Commission 2 – Gravity Field

President: **Adrian Jäggi** (Switzerland)
Vice President: **Mirko Reguzzoni** (Italy)

https://com2.iag-aig.org/

Terms of Reference

The accurate determination of the gravity field and its temporal variations is one of the three fundamental pillars of modern geodesy (besides of 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 2015-19. Main drivers for the activities of the present period 2019-23 are related to the IAG resolutions adopted at the XXVII IUGG General Assembly 2019 in Montreal, concerning the establishment of the International Height Reference System (IHRS) and the establishment of the Infrastructure for the International Gravity Reference Frame (IGRF).

Commission 2, at the start of the new period, consists of six sub-commissions (SCs), plus some Joint Study Groups (JSG) and Joint Working Groups (JWG), 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 joint working groups (JWGs) and joint study groups (JSGs) 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 2019-23 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.

The necessary WGs and SGs can be established at any time and they can be dissolved when they reached their goals or if they are not active.

Objectives

The main objectives of Commission 2 are as listed in the IAG by-laws:

- 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

Structure

Sub-Commissions

SC 2.1: Land, Marine and Airborne Gravimetry
Chair: *Derek van Westrum* (USA)

SC 2.2: Geoid, Physical Height Systems and Vertical Datum Unification
Chair: *George Vergos* (Greece)

SC 2.3: Satellite Gravity Missions
Chair: *Frank Flechtner* (Germany)

SC 2.4: Regional Geoid Determination
Chair: *Hussein Abd-Elmotaal* (Egypt)

SC 2.4a: Gravity and Geoid in Europe
Chair: *Heiner Denker* (Germany)

SC 2.4b: Gravity and Geoid in South America
Chair: *Maria Cristina Pacino* (Argentina)

SC 2.4c: Gravity and Geoid in North and Central America
Chair: *Xiaopeng Li* (USA)

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 2.4f: Gravity and Geoid in Antarctica
Chair: *Mirko Scheinert* (Germany)

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)

Joint Study Groups

JSG 3.1: Geodetic, seismic and geodynamic constraints on GIA (Joint with: Comm 1, Comm 3)
Chair: R. Steffen (Sweden)

JSG T.28: Forward gravity field modelling of known mass distributions (Joint with: ICCT, Comm 3, GGOS)
Chair: *D. Tsoulis* (Greece)

JSG T.35: Advanced numerical methods in physical geodesy (Joint with: ICCT, GGOS)
Chair: *R. Čunderlík* (Slovakia)

JSG T.23: Spherical and spheroidal integral formulas of the potential theory for transforming classical and new gravitational observables (Joint w.: ICCT, GGOS)
Chair: *M. Šprlák* (Australia / Czech Republic)

JSG T.26: Geoid/quasi-geoid modelling for realization of the geopotential height datum (Joint with: ICCT, GGOS)
Chair: *J. Huang* (Canada), *Y.M. Wang* (USA)

JSG T.25: Combining geodetic and geophysical information for probing Earth's inner structure and its dynamics (Joint with: ICCT, Comm 3)
Chair: *R. Tenzer* (China)

JSG T.34: High resolution harmonic analysis and synthesis of potential fields (Joint with: ICCT, GGOS)
Chair: *S. Claessens* (Australia)

JSG T.30: Dynamic modeling of deformation, rotation and gravity field variations (Joint w.: ICCT, Comm 3)
Chair: *Y. Tanaka* (Japan)

JSG X.X: Machine learning in geodesy (Joint with: ICCT, Comm 1, Comm 3, Comm 4, GGOS)
Chair: *B. Soja* (USA)

JSG T.37: Theory and methods related to high-resolution digital topographic and bathymetric models (Joint with: ICCT, Comm 1, Comm 3, GGOS)
Chair: *D. Carrion* (Italy)

Joint Working Groups

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

JWG 2.1.2: Unified file formats and processing software for high-precision gravimetry Frame (joint with IGFS, IGETS, BGI)
Chair: *Ilya Oshchepkov* (Russia)

JWG 2.2.1: Error assessment of the 1 cm geoid experiment (joint with ISG, IGFS)
Chair: *Martin Willberg* (Germany)

JWG C.3: Geodesy for the Cryosphere: advancing the use of geodetic data in polar climate modelling (Joint with: ICCC, Comm 3)
Chair: *Bert Wouters* (Netherlands)
JWG C.4: Sea level and vertical land motion (Joint with: ICCC, Comm 1, Comm 4, GGOS)
Chair: *Roelof Rietbroek* (Germany)
JWG C.5: Understanding the monsoon phenomenon from a geodetic perspective (Joint with: ICCC, Comm 3, Comm 4, GGOS)
Chair: *Balaji Devaraju* (India)
JWG C.6: Numerical Simulations for Recovering Climate-Related Mass Transport Signals (Joint with: ICCC, GGOS)
Chair: *Roland Pail* (Germany)
JWG C.7: Satellite geodetic data assimilation for climate research (Joint with: ICCC, GGOS)
Chair: *Mehdi Khaki* (Australia)
JWG C.8: Methodology of comparing/validating/testing climate simulations to/with geodetic data (Joint with: ICCC, ICCT)
Chair: *Jürgen Kusche* (Germany)
JWG Q.1: Quantum gravimetry in space and on ground (Joint with: IAG Project QuGe)
Chair: *F. Pereira* (France)
JWG Q.2: Laser interferometry for gravity field missions (Joint with: IAG Project QuGe)
Chair: *M. Murböck* (Germany)
JWG Q.3: Relativistic geodesy with clocks (Joint with: IAG Project QuGe)
Chair: *G. Petit* (France)

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 by the Commission 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 Austin in September 2020 and in 2022 (location TBD). The other two symposia where a Commission 2 meeting will be held are the IAG Scientific Assembly 2021 in Beijing, China, and the IUGG General Assembly 2023 in Berlin, Germany.

The status of Commission 2, including its structure and membership, as well as 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/.

Steering Committee

President Commission 2: *Adrian Jäggi* (Switzerland)
Vice President Comm. 2: *Mirko Reguzzoni* (Italy)
Chair Sub-Comm. 2.1: *Derek van Westrum* (USA)
Chair Sub-Comm. 2.2: *George Vergos* (Greece)
Chair Sub-Comm. 2.3: *Frank Flechtner* (Germany)
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: *Riccardo Barzaghi* (Italy)
Representative of ICCT: *Pavel Novák* (Czech Republic)
Member-at-Large: *Laura Sanchez* (Germany)
Member-at-Large: *Min Zhong* (China)
Immediate Past President: *Roland Pail* (Germany)

The steering committee will meet at least once per year. These meetings are open for all interested IAG members.

Sub-Commissions, Working Groups and Study Groups

SC 2.1: Gravimetry and Gravity Network

Chair: *Derek van Westrum* (USA)
Vice-Chair: *Przemyslaw Dykowski* (Poland)

Terms of Reference

Geodesists and geophysicists utilize gravity and gravity gradient datasets from a wide variety of sources: local relative gravity campaigns, pointwise absolute gravity observations, gravity variation in time at fixed locations, and continental 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. IAG Sub-commission 2.1, "Land, Marine and Airborne Gravimetry" 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 and gravity gradient measurements.

Objectives

SC2.1 provides the scientific community with the means to assess the accuracy of absolute gravity observations through the organization of regular international absolute gravimeter comparisons. These efforts are in cooperation with the metrology community: the 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. The relationship allows for direct traceability of gravity data to international standards.

SC2.1 supports 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 Gravity Reference Frame.

SC2.1 supports 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.

To facilitate the exchange of all terrestrial gravity data and metadata, SC2.1 is actively supporting the creation of a unified file format in an open source environment.

Finally, SC2.1 promotes research and development into new instruments and techniques by stimulating communication and cooperation between scientific groups. The subcommission will encourage regional meetings and workshops dedicated to specific problems when and where appropriate.

Program of Activities

- Host the JWG2.1.1, "Establishment of an International Gravity Reference Frame", along with IGFS, BGI and IGETS
- Host the JWG 2.1.2 "Unified file formats and processing software for high-precision gravimetry," along with IGFS, BGI and IGETS
- Host the SG2.1.1 "Developments in near Earth gravimetry: instruments, analysis, and applications"
- Provide access to the results of comparisons of absolute gravimeters via the AGrav database at BKG-BGI
- Appoint the Steering Committee consisted of the members experienced in the fields of gravimetry related to the activities of SC2.1 and the contact persons for European, East Asia and Western Pacific, South America and North America Gravity Networks.

Support IAG Commission 2 Symposia such as GGHS.

SG 2.1.1: Developments in Gravity Instrumentation, Analysis, and Applications

Chair: *Derek van Westrum* (USA)
Vice-Chair: *Przemyslaw Dykowski* (Poland)

Terms of Reference

SG2.1.1 is focused on methods and instrumentation used in collecting and analyzing terrestrial (non-satellite) gravity and gravity gradiometry data. New developments in both "classic" and quantum absolute instruments, as well as novel relative instruments, are happening a rapid pace and are of great interest to the geodetic community. In addition, communication of such developments between the geodesy community and metrology community is essential.

SG2.1.1 also supports research in the analysis of gravity data. Examples include standard absolute corrections, barometric loading, reduction of relative gravity networks, software, and file formats.

SG2.1.1 also promotes innovations in the use of gravity and gravity gradient data. As examples, time varying gravity signals are being used to fine tune ice melt models, biological processes, and of course, geoid change.

Objectives

- Communication between research groups developing novel instruments and the community of gravity scientists
- Coordination of scientific efforts regarding mobile platforms.
- Promotion and coordination in the establishment and measurements of regional gravity networks.
- Organization of scientific workshops and meetings for the discussion of techniques and methods of terrestrial gravity measurements.

Members

Chair: *Derek van Westrum* (USA)
Vice Chair: *Przemyslaw Dykowski* (Poland)
Mirjam Bilker-Koivula (Finland)
Sylvain Bonvalot (France)
John Crowley (Canada)
Yoichi Fukuda (Japan)
Silvia Alicia Miranda (Argentina)
Ilya Oshchepkov (Russia)
Wu Shuqing (China)
Hartmut Wziontek (Germany)

JWG 2.1.1: Establishment of the International 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 "Gravity Field" is the establishment of the International Gravity Reference System and Frame (IGRF). These activities are motivated by the IAG Resolutions No. 2 of 2015 (IUGG General Assembly Prague) and No. 4 of 2019 (IUGG General Assembly Montreal). The IAG Sub-Commission 2.1 "Land, Marine and Airborne Gravimetry" 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. 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 Global Geodetic Observing System (GGOS).

Objectives

Within IAG Sub-Commission 2.1 "Land, Marine and Airborne Gravimetry" the realization of the International Gravity Reference Frame (IGRF) will be initiated. The IGRF is the implementation of the International Gravity Reference System (IGRS). The IGRS 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 IGRF as the realization of the IGRS is based on observations with absolute gravimeters (AG) which are monitored at reference stations and during comparisons. The IGRF further defines a set of conventional models for the correction of temporal gravity changes. Finally, the IGRF demands a compatible infrastructure accessible to end-users.

The JWG focuses on the establishment of such an 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 consistency of AGs within their reported uncertainty estimates, and core stations will link to space geodetic techniques and the International Height Reference Frame (IHRF).

The absolute gravity database "AGrav" which already is a fixed part of the BGI (International Gravimetric Bureau) services is proposed to serve as a central inventory to document all IGRF 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) ensures good practice in the field of AG comparisons.

The activities should be further aligned with the JWG on the Implementation of the International Height Reference Frame.

Members

Mirjam Bilker Koivula (Finland)
Przemyslaw Dykowski (Poland)
Andreas Engfeldt (Sweden)
Reinhard Falk (Germany)
Jaakko Mäkinen (Finland)
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Jonas Ågren (Sweden)
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Axel Rülke (Germany)
Laura Sanchez (Germany)
Roman Sermyagin (Russia)
Heping Sun (China)
V.M. Tiwari (India)

Objectives

- Review of existing software, data types, data formats and processing standards in high-precision gravimetry; develop requirements for a unified format and data processing software.
- Test of the compatibility of existing software

JWG 2.1.2: Unified file formats and processing software for high-precision gravimetry frame

(joint with IGFS, IGETS, BGI)

Chair: *Ilya Oshchepkov* (Russia)
Vice-Chair: *Vojtech Pálinkáš* (Czech Republic)

Terms of Reference

Absolute gravity measurements have become widely used in geodesy since the 1970s when several transportable absolute gravimeters were introduced, since then their number has increased dramatically and continues to do so. The absolute gravimeters are used not only in geodesy, but also in metrology, geophysics, hydrology and other applications. The IAG's Commission 2 “Gravity Field” and its JWG 2.1.1 are working on the establishment of the International Gravity Reference System/Frame (IGRS/IGRF), which will be based solely on the absolute gravity measurements. The latter task will require a possibility for re-processing of all historical, current and future data, as well as their long-term availability for all interested parties.

The current ability to exchange and to re-process raw data of absolute gravity measurements is limited by the fact that each manufacturer uses their own proprietary software and different data storage formats. Also differences in the implementation of processing standards may exist. In such a situation it is difficult to ensure reproducibility and traceability to the SI of an individual experiment. Another difficulty arises from the requirement for a re-processing of old measurements after the introduction of new processing standards, when neither data nor software are available anymore.

The JWG 2.1.2 aims to create a unified, meter and software independent, format for storing and sharing not only the processing results and metadata, but also the raw data of gravity measurements. Different software will be evaluated and discrepancies will be discovered and resolved. Perspectively, an open source software should be established to eliminate the above mentioned problems, as well as to implement a standard procedure for handling absolute gravity measurements for the IGRF. The activities need a close cooperation with the manufacturers of absolute gravimeters in order to align instrument specific data handling and a transparent processing and to implement a common exchange format.

- Develop a unified data storage format for high-precision gravity measurements: description, converter and software implementation.
- Develop a unified processing software to process any high-precision gravity measurements with a wide support for any processing procedure.

Members

Brian Ellis (USA)
Jacques Liard (Canada)
Jeffrey Kennedy (USA)
Jaakko Mäkinen (Finland)
Sergey Svitlov (Germany)
Pierre Vermeulen (France)
Marc Véronneau (Canada)
Hartmut Wziontek (Germany)
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Igor Sizikov (Russia)
Christian Ullrich (Austria)
Axel Rülke (Germany)
Domenico Iacovone (Italy)
Alessandro Germak (Italy)
Shuqing Wu (China)
Derek Van Vestrum (USA)
Mirjam Bilker-Koivula (Finland)
Przemyslaw Dykowski (Poland)

SC 2.2: Geoid, Physical Height Systems and Vertical Datum Unification

Chair: *George 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. 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 employed in order to properly model the high-frequency part of the gravity field spectrum. Such combination of heterogenous data has been deemed a mandatory in order to reduce the omission error as well as to properly model the contribution of topography.

Traditional levelling might also be integrated on a regional or local scale. Finally, 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.

The IAG SC 2.2 aims at bringing together scientists and geodesists 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. It includes topics (state of art methodologies for processing, analyzing, utilizing data, unifying datums, etc.), and 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 IAG Sub-Commission 2.2 (SC2.2) 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. This includes for instance:

- Realization of the International Height Reference System (support to the Joint Working Group with the GGOS Focus Area Unified Height System "Implementation of the International Height Reference Frame (IHRF)")
- 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 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 (support of ICCT SG:

Geoid/quasi-geoid modelling for realization of the geopotential height datum)
- Investigation of the error budget od potential determination and vertical reference frames unification (support to Commission 2 WG: Error assessment of the 1 cm geoid experiment)
- 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.

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.

JWG 2.2.1: Error assessment of the 1 cm geoid experiment

(joint with ISG, IGFS)

Chair: *Martin Willberg* (Germany)
Vice-Chair: *Tao Jiang* (China)

Terms of Reference

The realization of the International Height Reference System (IHRS) will be based on reference stations, which are calculated from a local combination of global gravity field models and regional gravity observations. This process, which is called regional geoid/gravity modeling is realized with different philosophies and theories inside the geodetic community. However, the final quality of the IHRS depends heavily on the consistency of all included modeling methods. Consequently, in the previous IAG period, within JWG 2.2.2 an effort was made to evaluate the differences in various regional geoid/gravity modeling approaches and standardize them to a specific degree.

Within 'the 1 cm geoid experiment' 15 participating groups have calculated a regional geoid/gravity model in the area of Colorado, US. Thereby, all groups used identical input data sets consisting of terrestrial and airborne gravity observations. After two iterations within 'the 1 cm geoid experiment', differences of a few centimeters remain between the final results of the contributing groups. Manifold reasons might be responsible for this difference, but major aspects are assumed to be differences in the procedure, the topographic reduction, and the individual data handling. Until now, the quality assessment of individual solutions was mainly analyzed by their variation from a joint mean value, which was interpreted as reference. However, the Colorado area contains a Geoid Slope Validation Survey (GSVS), where positions, gravity values and deflections of the vertical were measured with very high quality along a set of 223 benchmarks. These values and the results of the GSVS processing are not yet published, but will be open to the public soon, thereby providing an improved reference (for this JWG).

The objectives of this JWG are to validate the results, to identify and quantify potential error sources, and to develop and improve methods for deriving realistic error estimates of the gravity potential values at the IHRS stations. Once available, the differences of individual geoid/height anomaly results to the improved reference from the GSVS shall be analyzed. The most possible reasons for these differences should be worked out. Especially, a modified computation set-up shall be defined, which enables to separate method-related and data-driven error contributions. This will be important to quantify the error level caused by different regional gravity modelling methods. If possible, these errors

shall be further reduced within an additional iteration step. Furthermore, different methods should be examined for their ability to estimate an appropriate error budget for the final results. This is of great importance, as the assessment of the total error is needed for the reference stations in the IHRS. Lessons from this JWG should then be transferred to the JWG for 'Implementation of the International Height Reference Frame – IHRF'.

Program of Activities

- Analyze the difference of various solutions to the GSVS reference
- Quantify the main error contributors of regional geoid modeling
- Estimation of the total error budget
- Derive recommendations for the IHRS realization from the viewpoint of regional gravity field modeling
- Organize conference sessions
- Report activities

Members

Chair: *Martin Willberg* (Germany)
Vice-Chair: *Tao Jiang* (China)
Laura Sánchez (Germany)
Yan Ming Wang (USA)
Vassilios Grigoriadis (Greece)
Marc Véronneau (Canada)
Sten Claessens (Australia)
Qing Liu (Germany)
Rene Forsberg (Denmark)
Hussein Abd-Emotaal (Egypt)
Koji Matsuo (Japan)
Bihter Erol (Turkey)
Jonas Ågren (Sweden)
Kevin Ahlgren (USA)
Matej Varga (Czech/Croatia)
Riccardo Barzaghi (Italy)
Representative person USP (Brazil)

SC 2.3: Satellite Gravity Missions

Chair: Frank Flechtner (Germany)
Vice-Chair: Matthias Weigelt (Germany)

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 by space-borne observation techniques. These missions are the only measurement systems which can directly observe mass distribution and mass transport in the Earth system based on proven new concepts and technologies, such as high-low satellite-to-satellite tracking (SST) using the GPS constellation, low-low SST based on micro-wave and laser ranging, and satellite gravity gradiometry (SGG), as well as space-borne accelerometry.

GRACE has produced 15+ years consistent long- to medium-wavelength global gravity field models and its temporal changes till June 2017 which are extended since May 2018 by GRACE-FO data. GOCE provided high- accuracy and high-resolution static gravity field models. In combination with complementary gravity field information from terrestrial data and satellite altimetry, an even higher spatial resolution can be achieved. Consequently, these satellite missions provide valuable contributions to many geoscientific application fields, such as geodesy, hydrology, oceanography, glaciology, and solid Earth physics.

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, 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, ...) as well as relevant IAG organizations such as the GGOS

Committee on Satellite and Space Missions and the GGOS Bureau of Products and Standards,
- 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. Also it will promote and jointly sponsor special sessions at IAG Symposia and other workshop/conferences.

SC 2.4: Regional Geoid Determination

Chair: *Hussein Abd-Elmotaal* (Egypt)
Vice-Chair: *Xiaopeng Li* (USA)

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.

Steering Committee

Chair SC2.4: *Hussein Abd-Elmotaal* (Egypt)
Chair SC2.4a: *Heiner Denker* (Germany)
Chair SC2.4b: *Maria Cristina Pacino* (Argentina)
Chair SC2.4c: *Xiaopeng Li* (U.S.)
Chair SC2.4d: *Hussein Abd-Elmotaal* (Egypt)
Chair SC2.4e: *Cheinway Hwang* (China-Taipei)
Chair SC2.4f: *Mirko Scheinert* (Germany)

SC 2.4a: Gravity and Geoid in Europe

Chair: *Heiner Denker* (Germany)

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.

Delegates

The regional sub-commission for Europe SC2.4a cooperates with national representatives from most of the countries in Europe and reports to sub-commission 2.4. The existing contacts and successful cooperation with the respective persons and national and international agencies shall be continued and extended.

SC 2.4b: Gravity and Geoid in South America

Chair: *Maria Cristina Pacino* (Argentina)
Vice-Chair: *Gabriel do Nascimento Guimarães* (Brazil)

Terms of Reference and Objectives

The Sub Commission 2.4b entitled Gravity and Geoid in South America, as part of the Commission 2 of IAG, 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.

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.

Delegates

Chair: *Maria Cristina Pacino* (Argentina)
Co-Chair: *Gabriel do Nascimento Guimarães* (Brazil)
Henry Montecino Castro (Chile)
Oscar Carranco (Ecuador)
Ana Crisitina Oliveira Concoro de Matos (Brasil)
Ayelén Pereira (Argentina)
Roberto Teixeira Luz (Brasil)
Silvia Alicia Miranda (Argentina)
Ivonne Gatica Placencia (Chile)
Norbertino Suárez (Uruguay)
Jorge Faure Valbi (Uruguay)

SC 2.4c: Gravity and Geoid in North and Central America

Chair: *Xiaopeng Li* (USA)
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 2022 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 prepared-ness applications. Likewise, it shall serve as the basis for the forthcoming International Great Lakes Datum in 2022 (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 Sub-commission will support geoid activities in countries where geoid expertise is limited by encouraging more advanced members to contribute their own expertise and software. The Sub-commission will encourage training and education initiative of its delegates (e.g., ISG geoid school, graduate studies and IPGH technical cooperation projects). Starting on 2011 the Sub-commission 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 the Sub-commission 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 Sub-commission 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 on November 9, 2015, Canada (CGS), USA (NGS) and Mexico (INEGI) will organize 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 Sub-commission.

Delegates

Chair: *Xiaopeng Li* (USA)
Vice-Chair: *David Avalos* (Mexico)
Rene Forsberg (Denmark)
Jianliang Huang (Canada)
Dan Roman (USA)
Laramie Potts (USA)
Yan Min Wang (USA)
Vinicio Robles (Guatemala)
Carlos E. Figueroa (El Salvador)
Anthony Watts (Cayman Islands)
Oscar Meza (Honduras)
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: *S.A. Benahmed Daho* (Algeria)

Terms of Reference

The African Gravity and Geoid sub-commission (AGG) belongs to the Commission 2 of the International Association of Geodesy (IAG). 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 and 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).

Delegates

Chair: *Hussein Abd-Elmotaal* (Egypt)
Vice-Chair: *S.A. Benahmed Daho* (Algeria)
Addisu Hunegnaw (Ethiopia)
Ahmed Abdalla (Sudan)
Atef Makhloof (Egypt)
Ayman Hassan (Egypt)
Bernhard Heck (Germany)
Charles Merry (South Africa)
Hassan Fashir (Sudan)
Ismail Ateya Lukandu (Kenya)
John B.K. Kiema (Kenya)
Joseph Awange (Kenya)
Joseph Kamguia (Cameroun)
Karim Owolabi (Namibia)
Kurt Seitz (Germany)
Mostafa Abd-Elbaky (Egypt)
Mostafa Ashry (Egypt)
Norbert Kühtreiber (Austria)
Patroba Odera (Kenya)
Peter Nsombo (Zambia)
Prosper Ulotu (Tanzania)
Walyeldeen Godah (Sudan)

SC 2.4e: Gravity and Geoid in the Asia-Pacific

Chair: *Cheinway Hwang* (China-Taipei)
Vice-Chair: *Wenbin Shen* (China)

Context

There are about 48 counties in the Asia-Pacific (AP) region. Many countries in the region have invested considerable resources on improved geoid models. Recent progress in satellite altimetry greatly increases coastal marine gravity accuracy. Satellite remote sensing data have been used to generate digital elevation models that are needed for geoid modeling. Many countries now increase their GNSS/leveling observation campaigns to collect data to assess and to control the qualities of gravimetric quasi/geoid models. All such datasets allow to improve geoid models in the Asia Pacific region.

Terms of Reference and Objectives

This sub-commission is a continuation of the previous sub-commission and will continue to promote gravity data collection, geoid processing and evaluating techniques, and geoid applications in the Asia-Pacific region. In particular, coastal marine gravity will be improved by recent altimetry data. We will organize workshops to exchange data and techniques of geoid modeling and assessing.

Program of Activities

a) Gravity and Related Data
- share available gravity data
- share available DEMs along common borders
- combine resources for terrestrial gravity surveys along common borders
- promote regional airborne gravity surveys
- determine improved coastal gravity anomalies from satellite altimetry

b) Gravimetric geoid and hybrid geoid quality control
- share GNSS/levelling and vertical deflection data for geoid quality control
- promote regional GNSS/leveling and vertical deflection campaigns
- connect regional vertical datums

c) Education & Research
- organize meetings and workshops to improve modeling and evaluation techniques of gravimetric quasi/geoids, and to promote their application to height modernization and vertical datum connection.
- propose technical sessions in scientific and professional conferences
- propose matters of common concern/interest

Delegates

Chair: Cheinway Hwang (China-Taipei)
Vice-Chair: *Wenbin Shen* (China)
Jay Hyoun Kwon (Korea)
Will Featherstone (Australia)
Koji Matsuo (Japan)
Ami Hassan Md Din (Malaysia)
Chalermchon Satirapod (Thailand)
Kosashi Prijatna (Indonesia)
Dinh Toan Vu (Vietnam)
Ronaldo Gatchalian (Philippines)
Ropesh Goyal (India)
Matt Amos (New Zealand, corresponding member only)

SC 2.4f: Gravity and Geoid in Antarctica

Chair: *Mirko Scheinert* (Germany)
Vice-Chair: *Fausto Ferraccioli* (UK)

Terms of Reference

Antarctica is the region that still features the largest data gaps in terrestrial gravity. Global gravity field solutions suffer from the lack of terrestrial data in Antarctica as well as from the polar data gap originating from the orbit inclination of dedicated satellite gravity field missions (esp. GOCE with a polar data gap of 1,400 km diameter).

The coverage with terrestrial (ground-based and airborne) gravity data in Antarctica has been improved during the last years. Efforts were successfully accomplished to publish a first Antarctic-wide gravity anomaly grid (Scheinert et al. 2016) and to record data over the polar data gap (Forsberg et al. 2017). However, the gravity data coverage in Antarctica is still insufficient. The data are heterogeneous and exhibit inconsistencies. Due to the vast extension of the Antarctic continent, its hostile environment and the difficult logistic conditions it is a long-lasting task to close the Antarctic data gaps in terrestrial gravity.

SC 2.4f shall pursue this objective and shall facilitate the necessary coordination to release an updated grid of terrestrial gravity data for Antarctica. Terrestrial gravity data are needed for the global high-resolution determination of the Earth's gravity field and/or for a validation of global gravity field models, for a regional improvement of the Antarctic geoid and for geophysical inversion to improve our knowledge on the subglacial topography and inner structure of the Earth.

Thus, SC 2.4f plays an important role to improve the cooperation between all interested scientists of geodesy and of neighbouring disciplines, mainly geophysics.

Program of Activities

- Promoting the collection of surface and airborne gravity data in Antarctica;
- Promoting new gravity surveys in Antarctica, especially airborne gravimetry;
- Promoting the establishment and (re-)measurement of reference gravity stations utilizing absolute gravity meters;
- Promoting the scientific exchange of latest developments in technology (esp. airborne gravimetry) and data analysis;
- Evaluation of existing and new surface and airborne gravity data, validation of global gravity field models in Antarctica;
- Investigation of optimum strategy for the combination of gravity data of different sources;
- Release of updated gridded gravity anomaly dataset(s) for Antarctica to the scientific public;
- Organization of special workshop on airborne geodesy and geophysics (especially aerogravimetry) with focus on Antarctica;
- Focus group for all scientists interested in Antarctic gravity and geoid, and cooperation with similar data initiatives, especially within the Scientific Committee on Antarctic Research (SCAR);

Delegates

Chair: *Mirko Scheinert* (Germany)
Don Blankenship (USA)
Alessandro Capra (Italy)
Fausto Ferraccioli (UK)
Christoph Förste (Germany)
René Forsberg (Denmark)
Larry Hothem (USA)
Graeme Eagles (Germany)
German L. Leitchenkov (Russia)
Jaakko Mäkinen (Finland)
Yves Rogister (France)
Koichiro Doi (Japan)
Michael Studinger (USA)

Corresponding Members
Matt Amos (New Zealand)

SG 2.4.1: Downward Continuation of Airborne Gravity Data for Local Geoid Improvement

Chair: *Xiaopeng Li* (USA)
Vice-Chair: *Jianliang Huang* (Canada)

Terms of Reference

Many countries have used or will use pure gravimetric geoid/quasi-geoid models as their height datum. This requires high accurate and high resolution local gravity data coverage. Airborne gravimetry is widely used for this purpose because of its efficiency both in terms of time and cost. One important step of using airborne gravity data in local geoid modeling is to downward continue the airborne gravity data from flight altitudes to the (quasi)geoid computation level.

The topic of downward continuation (DWC) has been studied for many decades without very conclusive answers on how different methods compare with each other. Often a

time, geoid modelers just pick one approach and use it without thorough comparisons. On the other hand, there are vast amounts of airborne gravity data collected by the GRAV-D project at NGS NOAA of the United States and by many other groups around the world. These airborne gravity data are collected on flight lines where the height of the aircraft actually varies significantly, and this causes challenges for users of the data. A downward continued gravity grid either on the topography or on the geoid is still needed for many applications such as improving the resolution of a local geoid model. Several classical and new downward continuation methods, such as, Least Squares Collocation and Residual Least Squares Collocation (RLSC), the Inverse Poisson Integral, Truncated Spherical Harmonic Analysis, and Radial Basis Functions (RBF), are tested on both simulated data sets and real GRAV-D airborne gravity data. Comprehensive theoretical and numerical comparisons are required to provide useful guidelines for correctly handling airborne gravity in local geoid computation.

Objectives

The main objectives of this SG are to:

- Review the theories of the downward continuation of airborne gravity data.
- Provide an official forum for in-depth discussion of very approaches.
- Develop efficient software to perform all considered approaches.
- Conduct in-depth analysis of the downward continuation results.
- Identify main problems and give recommendations.
- Publish downward continued airborne gravity grid and tool boxes.

Program of Activities

- Circulating and sharing information, ideas, progress reports, papers and presentations.
- To launch a proposal for state-of-the-art cooperation on the topic of downward continuation.
- Development/improvement of downward continuation tools.
- Presenting research findings at major international geodetic or geophysical conferences, meetings, and workshops.
- Focus on error assessment of results produced by various methods.
- To open a web page to published downward continued airborne gravity grid products and related software tool boxes.

Members

Chair: *Xiapeng Li* (USA)
Vice Chair: *Jianliang Huang* (Canada)
René Forsberg (Denmark)
Cheinway Hwang (Taiwan)
Roland Klees (Netherlands)
Cornelis Slobbe (Netherlands)
Martin Willberg (Germany)

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 CryoSat-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 that 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 this IAG sub-commission 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

Sub-Commission 2.5 will:

- Establish a close link between this sub-commission and 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; and
- 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.

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; and
- 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.

SC 2.6: Gravity Inversion and Mass Transport in the Earth System

Chair: *Wei Feng* (China)
Vice-Chair: *Roelof Rietbroek* (Germany)

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 sub-systems 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 sub-commission will establish Work Groups (WGs) 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.

WG 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, 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

Chair: *Wenbin Shen* (China)
Vice-Chair: *Cheinway Hwang* (China-Taipei)
Carla Braitenberg (Italy)
Benjamin Fong Chao (China-Taipei)
Tonie van Dam (Luxembourg)
Xiaoli Deng (Australia)
Hao Ding (China)
Xiaoli Ding (Hong Kong, China)
Jeffrey T. Freymueller (USA)
Yuanjin Pan (China)
Jim Ray (USA)
Mirko Reguzzoni (Italy)
Lorenzo Rossi (Italy)
Xiaodong Song (USA)
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Robert Tenzer (Hong Kong, China)
Leonid Zotov (Russia)