Commission 1 - Reference Frames

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

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

1 Terms of Reference

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

1.1 Objectives

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

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

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

1.2 Program of Activities

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

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

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

1.3 Structure

Sub-Commissions

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

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

Working Groups

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

Joint Working Groups

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

Joint Study Groups

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

1.4 Steering Committee

The steering committee will meet at least once per year.

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

1.5 Overview of Working Groups and Study Groups

Groups related to SC 1.1

JWG 1.1.1 GENESIS
(joint with IERS, GGOS)
Chair: Johannes Böhm
JWG 1.1.2 Atmospheric ties
(joint with GGOS)
Chair: Jungang Wang (Germany)
JWG 1.1.3 Lunar reference frames
(joint with IAU)
Chair: Agnès Fienga (France)

Groups related to SC 1.2

JWG 1.2.1 GNSS scale information for global reference frames
(joint with IGS)
Chair: Paul Rebishung (France)
JWG 1.2.2 Metrology of space geodetic infrastructure
(joint with IERS, GGOS)
Chair: Ryan Hippenstiel (USA)
JWG 1.2.3 Impact of geophysical models on reference frames
(Joint with Comm 3)
Chair: Jeff Freymueller (USA)
JWG 1.2.4 Evaluation of the terrestrial reference frames
(joint with IERS)
Chair: Guilhem Moreaux (France)

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

Groups related to SC 1.4

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

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

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

2 Sub-Commissions, Working Groups and Study Groups

SC 1.1: Coordination of Space Techniques

Chair: Krzysztof Sośnica (Poland)

Terms of Reference

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

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

Objectives

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

JWG 1.1.1: GENESIS

(joint with IERS, GGOS)
Chair: Johannes Böhm

Terms of Reference

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

Objectives

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

Members

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

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

Ex-officio Members of IERS

Robert Heinkelmann (Germany)
Daniela Thaller (Germany)

Ex-officio Members of GGOS

Detlef Angermann (Germany)
José Rodríguez Pérez (Spain)

Corresponding Members

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

JWG 1.1.2: Atmospheric ties

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

Terms of Reference

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

Objectives

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

Program of Activities

The working group will concentrate on the following activities:

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

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

Members

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

JWG 1.1.3: Lunar reference frames

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

Terms of Reference

Recently, several organizations have established plans to visit the Moon for exploration and science. These led to the recognition that updated localization standards for both surface and orbital activities at the Moon are needed and should therefore be a priority for operations leading to exploration. The objective of this WG is to address the issues of the connection between Celestial, Earth and Lunar Reference Frames for the future missions in coordination with the IAG, IAU, and IERS and to formulate recommendations regarding the definition, the realization, and the dissemination of Lunar Reference Systems, across agencies and user communities. Experience acquired with the establishment of the Earth Reference Frame (ITRF, GCRF) will serve as the foundation for this task. The work of this group will be connected with on-going Lunanet International interoperability standardization work being performed by NASA, ESA and JAXA.

Objectives

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

Program of Activities

The group will:

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

Members

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

Corresponding members

Masaya Murata (Japan)
Jinsong Ping (China)

SC 1.2: Global Reference Frames

Chair: Mathis Bloßfeld (Germany)

Terms of Reference

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

A further step forward could be established by investigating relativistic reference frames based on a network of clocks in space linked with time transfer technologies. Such realized frame would be entirely decoupled from ground fixed stations and could be used to reference any point on the Earth's surface. The relativistic frequency shift between clocks in space and on the ground would be a direct measurement of the Earth gravity potential. This technology can be used to realize a world height system based on a network of ground clocks. While this ultimate goal still requires intensive research works, TRF and future World Height Systems need to be studied in closer partnership in order to connect reference benchmarks, gravimeters or clocks to the TRF but also to provide consistent coordinate and height time-variations. The work of this Sub-Commission will be done in partnership with the IERS as well as with GGOS.

Objectives

The main objectives of SC 1.2 are the following:

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

Link to Services

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

Corresponding Member

Georgios Vergos (Greece); Representative of IFGS

JWG 1.2.1: GNSS scale information for global reference frames

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

Terms of Reference

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

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

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

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

However, the subsequent analysis of the contributions of the four techniques to ITRF2020 conducted at the Institut National de l'Information Géographique et Forestière (IGN) concluded that there was a +4.3 mm scale offset at epoch 2015.0 and a +0.11 mm/yr drift between the Galileo-based scale of the IGS repro3 solutions and the average scale of the SLR and VLBI solutions selected to define the ITRF2020 scale. A comparable offset of +4.9 mm at epoch 2010.0 (but no clear drift) was also found between the repro3 scale and that of the SLR contribution to ITRF2020 in a similar analysis conducted at the Jet Propulsion Laboratory (JPL). A third analysis conducted at the Deutsches Geodätisches Forschungsinstitut at the Technische Universität München (DGFI-TUM) concluded that there was good agreement (0.25 mm at epoch 2010.0; 0.025 mm/yr) between the repro3 scale and that of the VLBI contribution to ITRF2020, but confirmed the existence of an offset and a drift between the repro3 scale and that of the SLR contribution to ITRF2020 (+2.2 mm at epoch 2010.0 and +0.1 mm/yr between the GNSS/VLBI average and SLR).

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

Objectives

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

Members

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

Daniela Thaller (Germany)
Arturo Villiger (Switzerland)

JWG 1.2.2: Metrology of space geodetic infrastructure

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

Terms of Reference

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

Objectives

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

Program of Activities

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

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

Members (to be updated as JWG develops)

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

Corresponding Members

Xavier Collilieux (France)
Robert Heinkelmann (Germany)

JWG 1.2.3: Impact of geophysical models on reference frames

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

Terms of Reference

This working group, joint between IAG SC 1.2 and IAG SC 3.4 has the goal of assessing and improving geophysical models, to help to develop models that are sufficiently accurate that they could be used to describe non-secular motion in reference frame definition. Two broad categories of models could be considered, with the priority being mass transport models and associated surface loading deformation. Work in the JWG is carried out on a best-effort basis and is described below in the Objectives. Meetings are primarily expected to be virtual/online. However, the goal is to have an in-person meeting at the IAG Scientific Assembly in Fall 2025. A meeting at the Fall 2024 AGU meeting is considered.

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

Objectives for Geophysical Loading Models

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

Objectives for Earthquake and Post-seismic Models

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

Program of Activities

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

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

Members (to be updated as JWG develops)

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

JWG 1.2.4: Evaluation of the terrestrial reference frames

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

Terms of Reference

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

The ITRF is used daily by a huge number of individuals and organizations in applications such as surveying, aircraft navigation, responding to disaster emergency etc. Furthermore, the ITRF provides the fundamental basis needed for a broad variety of Earth system research applications. Examples are the determination, monitoring, and interpretation of global change phenomena on different temporal and spatial time scales (i.e. sea-level rise and ice sheet melting), of Earth Orientation and Rotation, relativity, lunar science, as well as the calibration and evaluation of ocean and ice altimetry missions. Furthermore, it is the basis for the understanding of dynamics and modelling of satellite orbits and can be used in scientific research such as plate tectonics and crustal deformation monitoring and static and time-varying gravity field modelling. In short, the ITRF serves as the backbone in geosciences.

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

Objectives

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

Members

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

Corresponding members

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

Ex-officio members

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

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

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

SC 1.3: Regional Reference Frames

Chair: Fernand Bale (Côte d'Ivoire)

Terms of Reference

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

Objectives

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

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

Program of Activities

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

SC 1.3a: Europe (EUREF)

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

Terms of Reference

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

Objectives

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

Structure, Working Groups

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

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

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

Program of Activities

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

Reference Network), EPOS (European Plate Observing System), UN-GGIM: Europe, etc.;

- Organize annual symposia addressing activities carried out at national and Europe-wide levels related to the global work and objectives of EUREF.

Members

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

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

Active honorary members

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

SC 1.3b: South and Central America (SIRGAS)

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

Terms of Reference

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

Objectives

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

Structure, Working Groups

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

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

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

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

Program of Activities

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

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

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

According to this it is necessary

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

Members

SIRGAS Executive Committee

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

SIRGAS Directing Council:

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

SIRGAS Scientific Council

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

SC 1.3c: North America (NAREF)

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

Terms of Reference

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

Objectives

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

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

Working Groups, Program of Activities

There are currently the following Working Groups:

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

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

Members

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

SC 1.3d: Africa (AFREF)

Chair: Elifuraha Saria (Tanzania)

Terms of Reference

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

Objectives

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

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

Program of Activities

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

SC 1.3e: Asia-Pacific (APREF)

Chair: Basara Miyahara (Japan)

Terms of Reference

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

Objectives

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

Program of Activities

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

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

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

Members

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

1. UN-GGIM-AP WG1 (Geodetic Reference Frame)
   Basara Miyahara (Japan); Chair
   Guorong Hu (Australia); Vice-Chair
   Yamin Dang (China)
   Asakaia Tabua (Fiji)
   Upendra Nath Mishra (India)
   Sidik Tri Wibowo (Indonesia)
   Seyed Abdoreza Saadat Mirghadim (Iran)
   Ahmad Sanusi bin Che Cob (Malaysia)
   Dalkhaa Munkhtsetseg (Mongolia)
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SC 1.3f: Antarctica

Chair: Martin Horwath (Germany)

Terms of Reference

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

Objectives

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

Program of Activities

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

Members

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SC 1.4: Interaction of Celestial and Terrestrial Reference Frames

Chair: Maria Karbon (Spain)

Terms of Reference

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

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

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

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

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

The definition of the EOP is based on the transformation between the ICRS and ITRS. However, while a reference frame may remain unaltered for years until a new version is released, EOP are subject to constant change and depend on continuous updates. Further, many applications need accurate predictions. Nonetheless, the EOP must remain consistent with the most recent reference frames. Similar to the ITRF, the individual space geodetic techniques deliver different EOP components with different accuracy, which are then combined in a multi-step process. This combination is linked to the ITRF and ICRF mainly only by the determination process of the EOP within the individual techniques.

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

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

Objectives

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

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

other limitations are imposed by

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

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

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

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

Terms of Reference

In the data analysis done for a new reference frame realisation (e.g., the ITRF or the ICRF), a multitude of models are used to correct for geophysical effects, for example atmospheric refraction, tides, and geophysical loading. Since the models used in the data analysis for the ITRF and the ICRF are not necessarily identical, this will lead to inconsistencies between the frames. These inconsistencies will also affect the EOP. The aim of the working group is to investigate the geophysical models used in the data analyses to find out their quality, as well how they impact the reference frames and the EOP. The work will mainly focus on the TRF and CRF, but emerging reference frames like the ITGRF, IHRF and the reference frame for the moon will also be considered.

Objectives

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

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

Chair: Minghui Xu (Germany)

Terms of Reference

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

Objectives

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

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

JWG 1.4.3: Consistent realization of TRF, CRF and EOP

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

Terms of Reference

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

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

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

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

Objectives

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

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

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