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)
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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)
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Corresponding Members

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Jean-Paul Boy (France)
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In-Mook Choi (Korea)
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Janis Kaminskis (Latvia)
Jeff Kennedy (USA)
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Martin Lederer (Czech Republic)
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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)

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Tao Jiang (China)
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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.

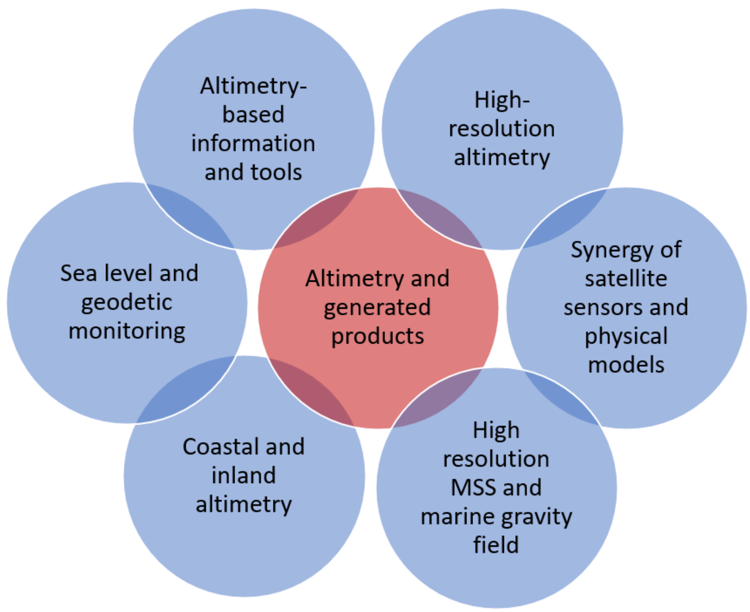

Fig. 1. Key clusters of the IAS.

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)
Cheinway Hwang (China-Taipei)
Per Knudsen (Denmark)
Eric Leuliette (USA)
Yuanyuan Jia (USA)
Isabelle Pujol (France)
Walter Smith (USA)
C.K. Shum (USA)
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.

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