networks or organizations (oceanic, atmospheric, hydrologic) and ii) a link to the GGOS Bureaus in order to communicate their requirements and recommendations to the IGFS Services. It will also implement standards and recommendations related to gravity field observations, secure consistency with geometric standards and promote their use within the geoscience community. Furthermore, the Central Bureau maintains the IGFS website and arranges gravity field related meetings and workshops.

Advisory Board

The IGFS Advisory Board is composed by the Chairs/Directors of the Gravity Services, the President of Commission 2, the President of GGOS and geodesists that are involved in scientific activities related to the gravity field:

- H. Abd-Elmotaal (Egypt)
- J.-P. Barriot (French Polynesia)
- S. Bonvalot (France); Chair BGI
- S. Bettadpur (USA); President IAG Commission 2
- M. Calvo (Spain); Chair IGETS
- R. Forsberg (Denmark)
- R. Goyal (India)
- T. Gruber (Germany)

- J. Huang (Canada)
- C. Hwang (Taiwan)
- E. S. Ince (Germany); Chair ICGEM
- A. Jäggi (Switzerland); Chair COST-G
- K. Kelly (USA); Chair IDEMS
- J. McCubbine (Australia)
- U. Marti (Switzerland); IAG Representative
- R. Pail (Germany)
- M. Reguzzoni (Italy); Chair ISG
- M. G. Sideris (Canada)
- L. Sánchez (Germany); GGOS President
- I. N. Tziavos (Greece)
- L. Vitushkin (Russia)
- G.S. Vergos (Greece); Chair IHRF-CC
- Y. Wang (USA)
- H. Wziontek (Germany)

Gravity Services

The Gravity Services are the "operating arms" of IGFS and are approved by the IAG Executive Committee. They are committed to produce services and products related to the gravity field of the Earth and/or the planets. Services and Centers can include bodies of structures external to the IAG (e.g., the BGI which is reporting to FAGS). They have their own governing bodies, nominated according to internal rules, also taking into account the interests of the supporting entities. In particular, each governing body has a Director, elected according to internal rules. Gravity Services maintain a list of data and products, providing them to the general public according to their policy of dissemination. They deliver services in the form of data archiving, data analysis and dissemination, software, training on gravity field estimation, support to field campaigns and so on.

IGFS Product Centers

- The COST-G (see https://cost-g.org/) will provide consolidated monthly global gravity field models in terms of spherical harmonic coefficients and derived grids by combining solutions from individual Analysis Centers. Terms of Reference can be found at https://cost-g.org/consortium/.
- The newly established IHRF-CC (https://ihrfcc.topo.auth.gr/) will manage the general coordination of activities for the IHRF and for the storage, publication, and servicing of the IHRF by implementing and updating a catalogue of the IHRF global reference stations. Terms of Reference can be found at http://igfs.topo.auth.gr/wp-content/uploads/2024/06/IHRF_CoordinationCenter_v5_Feb2024.pdf.

6 Point of Contact

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Web site: https://igfs.topo.auth.gr/igfs-central-bureau/
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Scientific Consultants: Ilias N. Tziavos, Chris Kotsakis, Dimitrios Tsoulis
Scientific Staff: Vassilios N. Grigoriadis
Scientific Staff & Secretary: Dimitrios A. Natsiopoulos

7 Publications, Meetings

Publications on the main activities can be found on the Gravity Services web pages:

- BGI - https://bgi.obs-mip.fr/
- ICGEM - https://icgem.gfz-potsdam.de/home
- ISG - https://www.isgeoid.polimi.it/
- IGETS - http://igets.u-strasbg.fr/
- IDEMS - https://idems.maps.arcgis.com/home/index.html

Either during the GGHS Symposium and/or during the IAG/IUGG Assembly, IGFS splinter meetings are usually planned.

International Centre For Global Earth Models (ICGEM)

https://doi.org/10.82507/iag-gh2024_icgem

Director: E. S. Ince (Germany)

ICGEM website - https://icgem.gfz-potsdam.de/home

1 Introduction

The determination of Earth's global gravity field is one of the main tasks of geodesy: it serves as a reference for geodesy itself and provides essential information for all geosciences about the Earth, its interior and its fluid envelope. Thus, it is important to model the gravity field globally and make the state-of-the-art models available to public as geodetic products. With accurate satellite measurements, it is now possible to map the static gravity field as well as its variations with much higher spatial and temporal resolution compared to the first of its kinds. The list of such models is continuously growing and requires dedicated maintenance. The International Centre for Global Earth Models (ICGEM) is one of the five Services coordinated by the International Gravity Field Service (IGFS) of the IAG. The primary objective of ICGEM is to collect and archive all existing static and temporal global gravity field models and provide an online interactive calculation service for the computation of gravity field functionals, freely available to the general public. The calculation of the different functionals of the geopotential (e.g. geoid, gravity anomaly, gravity disturbance, equivalent water height) from a defined global model, on a specified grid or on points with

respect to a defined reference system, is not trivial and is a responsibility of geodesy, too. Additionally, it is important to visualise the spatial and temporal distribution of the global gravity field and therefore interactive visualisation is also provided by ICGEM.

With the initiation of IGFS and the commitment for hosting and financial support by German Research Centre for Geosciences (GFZ), the ICGEM Service was established in 2003. Initially, it aimed to collect and archive static gravity field models. Due to the increasing interest of users and model developers, temporal gravity field models have also been made available on the same platform after the launch of GRACE mission. The service has been extensively used and promises further developments to serve multidisciplinary research. During the last couple of years, topographic gravity field models derived from digital elevation models and density estimations, combined temporal gravity field solutions, as well as simulated temporal gravity field models developed for the Mass change And Geosciences International Constellation (MAGIC) have also been made available by ICGEM. Apart from the growing data archive, the calculation service is also growing with new and updated tools such as G3 (GFZ GRACE Gravity) Browser dedicated to the calculation of temporal gravity field model series in terms of water column, gravity anomalies, and geoid, which is of educational importance.

2 Mission, Objectives

Over the years, the mission and objectives of the ICGEM Service have also grown and reshaped to better serve the community. ICGEM is designed as a web-based service and currently includes the following:

- collecting and long-term archiving of existing static global gravity field models, solutions from dedicated shorter time periods (e.g. monthly GRACE/ GRACE-FO models), topographic gravity field models and since 2023, simulated gravity field models of daily, weekly, and monthly scales;
- making the above-mentioned models available on the web in a standardized format as described in Förste et al. (2023) (https://icgem.gfz-potsdam.de/docs/ICGEM-Format-2023.pdf);
- since late 2015, the possibility of assigning Digital Object Identifiers (DOIs) to the models, static and time-varying coefficients of Earth's gravity field as well as topographic gravity field models;
- a web interface to calculate gravity field functionals from the spherical harmonic models on freely selectable grids and user-defined points;
- since 2023, G3 Browser to compare temporal gravity field series, with different filter and corrections applied (https://icgem.gfz-potsdam.de/g3);
- since 2024, a web interface to calculate the differences of gravity field functionals calculated based on two different long term gravity field models;
- since 2024, possibility to save and share the list of calculations requested together with their results in different data formats;
- a 3D interactive visualisation of the models (geoid undulations, gravity anomalies, and equivalent water heights);

- quality checks of the static gravity field models via comparisons with other models in the spectral domain and w.r.t. GNSS/levelling-derived geoid undulations;
- the visualisation of surface spherical harmonics as tutorial;
- the theory and formulas of the calculation service documented in GFZ's Scientific Technical Report STR09/02 (Barthelmes, 2013) (https://icgem.gfz-potsdam.de/docs/str-0902-revised.pdf);
- manuals and tutorials for global gravity field modeling and usage of the service (Barthelmes, 2014) (https://icgem.gfz-potsdam.de/docs/GlobalModelsEncyclopedia.pdf, for updated version see https://link.springer.com/referenceworkentry/10.1007/978-3-319-02370-0_43-3);
- scientific journal papers for educational and reference purposes (Ince et al. 2019) https://essd.copernicus.org/articles/11/647/2019/;
- the ICGEM web-based gravity field discussion forum (https://icgem.gfz-potsdam.de/guestbook) for questions on ICGEM and its products and for knowledge exchange.

3 Products

The models

ICGEM relies on other centres and institutes who develop static and temporal gravity field models. By April 2024, *180 static gravity field models* are made available on ICGEM (http://icgem.gfz-potsdam.de/tom_longtime). Apart from 15 older models, the models are available in the form of spherical harmonic coefficients.

The list of *models from dedicated time periods* (e.g., monthly solutions from GRACE and GRACE-FO) is growing in parallel to the growing needs of relevant applications. Apart from the monthly models of Science Data System Centres CSR, JPL, and GFZ, various other solutions such as from CNES/GRGS and ITSG are also available. Also, the combined monthly models produced based on the IGFS COST-G (Combination Service for Time-variable Gravity Fields) standards have been made available (http://icgem.gfz-potsdam.de/series).

Upon request, *topographic gravity field models* have been made available for the first time in 2014 (http://icgem.gfz-potsdam.de/tom_reltopo). Such models can enhance the benefit from the gravity field products in high frequency components and in multidisciplinary studies such as in crustal modeling and terrain correction. Finally, since 2023, simulated temporal gravity field models developed based on different orbit configuration scenarios of MAGIC mission are available on the ICGEM Service (https://icgem.gfz-potsdam.de/sl/simulated).

Digital Object Identifiers (DOI)

In order to support open science and open data, ICGEM does not only provide free access to the models but supports the assignment of *Digital Object Identifiers (DOI)* to make the models citable. Since 2016, ICGEM together with the GFZ Library and Information Services, provides a service to assign DOI to the models, i.e. to the datasets of the coefficients. Many recent gravity field models have already been assigned DOIs.

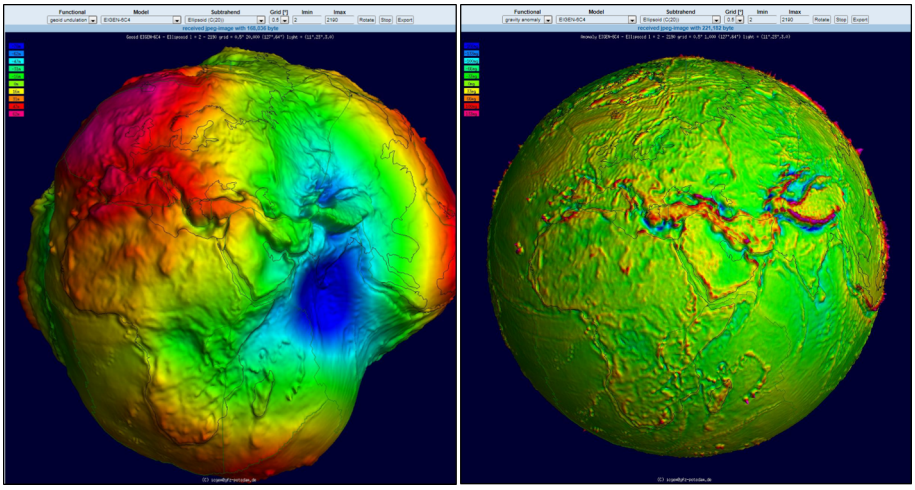


Fig. 1. Examples of the visualisation service for geoid undulation and gravity anomaly computed from a high-resolution combined static gravity field model

ICGEM encourages and supports model developers to request DOI at http://pmd.gfz-potsdam.de/panmetaworks/metaedit.

The 3D visualisation

An online interactive service for the *visualisation* of the models (in terms of height anomalies and gravity anomalies) as illuminated projection on a freely rotatable sphere is available (http://icgem.gfz-potsdam.de/vis3d/longtime, see also Fig. 1). Differences between two models, arbitrary degree windows, zooming in and out, are possible. The visualisation of spherical harmonics is also possible for tutorial purposes (https://icgem.gfz-potsdam.de/vis3d/tutorial).

The calculation service

A web-interface to *calculate gravity field functionals* from the spherical harmonic models on freely selectable grids or at user-defined points with respect to a reference system of the user's choice is provided. The following functionals are available in the grid calculation (http://icgem.gfz-potsdam.de/calcgrid) and can be downloaded in the ICGEM Format-XYZ Ascii, GeoTiff, and Surfer 7 Grid formats:

- pseudo height anomaly on the ellipsoid (or at arbitrary height above the ellipsoid);
- height anomaly (on the Earth's surface);
- geoid height (height anomaly plus spherical shell approximation of the topography);
- gravity disturbance;
- gravity disturbance in spherical approximation (at arbitrary height above the ellipsoid);

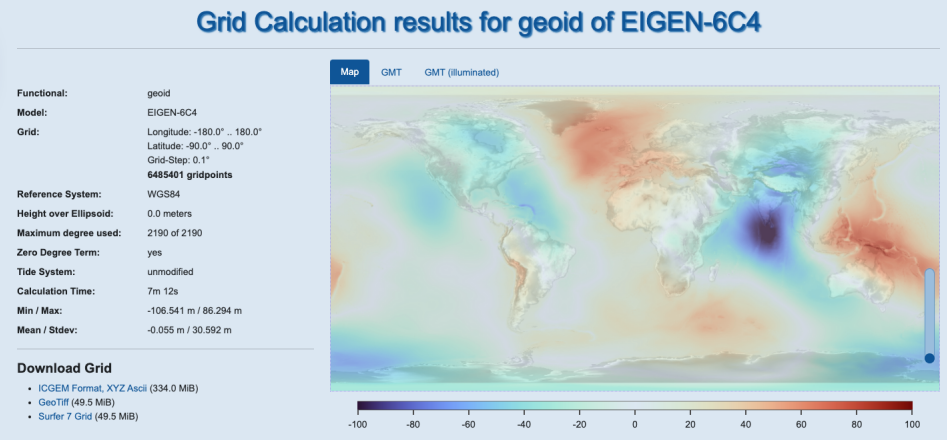


Fig. 2. Calculation service with updated visualisation and download options

- gravity anomaly (classical and modern definition);
- gravity anomaly (in spherical approximation, at arbitrary height above the ellipsoid);
- simple Bouguer gravity anomaly;
- gravity at the Earth's surface (including the centrifugal acceleration);
- gravity on the ellipsoid (or at arbitrary height above the ellipsoid, including the centrifugal acceleration);
- gravitation on the ellipsoid (or at arbitrary height above the ellipsoid, without centrifugal acceleration);
- second derivative in spherical radius direction (at arbitrary height above the ellipsoid);
- equivalent water height (water column).

Additionally, differences of any functional computed using two different models can also be calculated directly via selecting "Differences between two Longtime Models" under Model Selection.

Beside the functionals listed above, deflections of vertical can be computed at user-defined points (http://icgem.gfz-potsdam.de/calcpoints). In the calculation setting, filtering is possible by selecting the range of used coefficients or the filter length of a Gaussian averaging filter. The calculated grids together with the calculation settings in the header part can be downloaded once the calculation is completed. For grid calculations, the corresponding plots created using OpenLayers and GMT (in Portable Network Graphics format) are available for download. Since 2018, calculations on user-defined points are available and the results can be downloaded in ASCII format as well. An example of the newly designed calculation service is presented in Fig. 2.

Evaluation

ICGEM continues to *evaluate the static gravity field models* w.r.t. GNSS/ levelling derived geoid undulations (https://icgem.gfz-potsdam.de/tom_gpslev) and in the spec-

tral domain w.r.t. already reliable models (https://icgem.gfz-potsdam.de/evalm). The quality measures used in the evaluation pages will be improved in the future. Apart from the gravity field models of the Earth, ICGEM hosts similar models for other celestial bodies (Moon, Mars, Venus and Ceres).

FAQs and Discussion Forum

In May 2017, to support the users from different disciplines and levels, ICGEM introduced the Frequently Asked Questions (FAQs) and their short and detailed answers. Such answers are expected not only to help students and researchers for educational purposes, but also to understand the background of the ICGEM products. Moreover, to increase the knowledge exchange with and among the users ICGEM's discussion forum is expanded so as to share gravity field related questions and information.

In December 2019, the ICGEM Subscription list was introduced: it is used to interact with the community and enhance the communication among the gravity field related scientists and students. News and updates are shared via this channel. The subscription (or unsubscription) can be performed via https://www.listserv.dfn.de/sympa/subscribe/icgemusers.

4 Program/Activities (2023-2027)

The current activities of ICGEM are mostly dedicated to meet the requirements of the users and model developers and outreach to all geosciences. ICGEM will be starting a new project, Service and Archive for Mass Distribution And mass Transport data (SAMDAT) in 2024 (https://gepris.dfg.de/gepris/projekt/527258067). The project aims to "respond to the growing need and community-derived demand for quality assured, well documented global gravity field models (GGMs) and related products with additional types of datasets that are enriched with metadata and provided in a sustainable and freely accessible research data infrastructure". Three new colleagues will join the ICGEM team for this purpose.

5 Structure

The ICGEM does not hold an official advisory board but items are discussed within the IGFS establishment.

Staff

The ICGEM is organized by means of the ICGEM Team supported by GFZ-Potsdam. At the moment, this team consists of two members working on the scientific and technical development:

- E. Sinem Ince; Director of ICGEM, scientific support
- Sven Reißland; technical support

6 Point of Contact

International Centre for Global Earth Models (ICGEM)
GFZ-Potsdam German Research Centre for Geosciences
Telegrafengerg
14467, Potsdam, Germany
Email: icgem@gfz-potsdam.de
Website: https://icgem.gfz-potsdam.de/home

7 Publications, Meetings

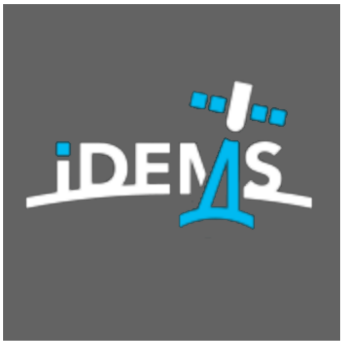
ICGEM publishes IAG reports every two- and four-year terms. All ICGEM publications as IAG reports or conference presentations are available electronically on the website https://icgem.gfz-potsdam.de/home.

International Digital Elevation Model Service (IDEMS)

https://doi.org/10.82507/iag-gh2024_idems

Director: Kevin M. Kelly (USA)

IDEMS website - https://idems.maps.arcgis.com/home/



1 Introduction

The International Digital Elevation Model Service (IDEMS) is one of the five Services of the International Gravity Field Service (IGFS) of the IAG. IDEMS provides a focus for distribution of data and information about digital elevation models (DEM), spherical-harmonic models of Earth's global topography, lunar and planetary DEM, relevant software and related data sets (including representation of Inland Water within Digital Elevation Models), which are available in the public domain. IDEMS is hosted and operated by the Environmental Systems Research Institute (Esri) (see http://www.esri.com/).

2 Products

Over the last 4 years, the IDEMS website (Fig. 1) has been continually updated with new DEM data sets, both terrestrial and planetary. IDEMS currently hosts 31 sources of terrestrial and planetary DEM data providers, 5 global Earth models and 126 references of DEM and bathymetry research papers relevant to geodesy and Earth sciences. Fig. 2 lists the current content available on the IDEMS website.

The IDEMS bibliography is updated regularly (currently two times per year) to provide the user community with an overview over key developments in DEM pro-

duction, validation and applications. The IDEMS bibliography includes recent and seminal papers describing relevant data sets of Earth's topography, bathymetry, ice data and composite elevation models. Some DEM sources appear in multiple categories to facilitate source discovery for the researcher. IDEMS serves as a repository of links to DEM data providers rather than a DEM data storage facility. The site also provides access to Esri's free ArcGIS Earth software which is fully integrated with the ArcGIS platform for accessing, sharing, and publishing maps and data (see https://www.esri.com/en-us/arcgis/products/arcgis-earth/overview).

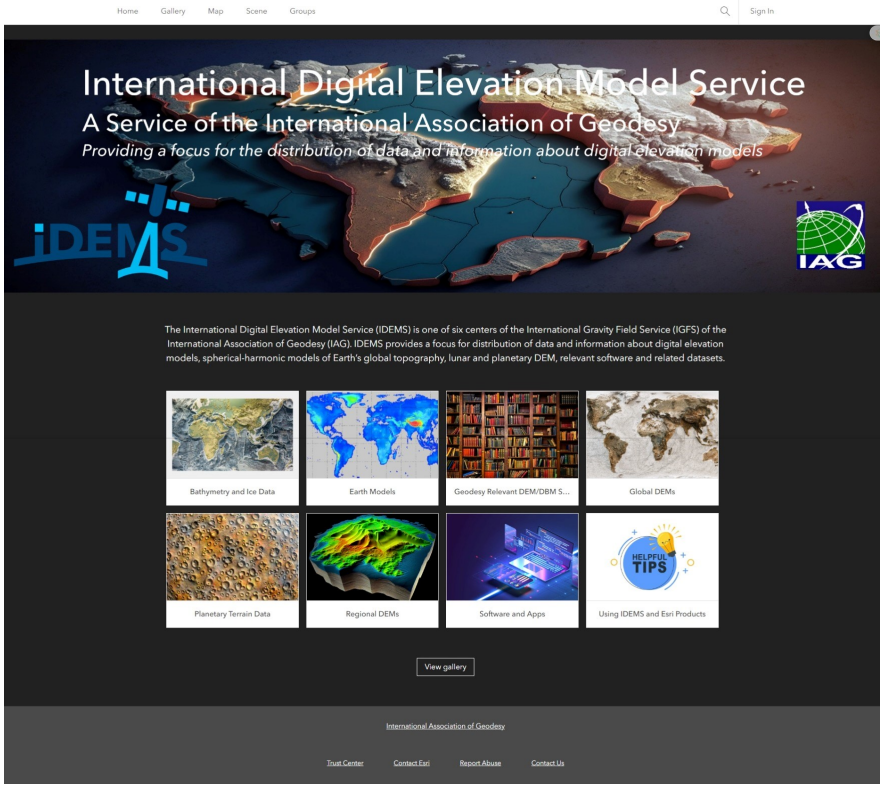


Fig. 1. Screenshot of IDEMS home page

Bathymetry and Ice Data (13)	Antarctica CryoSat-2 DEM
	Bedmap2
	BOEM Northern Gulf of Mexico Bathymetry
	Elevation Coverage Map (Esri)
	Flight MH370 Bathymetry
	Global Bathymetry BTM (Esri)
	Global Water Body Map (G3WBM)
	Ice, Cloud, and Land Elevation (ICESat / GLAS Data)
	Polar Geospatial Center
	Randolph Glacier Inventory (RGI 6.0)
	SRTM15+V2.0 (15 arc-sec grid), 2019
	SRTM30_PLUS (30 arc-sec grid), 2014
	Svalbard time-lapse terrain data
Global DEMs (16)	ALOS/PRISM AW3D30
	ASTER GDEM v2
	EarthDEM (Polar Geospatial Center)
	Elevation Coverage Map (Esri)
	Esri Elevation Layers
	ETOPO1 (60 arc-sec grid), 2009
	Global Terrain DEM (Esri)
	Global Water Body Map (G3WBM)
	MERIT DEM (SRTM-based Bare-Earth model), 2017
	NASADEM (reprocessed SRTM model), 2017
	SRTM v3 (NASA)
	SRTM v4.1 (CGIAR-CSI)
	SRTM15+V2.0 (15 arc-sec grid), 2019
	SRTM30_PLUS (30 arc-sec grid), 2014
	TanDEM-X DEM
	Viewfinder Panorama DEMs (2014)
Regional DEMs (7)	Antarctica CryoSat-2 DEM
	Arctic DEM Explorer
	OpenTopography
	Elevation Coverage Map (Esri)
	Esri Elevation Layers
	Polar Geospatial Center
	Svalbard Time-Lapse Terrain Model
Planetary Terrain Data (3)	NASA Planetary Data System (PDS) Geosciences Node
	Planetary topography data archive
	USGS Astrogeology Science Center
Earth Models (5)	Earth2014 (60 arc-sec), 2014
	ICE-6G GIA Model
	Preliminary Reference Earth Model (PREM)
	Topographic Earth Models (LMU Munich)
	SRTM2gravity, 2018

Fig. 2. DEM and related data sources hosted on IDEMS

3 Program/Activities (2023-2027)

The routine activities at IDEMS focus on adding new DEM, bathymetry and relevant earth or planetary models to the service website. These datasets support global gravity field and regional geoid modeling. Research activities involving IDEMS over the 2023-2027 term include methods of combining high-resolution topographic and bathymetric models in geodesy.

4 Structure

The Governing Board of IDEMS consists of five members who oversee the operation and general activities of the Service:

- Mr. Kevin M. Kelly; Director of IDEMS
- Dr. Fei Wang; Deputy Director of IDEMS
- Dr. Riccardo Barzhagi; IAG/IGFS representative
- Dr. Christian Hirt; Advisory member
- Dr. Michael Kuhn; Advisory member

International Geodynamics and Earth Tide Service (IGETS)

https://doi.org/10.82507/iag-gh2024_igets

Chair: Marta Calvo (Spain)
Central Bureau Director: Jean-Paul Boy (France)

IGETS website -http://igets.u-strasbg.fr

1 Introduction and Objectives

The primary objective of the International Geodynamics and Earth Tide Service (IGETS) is to provide a service to monitor temporal variations of the Earth gravity field through long-term records from ground gravimeters, tiltmeters, strainmeters and other geodynamic sensors. IGETS provides support to geodetic and geophysical research activities using superconducting gravimeter (SG) data within the context of an international network. It further collects, archives and distributes Earth tide records from long series of measurements with other gravimeters, tiltmeters, strainmeters and other geodynamic sensors. IGETS continues the activities of the Global Geodynamic Project (GGP) and the International Center for Earth Tides (ICET). The latest Terms of Reference (ToR) of IGETS can be found on its website: http://igets.u-strasbg.fr.

2 Products and Activities

IGETS is the main data center of worldwide high-precision superconducting gravimeter records. The products hosted at IGETS are:

- Raw gravity and local air pressure records sampled at 1 or 2 seconds, in addition to the same records decimated at 1-minute samples (Level-1 products).

- Gravity and local air pressure data corrected for instrumental perturbations, ready for tidal analysis. This product is derived from the previous datasets, and is computed by one or several Analysis Centers (Level-2 products).
- Gravity residuals after particular geophysical corrections (including solid Earth tides, polar motion, tidal and non-tidal loading effects). This product is also derived from the previous datasets and is computed by one or several Analysis Centers (Level-3 products).

IGETS strives to provide long-term gravity residuals based on repeated absolute gravity measurements at particular stations accessible on the Absolute Gravity database (AGrav) operated at BGI (https://bgi.obs-mip.fr/data-products/gravity-databases/absolute-gravity-data/) and at BKG (https://agrav.bkg.bund.de).

IGETS also acts as the main data center of long-term series recorded from other geodynamic sensors (spring gravimeters, tiltmeters, strainmeters, etc.), including the historical dataset from the ICET databank.

IGETS may conduct comparison, validation and distribution of tidal analysis software or any other software, which can be used to process or correct gravity, tilt or strain long-time series.

IGETS may organize symposia and workshops to provide a forum for presentation and discussion of all aspects of its activities.

Following activities are worth mentioning for 2023-2027:

- extension of the dataset by including new stations from other geosciences disciplines by establishing the Environmental Applications Representative;
- update of the ISDC datacentre;
- ensuring the provision of Level-2 data.

3 Structure

The IGETS accomplishes its mission through the following components:

- Permanent Components: Stations, Analysis Centers, Data Centers
- Central Bureau (CB)
- Directing Board (DB)

IGETS accepts at any time proposals from scientific individuals, groups or institutions to become a new permanent component of the Service (this can be a new Station, or an Analysis and/or Data center). The DB will review such proposals for approval.

Stations

The IGETS network provides high-quality and high-stability measurements of gravity, tilts and strain, including superconducting gravimeters (see a state-of-the-art device in Fig. 1). Stations should comply with the performance standards specified by the DB.

Fig. 1. Superconducting gravimeter (OSG-030) at Wettzell station

Analysis Centers

The Analysis Centers are committed to produce data products according to the recommendations and specifications defined by the DB, and send their final products to the main Data Center for dissemination to researchers and other users. They may produce any of the IGETS products, or any of the corrections needed to compute them.

The primary Analysis Center is responsible for computing SG corrected data (the Level-2 products). The final SG residuals (the Level-3 products) are computed by the secondary Analysis Center. The institutions in charge of these tasks are given in the attachment to the ToR (accessible on the IGETS website); they can be changed by the DB with 2/3 majority. The primary Analysis Center was hosted by the University of Polynesia (Tahiti, French Polynesia) and has stopped its activity at the end of 2023. The EOST (Ecole et Observatoire des Sciences de la Terre in Strasbourg, France) became the primary Analysis Center and is currently in charge of computing both Level-2 and -3 data products. A proposition for a secondary Analysis Center has been received and will be reviewed by the DB.

Data Centers

The IGETS Data Centers are repositories of data products, including station log files. Their primary objectives are to collect, archive and distribute these data with efficiency and reliability. Data Centers may mirror some of the other data centers to increase the accessibility of the IGETS datasets.

The primary Data Center hosts all SG data products (Levels 1, 2 and 3). A secondary Data Center is hosting all other datasets, including historical products. The institutions in charge of these tasks are given in the attachment to the ToR (accessible on the IGETS website); they can be changed by the DB with 2/3 majority. At present, the primary Data Center is the Information Systems and Data Center (ISDC) at GFZ (Potsdam, Germany). The secondary Data Center is hosted at EOST (Strasbourg, France).

Central Bureau

The CB is the executive arm of the IGETS DB, and is responsible for all operational activities of the Service. It coordinates IGETS activities, facilitates communications, maintains the documentation and organizes reports, meetings and workshops.

It operates for a term of four years. One year prior to the end of the term, the DB formally reviews the performance of the CB, and may then request the CB to reconfirm its commitment for another four years. If the CB declines, or if the DB chooses to change the CB, then the DB announces a call for proposal for a new IGETS CB to take the responsibility including a six-month transition phase. The Director of the CB is a member of the DB.

Currently, the CB is hosted by the EOST (Strasbourg, France).

Directing Board

The DB sets the objectives, determines policies, adopts standards, and sets the scientific and operational goals for IGETS. The DB exercises general oversight of the activities of IGETS, including modifications to the organization that are deemed appropriate and necessary to maintain efficiency and reliability. It may take appropriate actions to ensure the quality of the IGETS products.

The IGETS Chair is one of the DB members and is elected by the Board for a term of four years with the possibility of re-election for one additional term. The Chair is the official representative of IGETS to external organizations.

The DB consists of representatives of the IGETS components, appointed members, Members-at-Large and ex officio members.

IGETS Associates (see below) elect the following DB members: Raw Data Preparation representative, Analysis Center representative, Data Center representative, Network representative, Scientific Product Evaluation representative, Environmental Applications Representative. The elected members have staggered four-year terms. There is no limit to the number of terms that a person may serve, however he/she may serve only two terms consecutively as an elected member. Appointed members are the Director of the CB and the representatives of IAG and other Services. The DB members elect the Members-at-Large in a second round after their own nomination or election, to ensure a better geographical distribution.

Since 2023, the IGETS DB is composed of:

- M. Calvo (Spain); Chair of IGETS
- J.-P. Boy (France); Director of the Central Bureau
- E. D. Antokoletz (Germany); Raw Data Preparation Representative

- S. Rosat (France); Analysis Center Representative
- Ch. Foerste (Germany); Data Center Representative
- H.-P. Sun (China); Network Representative
- Ch. Voigt (Germany); Scientific Product Evaluation Representative
- M. Reich (Germany); Environmental Applications Representative
- S. Bonvalot (France); BGI Representative
- M. Calvo (Spain); IAG Representative
- N. Sneeuw (Germany); IGFS Representative
- H. Wziontek (Germany); ITGRF Representative
- D. Crossley (USA); Member-at-Large
- J. Hinderer (France); Member-at-Large
- B. Meurers (Austria); Member-at-Large

Most DB decisions are made by consensus or by simple majority vote of the members present. In case of a tie, the Chair decides how to proceed. If a 2/3 quorum is not present, the vote shall be held later by electronic mail. A 2/3 majority vote of all DB members is required to modify the ToR, to change the Chair, or to replace any of the members before their normal term expires.

The DB meets at least annually. The DB conducts periodic reviews of the IGETS organization and its mandate, functions, and components.

4 Members

IGETS Associates

Individuals associated with organizations that support an IGETS component may become IGETS Associate Members. Associate Members take part in the election of the incoming members of the DB.

Corresponding Members

IGETS Corresponding Members are individuals who express interest in receiving IGETS publications, wish to participate in workshops or scientific meetings organized by IGETS, or generally are interested in IGETS activities.

5 Contacts

- Jean-Paul Boy; IGETS Central Bureau Director; jeanpaul.boy@unistra.fr
- Marta Calvo; IGETS Chair; mcalvo@transportes.gob.es
- Christian Voigt; Head of IGETS database; christian.voigt@gfz-potsdam.de;
- Hartmut Wziontek; past IGETS Chair; hartmut.wziontek@bkg.bund.de.

6 Publications

The IGETS CB maintains a comprehensive website as the primary vehicle for the distribution of information within the IGETS community. This site can be accessed at http://igets.u-strasbg.fr. Many IGETS and related publications can be accessed online.

International Gravimetric Bureau – Bureau Gravimétrique International (BGI)

https://doi.org/10.82507/iag-gh2024_bgi

Director: Sylvain Bonvalot (France)

BGI website - http://bgi.obs-mip.fr

1 Introduction

The Bureau Gravimétrique International (BGI) was created in 1951 during the IUGG General Assembly as a scientific Service of the IAG for ensuring the collection, validation, archiving of all gravity measurements acquired at the Earth surface and their distribution to scientific users. The technological and scientific evolutions which took place over the following decades in the area of gravimetry (improvements in field, airborne and seaborne gravity meters, development of absolute gravity meters, space gravity missions, etc.) have led to a significant increase of the number, diversity and accuracy of the gravity field observables. Following these evolution, the BGI has contributed to original databases and services (products, documentation, tutorials, software) for a wide international community concerned with the studies of the Earth gravity field. The BGI has been set up in France (Paris, then Toulouse) and has benefited from the recognition by the International Science Council (ISC) as one of the Services of the Federation of Astronomical and Geophysical Services (FAGS).

Today, the BGI is an official IAG Service and contributes with the other Services to IAG Commissions and Working Groups and to the GGOS.

Before the era of the satellite gravity missions, the BGI has played a major role in supporting the computation of global and regional models of the Earth's gravity field, primarily based on terrestrial gravity measurements together with Satellite Laser Ranging (SLR) data. It has also provided accessibility to the global network of stations for referencing the worldwide gravity data surveys in a same absolute reference system

(Potsdam and IGSN71 networks). Today, relative and absolute gravity measurements, derived from field surveys (land, airborne and seaborne), monitoring networks and laboratory experiments, provide unprecedented precision and accuracy on the spatial and temporal variations of the Earth's gravity field. They remain fundamental in many issues such as the determination of the short wavelengths of the Earth gravity, the calibration/validation of the results derived from satellite observations or from other relative gravity observations, and the definition of the global Earth gravity reference frame. They serve a wide range of applications in Planetary, Solid Earth, Oceanography, Atmospheric, Hydrologic sciences and metrology, for instance.

The BGI operates within IAG in close collaboration with the other gravity Services (ISG, ICGEM, IDEMS, IGETS), with IGFS COST-G, and is strongly committed in the activities of GGOS, of Commission 2 - Gravity Field and in several IAG Working Groups related to the determination of the Earth gravity field, to the definition of protocols and standards in gravimetry as well as to the development and evaluation of innovative instrumentation (quantum gravimetry for instance). The strategic plan for the period 2023-2027 will maintain this objective, ensuring a long-term usability and sustainability of the highest-quality gravity data.

The BGI has its Central Bureau in Toulouse, France (GET/OMP) and operates with the support of various French agencies (CNES, CNRS/INSU, IGN, IRD, SHOM, BRGM, IFREMER), research labs and universities (Toulouse, Paris, Strasbourg, Montpellier, Nice, Brest, Le Mans). BGI also benefits from the close collaboration with agencies worldwide in charge of national gravity surveys and networks or regional data compilation: from Germany (BKG), Italy (POLIMI), Greece (AUTh), Czech Republic (VÜGTK), Denmark (DTU) and USA (NGA).

2 Mission, Objectives

The primary task of BGI is to improve the global knowledge of the Earth's gravity field through the collection, homogenization and validation of all available static gravity measurements (relative or absolute) and make this information available to a large variety of users for scientific applications. With this aim, BGI holds and maintains for IAG the four fundamental global databases of relative and absolute static gravity measurements and serves the scientific community. The current services provided by BGI include:

- Access to gravity data, reference stations, products, software and documentation.
- Archiving and validation of gravity dataset and products provided to BGI and attribution to data providers of a traceable international reference through a Digital Object Identifier (DOI).
- Realization and/or evaluation of global models as well as regional data compilations carried out for gravity or geoid studies.

BGI also actively contributes to the definition of protocols, practices and recommendations aimed at improving the gravity data acquisition and processing and the realization of gravity surveys and networks. BGI is more specifically involved in the following actions:

- Definition and establishment of the International Terrestrial Gravity Reference System & Frame (ITGRS/ITGRF), promoted through the IAG JWG 2.1.1.
- Evaluation of new sensors for measuring absolute gravity (cold-atom absolute gravity meters).
- Support the realization of national absolute gravity networks.

Finally, BGI also contributes with his collaborators to other research and development activities (software developments, research in geophysics and geodesy, etc.), as well as to educational activities in gravimetry (summer schools, tutorials, etc.).

3 Products and services

3.1 Global gravity databases

Land and marine gravity data

The relative gravity databases have been maintained and expanded since the early days of BGI. They have been extensively used for the definition of Earth gravity field models and for many applications in geodesy, satellite orbit computation, oceanography, geophysics, etc. They now contain over 12 million surface observations, providing precise, high-resolution information on the short wavelengths of the Earth's gravity field complementary to airborne and satellite gravity measurements. Since 2023, all data sets derived from old or recent surveys are granted a DOI assigned by the BGI.

Absolute gravity database (AGrav)

The absolute gravity database was set up in 2008 in cooperation between BGI and BKG (Bundesamt fur Kartographie und Geodasie, Germany) for collecting all available information on absolute gravity measurements acquired on Earth and for ensuring storage and long-term availability of data and processing details. The database can be accessed by a web-based interface which provides publicly available metadata as well as complete datasets for the community of users contributing to the archive. A simple web-based exchange format was selected to facilitate the upload of absolute gravity data to the database by the owner institutions. A new database and web interface developed jointly by BGI (Toulouse) and BKG (Leipzig), with the technical support from OMP Toulouse Data Service (Sedoo) was released in spring 2024 (Fig. 1). It offers new features and now provides the most comprehensive information on absolute gravity stations and measurements worldwide (raw or processed data, description of stations, instruments, involved institutions, contacts, etc.). The AGrav database will also serve as the reference data repository for the ITGRF. For correct data referencing, a DOI will be assigned to each instrument or network contributing to the AGrav database as well as to the ITGRF.

IGSN71 gravity reference stations

The gravity reference stations established and connected to the former IGSN71 and Potsdam reference systems have been previously collected and archived at BGI. For

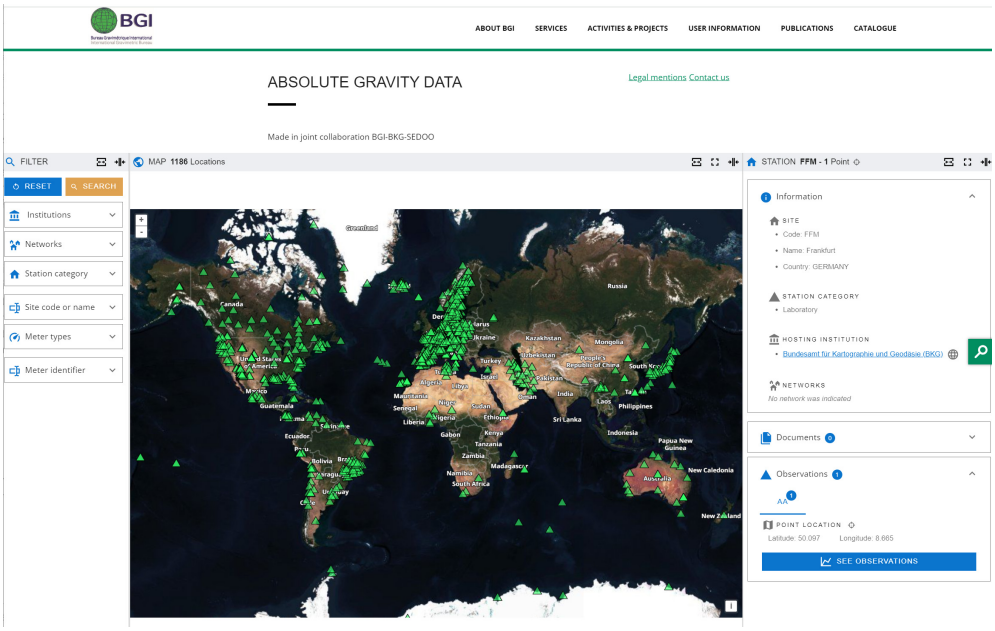


Fig. 1. The new Absolute Gravity database (AGrav) launched in 2024

decades, these stations have provided the only available information on absolute gravity value for tying local or regional relative gravity surveys (terrestrial, marine, airborne) in a global reference frame. Even if a significant number of reference stations should have disappeared with time, this original IGSN71 database remains accessible and is still used in some countries for calibration of relative surveys. This global gravity reference network will be advantageously replaced by the ITGRS/ITGRF based on the increasing network of actual absolute gravity measurements and made available from the AGrav database.

3.2 Global or regional gravity grids and models

BGI also contributes to the realization of derived gravity products aimed at supporting studies of the Earth gravity field at global or regional scales. The products mostly used by scientific users are the digital global grids from the World Gravity Map [6] which represent the first gravity anomalies (Bouguer, isostatic and surface free-air anomalies) computed in spherical geometry taking into account a realistic Earth model (Fig. 2). They include 1 minute resolution terrain corrections computed from the contribution of most surface masses (atmosphere, land, oceans, inland seas, lakes, ice caps and ice shelves). The World Gravity Map is also available as a set of 3 global maps realized for the Commission for the Geological Map of the World (CGMW). Other global or regional gravity models or data compilations computed at BGI or provided by other contributors may also be made available on the BGI website.

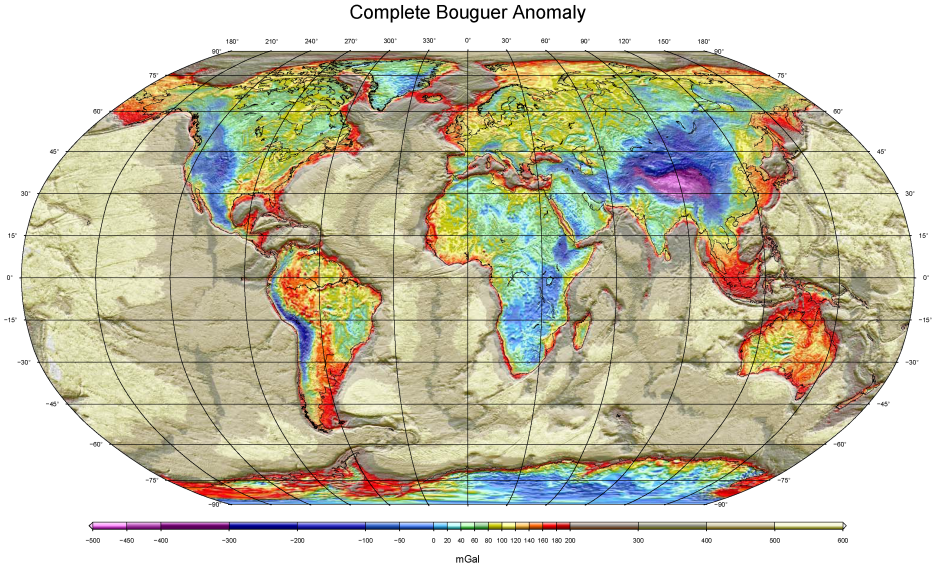


Fig. 2. Complete spherical Bouguer anomaly map of the word (source: BGI)

3.3 Software

BGI makes available on its website home-made tools and software developed for gravity data acquisition or validation such as CG6TOOL [7] for Scintrex gravity data processing or MGL_QuickView [8] for quick visualization of FG5 or A10 Micro-g LaCoste data acquisition results (project files).

3.4 Other services

- Online tools for prediction gravity at a given site.
- Documentation (historical bulletins 1950-2002, reports).
- Attribution of DOIs for relative and absolute gravity data set, products or software provided by contributors.

4 Program/Activities (2023-2027)

4.1 Database and services

The current activities at BGI are mostly dedicated to consolidate and validate the IAG global relative and absolute gravity databases and to develop pertinent and updated products and services for long-term sustainability and usability of gravity data for scientific purposes. The most significant actions released in 2023-2024 include:

- *A new BGI website* that provides services and information to both users and contributors. A catalogue of products freely distributed has been added.
- *The re-launch of the Absolute gravity database (AGrav)* with a new web interface and functionalities. AGrav is now accessible on the BGI website (https://bgi.obs-mip.fr) as well as from BKG (https://agrav.bkg.bund.de). Further developments are in progress to facilitate its maintenance and update (edition of metadata, upload of new dataset, check of data consistency, etc.) and its use (selective display of observations from a given network/institution/ instrument, plot of absolute gravity times series for a given station, etc.). The database will be updated with new contributions from corner-cube or quantum gravity instruments and the link to the development of the ITGRF will be strengthened.
- *The assignment of a DOI* to gravity datasets, products and software provided and archived at BGI. DOI are for instance already assigned to gravity datasets (either from recent or old gravity surveys) or to other products such as global or regional grids and models, data compilations, software, etc. For easier referencing, DOI landing pages have been developed. This will be extended soon to the AGrav database, with the assignment of DOIs to the absolute gravity instruments and networks from the contributing institutions.

4.2 Collection and validation of gravity data

BGI currently archives and validates new incoming gravity datasets. Data, products or software available at BGI are mostly dedicated to support scientific and academic activities. The contribution of countries, agencies and scientists involved in gravity data acquisition (relative or absolute measurements from field, marine or airborne surveys) is essential for improving the global coverage and accuracy of the Earth gravity field and for contributing to the determination of the new ITGRF. The archiving of new data sets also enables BGI to better validate the gravity observations in a global reference frame and restore them in standard and unified formats useful for the scientific end users. National agencies worldwide involved in the acquisition or compilation of gravity measurements and who wish to contribute to the updating of the IAG and ITGRF global gravity databases for a given country or region and to reference their works are invited to contact BGI.

4.3 Support to IAG/GGOS activities

The BGI contributes within IAG and GGOS to several Commissions, Working Groups and Projects aimed at improving:

- the global knowledge and accuracy of the Earth gravity;
- the definition and realization of gravity standards and networks;
- the development and evaluation of new gravity sensors (quantum gravimetry).

4.4 Development of the ITGRF

For the next 4 years, BGI will be strongly involved along with BKG in the development of the ITGRF. This initiative, launched in 2015, is being led by the IAG JWG

2.1.1, with support from the IAG Services BGI, IGETS and IGFS [9, 10]. It aims to provide a long-term global gravimetric reference based on absolute and traceable gravimetric measurements such as those provided by state-of-the-art absolute gravimeters (corner-cube or cold-atom). The proposed definition of ITGRS/ITGRF has given rise to several IAG resolutions since 2019 and will replace the obsolete International Gravity Standardization Net 1971 (IGSN71) developed in the 70's. It includes:

- *A primary global network of gravity reference stations* that will provide accurate, long-term absolute monitoring of the gravity field at selected stations where gravity can be continuously monitored at the µGal level (10^{-8} m s^{-2}). This network, possibly combined with other geodetic techniques, will contribute to the IAG/GGOS geodetic base site infrastructure. The target accuracy for this reference network, based on high-precision measurements, is of the order of a few µGal.
- *A secondary global network of gravity sites* determined from field or laboratory absolute gravity measurements, which will provide reference values for relative terrestrial, shipborne or airborne surveys, or for calibrating relative instruments. The target accuracy for this secondary network is of the order of a few to a few tens of µGal. The main contribution to this global network comes from the worldwide agencies responsible for national geodetic infrastructures.

4.5 New technologies of gravity measurements: Quantum gravimetry

BGI and its associated teams are involved in the evaluation of new gravity sensors such as those based on cold-atom technologies. In France, they have accompanied within the last few years the development and the evaluation of the first commercial Absolute Quantum Gravimeter (AQG) designed by MuQuans company, now eXail (Menoret et al., 2018) and of the first hybrid absolute gravimeter (including accelerometers and cold-atom sensor) designed by ONERA (France) for moving shipborne or airborne platform [11, 12]. They are also involved through the LNE lab in metrological developments in quantum gravimetry and in national and international inter-comparisons of absolute gravity meters (Fig. 3). These activities directly contribute to the IAG QuGe Project and to its WG Q.1 "Quantum gravimetry in space and ground".

4.6 Gravity compilations and studies

BGI will continue its activities related to regional gravity compilations. It has recently supported the realization of the Pan-Alpine gravity database [13] and a compilation on Vietnam and surrounding areas [14–16]. It also leads with the gravity group from POLIMI (Italy) the GeoMed2 project aiming at the realization of a high-resolution gravity and geoid model of the Mediterranean Sea. Gravity products derived from these studies are made publicly available from the BGI website.

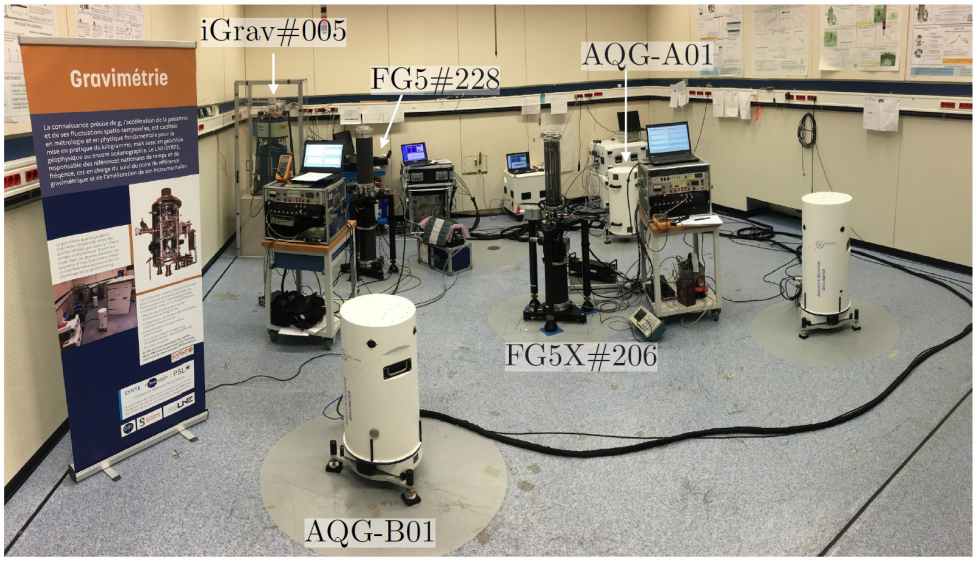


Fig. 3. Inter-comparison of quantum gravimeters at LNE facilities (source: S. Merlet)

4.7 Gravity surveys and networks

BGI associated teams also support the realization of gravity surveys and networks in the frame of national or international research projects with national agencies on the French territory as well as on other continents.

5 Structure

The BGI Central Bureau (management, secretariat and technical staff) is located in Toulouse, France, in the premises of the Observatoire Midi-Pyrénées (OMP) and Geosciences Environnement Toulouse (GET) research unit. BGI is supported by French agencies and universities, each of which has a representative member in the BGI Advisory Board (see list of experts below).

- Centre National d'Etudes Spatiales (CNES)
- Bureau de Recherches Géologiques et Minières (BRGM)
- Centre National de la Recherche Scientifique (CNRS)
- Institut National de l'Information Géographique et Forestière (IGN)
- Institut de Recherche pour le Développement (IRD)
- Service Hydrographique et Océanographique de la Marine (SHOM)
- Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)
- Institut de Physique du Globe de Paris (IPGP)
- Ecole et Observatoire des Sciences de la Terre (EOST)
- Ecole Supérieure des Géomètres et Topographes (ESGT)
- Université de Toulouse (GET/OMP)

- Université de Montpellier (Géosciences Montpellier)
- Université de Nice Sophia-Antipolis (GeoAzur)
- Université de Brest (Géosciences Océan)

Then, several French research units are involved in essential tasks carried out at BGI for the compilation, validation, analysis of gravity data, for the data acquisition (realization of gravity surveys or networks) as well as for the improvement of terrestrial gravity instrumentation and metrology (including quantum gravimetry).

Central Bureau (France)

- S. Bonvalot (GET/OMP, Toulouse); Director
- L. Seoane (GET/OMP, Toulouse); Deputy Director
- G. Balmino (GET/OMP, Toulouse)
- A. Briais (GET/OMP, Toulouse; GeoOcean/IEUM, Brest)
- S. Bruinsma (GET/OMP, Toulouse)
- G. Gabalda (GET/OMP, Toulouse)
- F. Reinquin (GET/OMP, Toulouse)

Advisory Board

Permanent correspondents (France)

- S. Merlet (LNE/SYRTE, Paris)
- A. Memin (GeoAzur, Nice)
- G. Pajot-Metivier (IPG, Paris)
- T. Gattacceca (IGN, St Mandé)
- R. Degoy (IGN, St Mandé)
- D. Rouxel (SHOM, Brest)
- C. Salaün (SHOM, Brest)
- M. Maia (GeoOcean/IUEM, Brest)
- G. Martelet (BRGM, Orléans)
- A. Peyrefitte (BRGM, Orléans)
- J.-P. Boy (EOST, Strasbourg)
- S. Rosat (EOST, Strasbourg)
- J.-D. Bernard (EOST, Strasbourg)
- N. Le Moigne (GM, Montpellier)
- J. Verdun (ESGT, Le Mans)

Permanent correspondents (other countries)

- H. Wziontek (BKG, Germany)
- V. Pálinkáš (VUGTK, Czech Republic)
- R. Barzaghi (POLIMI, Italy)
- G. Vergos (AUTh, Greece)
- R. Forsberg (DTU, Denmark)

IAG Representative

- U. Marti (FOT, Switzerland)

IGFS Representative

- R. Barzaghi (POLIMI, Italy)

6 Point of contact

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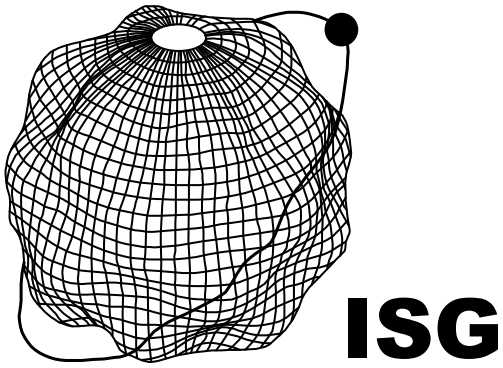
International Service for the Geoid (ISG)

https://doi.org/10.82507/iag-gh2024_isg

President: Mirko Reguzzoni (Italy)
Director: Daniela Carrion (Italy)

ISG website - https://www.isgeoid.polimi.it/



1 Introduction

The International Service for the Geoid (ISG) was established in 1992 with the former name International Geoid Service (IGeS), as a working arm of International Geoid Commission (IGeC). It is actually an official Service of the IAG under the "umbrella" of the International Gravity Field Service (IGFS). It aims at collecting, analysing, and redistributing local, regional, and continental geoid models and providing technical support to people involved in geoid-related topics for both educational and research purposes. In the framework of its activities, ISG performs research taking advantage of its archive and organizes seminars and specific training courses on geoid determination, supports students and researchers in geodesy as well as distributes training material on the most common algorithms for geoid estimation [17].

2 Mission, Objectives

The main tasks of ISG are:

- to collect geoid estimates worldwide, when possible validate them, and disseminate them upon request among the scientific community. Other auxiliary data useful for the geoid determination may also be collected by ISG, without redistributing data that are already provided by other IAG Services;
- to collect, test and - when allowed - distribute software for the geoid determination;
- to conduct researches on methods for the geoid determination, also defining optimal procedures for merging all available data and models;
- to organize international schools on geoid determination addressing both theoretical and practical topics, possibly every two years. During the schools, students are trained in the use of the relevant software for geoid computation;
- to support agencies or scientists in computing local and regional geoid models, especially in developing countries, also organizing special training courses;
- to disseminate training material and software on geoid computation, e.g. lecture notes of the schools;
- to issue the Newton's Bulletin, which is of technical and applied nature, collecting papers and reports on gravity and geoid;
- to establish and maintain a website to present the Service activities, show and distribute the geoid models, software and publications, offer web services for the manipulation and exploitation of the geoid models, announce news and international schools on geoid determination.

Data and software given to ISG remain property of the authors, who decide upon the conditions of use and can allow, restrict or deny their distribution. ISG itself can indeed perform geoid computations within different projects, while remaining a non-profit institution.

3 Products

- Database of local and regional geoid models, in the form of grids or sparse points, stored and distributed in a homogeneous file format, with digital object identifiers (DOIs) assigned in collaboration with GFZ Data Services;
- Software archive for local geoid estimation, for terrain gravity effect calculation and for handling global models;
- Documentation on available data and software;
- International schools and on request training courses on geoid computation;
- Lecture notes and other geoid related publications;
- Newton's Bulletin and the former IGeS Bulletin;
- Research results on gravity and geoid matters.

4 Program/Activities (2023-2027)

Beyond institutional activities, the following research topics are worth mentioning:

- computation of improved geoids for Italy and the Mediterranean area;
- integration of ground, airborne, shipborne and satellite gravity data for geoid modelling;
- integration of local, regional, continental and global geoid models;
- participation within IGFS to the validation of new global gravity models, the study of the height datum unification problem, as well as the realization of the International Height Reference Frame (IHRF);
- participation within GGOS to the fostering of DOIs assignment to geodetic data and models;
- study of improved methodologies for the determination of the geoid at local and global level.

5 Structure

ISG is an official IAG Service, coordinated by IGFS and is also related to the activities of the IAG Commission 2 - Gravity Field. Its structure, tools and activities are illustrated in the ISG reports to the Advisory Board of IGFS.

The Service is hosted by the Department of Civil and Environmental Engineering at Politecnico di Milano. ISG staff is currently composed of researchers and a secretary. They nominate, upon recommendation of IGFS, a President for the international representation and a Director for the operative management. In addition, the ISG Advisory Board are scientists who have/had an outstanding activity in the field of geoid determination and can also represent ISG in both research and teaching activities. Finally, within the ISG structure, Working Groups can be established for specific purposes, limited in time.

Staff (2023-2027)

- M. Reguzzoni (Italy); President (also Repr. to the IHRF-CC Directing Board)
- D. Carrion (Italy); Director
- F. Sansò (Italy); Past President
- R. Barzaghi (Italy); Past President
- G. Sona (Italy); Past Director
- A. Albertella (Italy)
- C. I. De Gaetani (Italy)
- L. Rossi (Italy)
- K. Batsukh (Italy)
- C. Vajani (Italy); Secretary

Advisory Board (2023-2027)

- N. Pavlis (USA)

- M. Sideris (Canada)
- J. Huang (Canada)
- R. Forsberg (Denmark)
- J. Ågren (Sweden)
- U. Marti (Switzerland); Repr. to GGOS Governing Board
- L. Sánchez (Germany)
- K. Elger (Germany)
- I. Tziavos (Greece)
- D. Blitzkow (Brazil)
- H. Abd-Elmotaal (Egypt)
- C. Hwang (China-Taipei); IAG Repr. to ISG

Product, Data and Analysis Centers

Data storage and processing centers are implemented through the Information and Communication Technology (ICT) services of Politecnico di Milano.

6 Point of Contact

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Permanent Service for Mean Sea Level (PSMSL)

https://doi.org/10.82507/iag-gh2024_psmsl

Head: Elizabeth Bradshaw (UK)
Technical lead: Andrew Matthews (UK)

PSMSL website - https://psmsl.org/

1 Introduction

For over 200 years, we have been observing the height of the ocean using tide gauges. These are perhaps more accurately called water level sensors, as they can be used in areas where there is little or no tide and they can be used to monitor variations in heights across a wide range of timescales, from high-frequency waves, storm surges and tides, to long-term changes in ocean currents, as well as changes due to the expansion of warming water and the melting of glaciers and ice caps.

Established in 1933, the Permanent Service for Mean Sea Level (PSMSL) is the global centre for the collection, analysis, interpretation and publication of monthly mean sea level data from in situ observations. The PSMSL is hosted and funded by the UK National Oceanography Centre (NOC) and is one of the key data centres for the Global Sea Level Observing System (GLOSS), an international programme of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The PSMSL is a Service of the IAG, a member of the GGOS Bureau of Networks & Observations, and continues to be one of the main data centres for the International Association for Physical Sciences of the Oceans (IAPSO). The PSMSL reports formally to IAPSO's Commission on Mean Sea Level and Tides (IAPSO-CMSLT). Further, the PSMSL operates under the auspices of the International Science Council (ISC) and is a regular member of the World Data System (WDS) of ISC.

2 Mission, Objectives

The PSMSL is the global databank for long-term mean sea level data. The primary purpose is to grow the mean sea level databank and fill gaps in the observational network. We are extending records and increasing the types of data collected. We

will create standards for metadata, data formats and software. We will be a centre of excellence, providing training and advice and fostering the development of sea level science in developing economies.

We want to provide free access to data, encourage its reuse, and provide expert training and support, while ensuring we are transparent and open with our processes.

- We want PSMSL to be the go-to data centre for Mean Sea Level data and for users to have confidence in our service.
- We want to distribute the best possible data and metadata.
- We want to be able to track who is using our data.
- We want to be able to give credit to everyone involved in the data lifecycle.

3 Products

The PSMSL database contains over 76000 station-years of monthly and annual values of Mean Sea Level (MSL) from over 2400 tide gauge stations around the world, received from approximately 200 national authorities. On average, approximately 800 stations per year are entered into the database. This database is used extensively throughout the sciences of climate change, oceanography, geodesy and geology, and is the main source of information for international study groups such as the Intergovernmental Panel on Climate Change (IPCC).

Data for all stations are included in the PSMSL METRIC (or total) data set. The METRIC monthly and annual MSL for any one station-year are necessarily required to be measured to a common datum, although, at this stage, datum continuity between years is not essential. The year-to-year datum checks become essential, however, if the data are subsequently to be included in the PSMSL Revised Local Reference (RLR) component of the data set.

This RLR dataset contains records for which time series analysis of sea level changes can be performed. Long records from this dataset have been the basis of all analyses of secular changes in global sea level during the last century. The geographical distribution of longer RLR records contains significant geographical bias towards the northern hemisphere, a situation that is being rectified by the establishment of the GLOSS global sea level network.

The PSMSL is also responsible for the Higher Frequency Delayed Mode (HF DM) data set of sea level information from the GLOSS Core Network. This consists of the original sea level measurements from each site (typically hourly values), which provide a strategic backup to the MSL information of the main PSMSL data set.

The PSMSL works with the International GNSS Service (IGS) Tide Gauge Working Group (TIGA) to maintain records of geodetic ties between tide gauges and GNSS receivers.

The PSMSL received funding from the European Union Horizon 2020 EuroSea project to create an international archive in which to preserve and deliver Global Navigation Satellite Systems Interferometric Reflectometry (GNSS-IR) data and to integrate these data with existing sea level observing networks. GNSS-IR sensors provide an alternative method to observe sea level. As well as recording the sea level, these sensors will also provide vertical land movement information from one location.

In addition, the PSMSL provides a range of sea level products (e.g. interactive anomaly and trend maps, tables of sea level trends) for its users. These findings are input to national and international scientific study groups regularly. A range of training materials and software products are also made available via its website, which can be consulted for more information.

4 Program/Activities (2023-2027)

We will continue to develop the strong outward image of the PSMSL as a group of scientists with comprehensive sea level expertise. We will showcase at international and national conferences the excellent science papers produced from the PSMSL data, with the aim of expanding its application and reputation. We will contribute to international and national reports and policy documents.

4.1 Improving our metadata in the context of FAIR, TRUST and CARE principles

It is important to the PSMSL that we are able to demonstrate where the data we distribute came from, give credit to those involved in the data lifecycle, and produce a full audit trail. If we have updated records, we need to be able to document why. This information needs to be delivered alongside the data. Currently, it is difficult to uniquely identify tide gauge locations, sensors and suppliers, which can lead to duplicate data on data aggregator websites. It may also be difficult to get a true picture of the status of a network, such as how many gauges are currently operational.

Clarity over the source and provenance of data will be improved by developing unique identifiers for sites and instruments, and by the exchange of data via well-described data services using controlled vocabularies.

We are working towards FAIR (Findable, Accessible, Interoperable, and Reusable), TRUST (Transparency, Responsibility, User Focus, Sustainability and Technology) and CARE (Collective benefit, Authority to control, Responsibility, and Ethics) principles. We aim to implement recommendations from the new IOC Oceanographic Data Exchange Policy and the updated GLOSS implementation plan when released.

We will continue to improve ocean observation metadata and will work with the GOOS Observations Coordination Group (OCG) and OceanOPS on the metadata harmonisation working group. Three technical working groups were set up following action items from the EuroGOOS Tide Gauge Task Team Meeting in July 2020. The PSMSL staff lead or sit on the Working Groups for site/station definition, unique ID definition and minimum metadata definition.

We are undertaking an international sea level data flow mapping exercise to help identify gaps, duplicates and differences in data streams.

4.2 Improving the PSMSL website and data delivery

We will continue to update and improve the PSMSL website and are working towards distributing our data in a wide variety of formats via our ERDDAP server. We will

make available automatic quality control software in MATLAB and Python to encourage the quality control of sea level data and improve the data flow of monthly and annual mean sea level data.

GLOSS currently has several data centres, each specialising in a different product (real time, delayed mode, etc.) This system, while functional, can cause confusion, so GLOSS plans to launch a unified data portal aggregating data from all centres. To facilitate this, each centre is planning to make their data available through an ERDDAP instance and we are defining a shared metadata model. More specialist users will still be able to access the individual data centres as before.

We aim to assign a Digital Object Identifier (DOI) to the PSMSL dataset, to enable us to more easily and accurately track data usage through published papers and be able to feedback to data suppliers who is using their data.

We are working on improving links with other services e.g., we will link to the GGOS IDS web service to show DORIS beacons at tide gauges.

4.3 Improving our delivery of GNSS-IR data

The development of GNSS-IR and the use of low-cost GNSS sensors to measure sea level may help fill in gaps in the current global tide gauge network. Installing GNSS-IR for sea level at sites would also enable the monitoring of vertical land motion and help measure and maintain geodetic ties between tide gauges and GNSS receivers. We developed a portal to distribute sea level data from over 300 GNSS receivers worldwide and created an interactive planning tool allowing users to determine the best place to install a receiver at any location. We developed a data format for the records, have created structured metadata, and the next step will be to populate the metadata using controlled vocabularies. We are developing a mechanism to deliver NRT GNSS-IR data through ERDDAP.

4.4 Sea level data rescue

The PSMSL continues to play a leading role in sea level data rescue by participating in the new GLOSS working group that was formed at the 17$^{\text{th}}$ Session of the Group of Experts for the Global Sea Level Observing System in November 2022. We will also issue the Zooniverse data with a DOI and publish a data rescue paper. We are currently exploring other techniques to digitise tide gauge charts, which may require the use of machine reading and learning techniques so data can be recovered algorithmically.

5 Structure

The PSMSL reports formally to the IAPSO-CMSLT (President Dr. G.T. Mitchum, USA). The formation of the CMSLT is currently being reviewed by IAPSO (2024).

Staff

Three members of staff work for PSMSL and we are supported by the NOC Sea Level sub-group. This sub-group provides technical and scientific advice and represents the PSMSL at conferences, meetings and workshops.

- Elizabeth Bradshaw; Head of the PSMSL
- Andrew Matthews; Technical lead of the PSMSL
- Chanmi Kim; PSMSL data manager
- Lesley Rickards; former Director

NOC advisory group

- Angela Hibbert; capacity building
- Svetlana Jevrejeva; projections, impact and adaptation
- Joanne Williams; surges, extremes and tides
- Simon Williams; GNSS and vertical land motion (VLM)
- Chris Wilson; ocean circulation and modelling
- Philip Woodworth; scientific advisor

6 Point of Contact

Permanent Service for Mean Sea Level
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Part VI

General Information

IAG on the Internet

Szabolcs Rózsa (Hungary)

Website - www.iag-aig.org

1 IAG Website

The IAG maintains an Internet site, which is a valuable source of information not only about the Association itself, but also about its scientific disciplines. The primary goal of the website is to communicate with the IAG members and make information available to the wider geoscientific community in the world as a whole.

Since the maintenance of the IAG website belongs to the activities of the Communication and Outreach Branch (COB), it is still hosted at the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BME) in Hungary. The website incorporates not only the IAG website, but also the four commissions and the ICCC, ICCM, ICCT websites. The layout of the website was redesigned in 2019 to fully support handheld devices, such as tablets, smartphones, etc. (Fig. 1).

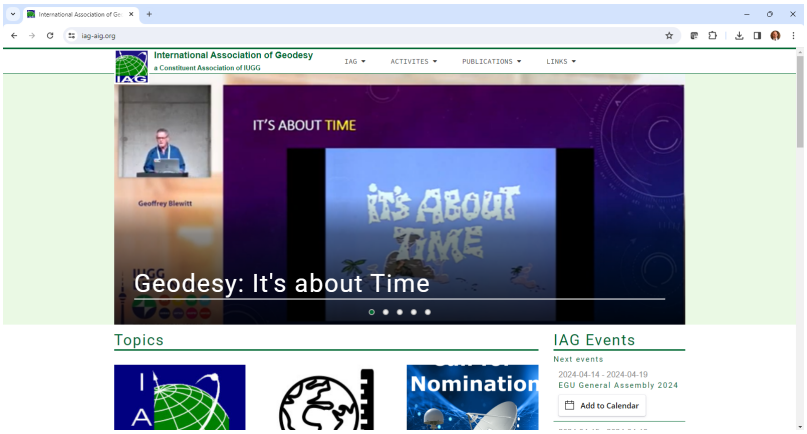

Fig. 1. IAG Website: www.iag-aig.org

Recently, a new top-level URL has been registered for IAG and geodesy in general: geodesy.science. Under this umbrella we would like to combine the activities of IAG and GGOS on the Internet. Currently the URL http://iag.geodesy.science points to the IAG website, http://ggos.geodesy.science points to the GGOS website, while http://products.geodesy.science points to the landing page of the geodetic products of

GGOS. The top-level http://geodesy.science will be devoted to a general introduction to geodesy for the wider public.

2 Topic of the Month

The Topic of the Month section of the opening page aims at promoting important scientific achievements and activities to the wider public. The latest scientific results, the establishment of international and interdisciplinary research projects and all other information, which may have a great impact on the geodetic community, can be posted on this section of the website.

Since the COB intends to publish a new topic every month, geodesists are kindly encouraged to submit new topics to the e-mail address:iagcob@iag-aig.org.

The Topics of the Month must include an image and a short introduction, too. Both are published on the opening page of the website, more details are given on separate pages.

3 Publishing on the IAG Website

The IAG COB encourages all the IAG members and geodesists in general to publish information on the IAG website. News, conference calls, job announcements, etc. can be submitted to the IAG COB for publication. Contributions can be sent to the e-mail address: iagcob@iag-aig.org.

4 IAG Newsletter on the Internet

The monthly IAG Newsletters are available on the IAG website in web and PDF format. Please visit the https://www.iag-aig.org/iag-newsletters link to find the latest newsletters. The newsletters are automatically delivered to more than 500 subscribers via e-mail. IAG members are automatically subscribed to the newsletter service. Others are encouraged to become a member of IAG and contribute to its activities or to subscribe to the IAG newsletter by e-mailing the COB (iagcob@iag-aig.org).

5 IAG on Social Media

In order to address the younger generations, the COB has opened the IAG page on Facebook and X (former Twitter). As of April 1, 2024, the Facebook page http://www.facebook.com/InternationalAssociationOfGeodesy has more than 2.500 "likers" and 2.600 followers. The X site of IAG is available at https://twitter.com/iag_geodesy. As of April 1, 2024 IAG has 1.555 followers on X. We would like to encourage everyone who is interested in geodesy to follow these pages, since the latest information published on the IAG website is available there, too. The followers of these pages are automatically notified about latest IAG news.

However, our appropriate presence on the social media needs more frequent news on geodesy and IAG. We would like to encourage IAG members and geodesists in

general to provide us input for these sites! Please feel free to contact the COB for publishing such geodesy-related information, because it really helps to improve the outreach activities of IAG.

We do appreciate your help and cooperation!

Publications of the IAG

Szabolcs Rózsa (Hungary)

Website - www.iag-aig.org

1 Journal of Geodesy

Twelve issues per year. Annual subscription or sale by unit:
Springer Verlag, Tiergartenstrasse 17, D – 69121 Heidelberg, Germany,
www.springer.com

2 IAG Symposia Series

Peer reviewed proceedings of selected IAG Symposia. Available at Springer-Verlag (see above). Latest issues (published or in preparation):

Vol. 152	Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2022) Beyond 100: The Next Century in Geodesy. Proceedings of the IAG General Assembly, Montreal, Canada, July 8-18, 2019. (DOI: https://doi.org/10.1007/978-3-031-09857-410.1007/978-3-031-09857-4)
Vol. 153	Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2023) 5th Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TG-SMM 2019). Proceedings of the Symposium in Saint Petersburg, Russia, October 1 – 4, 2019. (DOI: https://doi.org/10.1007/978-3-031-25902-910.1007/978-3-031-25902-9)
Vol. 154	Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2023) Geodesy for a Sustainable Earth. Proceedings of the 2021 Scientific Assembly of the International Association of Geodesy, Beijing, China, June 28 – July 2, 2021. (DOI: https://doi.org/10.1007/978-3-031-29507-210.1007/978-3-031-29507-2)
Vol. 155	Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2024) X Hotine-Marussi Symposium on Mathematical Geodesy. Proceedings of the Symposium in Milan, Italy, June 13-17, 2022. (DOI: https://doi.org/10.1007/978-3-031-55360-810.1007/978-3-031-55360-8)
Vol. 156	Freymueller, Jeffrey T., Sánchez, Laura (Eds., 2024) Gravity, Positioning and Reference Frames (2024). Proceedings of the IAG Symposia - GGHS2022: Gravity, Geoid, and Height Systems 2022, Austin, TX, United States of America, September 12 – 14, 2022; IAG Commission 4: Positioning and Applications, Potsdam, Germany, September 5 – 8, 2022; REFAG2022: Reference Frames for Applications in Geosciences, Thessaloniki, Greece, October 17 – 20, 2022.

3 Geodesist's Handbook

Quadrennial special issues of the Journal of Geodesy, published since 1980, contain the actual IAG Statutes, Bylaws and rules, summaries of the latest IAG General Assembly, the structures and the program descriptions for all IAG components for the respective upcoming period.

4 Travaux de l'Association Internationale de Géodésie (IAG Reports)

The IAG Reports (Travaux de l'Association Internationale de Géodésie) are published on the occasion of the IAG General and Scientific Assemblies every two years and contain the reports of all IAG components and sub-components. They were published as printed volumes until 2003 (since 1991 also available in digital form) and since 2005 online only at https://www.iag-aig.org/travaux.

5 Geodetic Data Centres, Educational Establishments for Geodesy

The IAG Communication and Outreach Branch (COB) compiles and maintains a list of Geodetic Data Centres and a list of addresses of Educational Establishments for Geodesy. All data compiled in these lists are regularly revised by the IAG national correspondents. Considering the fact that addresses are subjected to frequent changes, the directory is stored as a file on the web, so as to sustain updates whenever useful.

All information is available at https://www.iag-aig.org/geodetic-data-centers and https://www.iag-aig.org/educational-institutions, respectively. Data are stored on the IAG website as soon as the responsible national correspondent sends them to the IAG COB (iagcob@iag-aig.org). All national correspondents are kindly asked to inform the COB of any change.

6 Geodetic Publication Series

The COB compiles and maintains a list of Geodetic Publication Series. All data compiled in this list are regularly revised by the IAG national correspondents. Given that addresses are subjected to frequent changes, the directory is stored on the web, so as to make updates. All information is available at https://www.iag-aig.org/publication-series. Data are stored on the IAG website as soon as the responsible national correspondent sends them to the IAG COB (iagcob@iag-aig.org). All national correspondents are kindly asked to inform the COB of any change.

7 IAG Directory

Due to the general data protection regulation, IAG ceases to publish the IAG Directory. For contact details, please contact the IAG Office at IAG-Office@bkg.bund.de.

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