Commission 3 – Earth Rotation and Geodynamics

President: **Janusz Bogusz** (Poland)
Vice President: **Cheng-Li Huang** (China)

https://com3.iag-aig.org/

Terms of Reference

The Earth must be considered as a dynamic system through the study of the global gravity field and its temporal variations, and the global and local deformation at the surface in order to define the Earth's internal structure and dynamics. Consequently, geodynamics is the science that studies how the Earth moves and deforms in response to forces acting on the Earth, whether they derive from outside or inside of our planet. This includes the entire range of phenomena associated with Earth rotation and Earth orientation in space such as polar motion, Universal Time (UT) or Length Of Day (LOD), precession and nutation, the observation and understanding of which are critical to the transformation between terrestrial and celestial reference frames. On the other hand, space and terrestrial geodetic techniques provide key observations to investigate a broad range of geophysical processes, thanks to their high accuracy, precision, and reliable georeferencing.

The modern geodesy successfully supports research and data analysis devoted to variations in Earth rotation, gravitational field and geocenter, caused by mass redistribution within and mass exchange among the Earth's fluid sub-systems, i.e., the atmosphere, ocean, continental hydrosphere, cryosphere, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle. It also includes tidal processes such as solid Earth and ocean loading tides, and crust and mantle deformation associated with tectonic motions and isostatic adjustment etc.

Geodesy is an important tool for exploring the geometry and temporal evolution of magma plumbing systems, as well as for monitoring and hazards assessment during volcanic unrest and eruption. Angular momenta and the related torques, gravitational field coefficients, and geocenter shifts for all geophysical fluids are the relevant quantities. They are observed using global-scale measurements and are studied theoretically as well as by applying state-of-the-art models; some of these models are already constrained by such geodetic measurements.

During the last few decades many geophysicists have come to use geodynamics in a more restricted sense to address processes such as plate tectonics and Post Glacial Rebound (PGR) that are dominantly endogenic in nature. Because the Earth as a mechanical system responds to both endogenic and exogenic forces, and because these responses are sometimes coupled, Commission 3 studies the entire range of physical processes associated with the motion and the deformation of the solid Earth.

Present-day ice mass changes induce an immediate elastic deformation of the Earth, while the integrated history of mass changes induces an additional viscoelastic deformation. Traditionally, these have been considered separately, which is a good approximation for long-ago load changes and regions of high mantle viscosity. The present-day and recent past load changes must be modeled together as the rapid viscoelastic relaxation is substantial and not easily separated from the immediate elastic changes.

Reference frames of GIA models are likely computed in the center of mass of the solid Earth frame, while the International Terrestrial Reference Frame (ITRF) is defined with origin at the center of mass of Earth system (including all fluids). This means a frame origin transformation is required to allow direct comparison to measurements in ITRF and ambiguity currently exists over the exact transformation between the two.

Among their many applications, geodetic measurements can now contribute to the study of the different phases of the seismic cycle, as they allow recording static and dynamic displacements during large earthquakes, as well as the slow postseismic and interseismic deformation contributing significantly to the process of monitoring natural hazards and risks. The purpose of Commission 3 is to promote, disseminate, and, where appropriate, to help coordinate research in this broad arena.

Sub-Commission 3.1 (Earth Tides and Geodynamics) addresses direct and indirect tidal phenomena that affect the position of fiducial sites and have to be corrected to provide accurate spatial referencing. Such referencing is needed for the observation and monitoring of changes of the Earth's surface at global, regional and local scales. Therefore, there is a considerable contribution of tidal research to global geodynamics and climate change by providing important constraints to geophysical models.

Sub-Commission 3.2 (Volcano Geodesy) addresses explosion in the quality and quantity of volcano geodetic data, which has created a need for new approaches to data analysis, interpretation, and modeling required for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano monitoring results.

Sub-Commission 3.3 (Earth Rotation and Geophysical Fluids) addresses the space-time variation of atmospheric pressure, seafloor pressure and the surface loads associated with the hydrological cycle, and Earth's (mainly elastic) responses to these mass redistributions.

Sub-Commission 3.4 (Cryospheric Deformation) addresses past and present changes in the mass balance of the Earth's glaciers and ice complexes which both induce present-day deformation of the solid Earth on a range of spatial scales, from the very local to global.

Sub-Commission 3.5 (Seismogeodesy) addresses studying the plate boundary deformation zones and integration of geodetic and seismological monitoring of seismically active areas by increasing and/or developing infrastructures dedicated to broadband observations from the seismic wave band to the permanent displacement.

Commission 3 interacts with Global Geodetic Observing System (GGOS), other Commissions and Services of the IAG as well as with other organizations such as the International Astronomical Union (IAU), International Association of Seismology and Physics of the Earth's Interior (IASPEI), International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) and International Association of Cryospheric Sciences (IACS).

Objectives

- To promote cooperation and collaboration on the theory, modelling and observation of Earth rotation and geodynamics.
- To ensure development of research in Earth rotation and geodynamics by organizing meetings, symposia, and sessions at conferences and general assemblies, by creating working groups on specific topics, and by encouraging the exchange of ideas and data and the comparison of methods and results with the goal of improving accuracy, content, methods, theories, and understanding of Earth rotation and geodynamics.
- To serve the geophysical community by facilitating interactions with organizations that provide the data needed to study Earth rotation and geodynamics.

Structure

Sub-Commissions

SC 3.1: Earth Tides and Geodynamics
Chair: *Carla Braitenberg* (Italy)

SC 3.2: Volcano Geodesy (joint with IAVCEI)
Chair: *Emily Montgomery-Brown* (USA)

SC 3.3: Earth Rotation and Geophysical Fluids
Chair: *Jianli Chen* (USA)

SC 3.4: Cryospheric Deformation
Chair: *Jeff Freymueller* (USA)

SC 3.5: Seismogeodesy
Chair: *Jean-Mathieu Nocquet* (France).

Joint Study Group

JSG 3.1: Geodetic, Seismic and Geodynamic Constraints on Glacial Isostatic Adjustment (joint with IASPEI and IAG Commissions 1 and 2)
Chair: *Rebekka Steffen* (Sweden)

Joint Working Groups

JWG 3.1: Improving Theories and Models of the Earth's Rotation (joint with IAU)
Chair: *José Ferrándiz* (Spain)

JWG 3.2: Global combined GNSS velocity field (joint with IAG Commissions 1 and 2)
Chair: *Alvaro Santamaría-Gómez* (France)

Program of Activities

Commission 3 fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing symposia, either independently or at major conferences in geodesy or geophysics. Some events will be focused narrowly on the interests of the Sub-Commissions and other entities listed above, and others will have a broader commission-wide focus.

Steering Committee

President Commission 3: *Janusz Bogusz* (Poland)
Vice President Comm. 3: *Chengli Huang* (China)
Chair Sub-Comm. 3.1: *Carla Braitenberg* (Italy)
Chair Sub-Comm. 3.2: *Emily Montgomery-Brown* (USA)
Chair Sub-Comm. 3.3: *Jianli Chen* (USA)
Chair Sub-Comm. 3.4: *Jeff Freymueller* (USA)
Chair Sub-Comm. 3.5: *Jean-Mathieu Nocquet* (France)

Representative of IERS: *Robert Heinkelmann* (Germany)
Representative of IGFS: *Nico Sneeuw* (Germany)
Representative of IGETS: *Hartmut Wziontek* (Germany)
Member-at-Large: *Matt King* (Australia)
Member-at-Large: *Laura Fernández* (Argentina)

Sub-Commissions

SC 3.1: Earth Tides and Geodynamics

Chair: *Carla Braitenberg* (Italy)
Vice-Chair: *Séverine Rosat* (France)

Terms of Reference

SC 3.1 addresses the entire range of Earth tidal phenomena and dynamics of the Earth, both on the theoretical as well as on the observational level. The Earth tide affects many types of high precision instrumentation, be it measurements of position, deformation, potential field or acceleration. The tidal phenomena influence both terrestrial and satellite-borne acquisitions. The tidal potential is a driving force that can be accurately calculated, and the tidal response observable as deformation and variations in Earth orientation and rotation parameters gives information on Earth's rheology.

Instruments sensitive enough to detect the tidal signal, record a large range of periodic and aperiodic phenomena as ocean and atmospheric tidal loading, ocean, atmospheric and hydrospheric non-tidal effects, deformation related to the earthquake cycle and even to gravitational waves, as well as plate tectonics and intraplate deformation.

The periods range from seismic normal modes over to the Earth tides and the Chandler Wobble and beyond, ending at the nutation period. Thus, the time scales range from seconds to years and for the spatial scales from local to continental dimensions. As tidal friction is affecting Earth rotation, all the physical properties of the Earth contribute to the explanation of this phenomenon. Therefore, the research on tidal deformation due to changes of the tidal potential as well as ocean and atmospheric loading are a prerequisite to constrain Earth's rheological properties.

Further, direct and indirect tidal phenomena affect the position of fiducial sites and have to be corrected to provide accurate spatial referencing. Such referencing is needed for the observation and monitoring of changes of the Earth's surface at global, regional and local scales. Therefore, there is a considerable contribution of tidal research to global geodynamics and climate change by providing important constraints to geophysical models.

Modern instrumental developments for which tidal phenomena are relevant are gravimeters and gradiometers based on superconductivity (SG), atom interferometry, micro-electromechanical-system (MEMS) gravimeters, Inertial Measurement Units, gravitational wave antennas, satellite gravimetry and atomic clocks. The improvements in gravimetric instrumentation leads to the use of gravimetry as a tool to detect underground mass changes, as naturally occurring hydrologic draughts or fluids injected into the underground for the purpose of temporary storage or for other purposes.

The Earth must be studied as a dynamic system through the study of the global gravity field and its temporal variations, and the global and local deformation at the surface in order to define the Earth's internal structure and dynamics. In the next few years, instrumental developments in portable absolute gravimeters can be expected, and further innovations can be envisaged from the ring laser technology.

The SC 3.1 will follow the instrumental developments and infer innovative applications. These geophysical observations together with other geodetic observations and geological information provide the means to better understand the structure, dynamics and evolution of the Earth system.

The existence of a network of superconducting gravimeters allows continuous monitoring of the gravity signal at selected stations with a precision of better than 10^{-10}. The range of applications of SGs has become very wide and applicable not only to Earth tides investigations, but also to support studies on Earth's seismic cycle and hydrological mass estimates. The SG network has had scientifically close relation to the SC 3.1 and IGETS (International Geodynamics and Earth Tide Service), which distributes the data. Therefore, the Chair of SC 3.1 is responsible for the close cooperation with the IGETS to provide effective service-with science coupling.

Objectives

Objectives of SC 3.1 include:

- to study and implement new observational techniques and improve existing ones, including clinometric and extensometric techniques;
- to demonstrate the importance of long term geodetic stations;
- to predict the signals observable with space geodetic techniques based on high precision terrestrial long term time series;
- to advance tidal data analyses and prediction methods;
- to enhance the models on the interaction among solid Earth, ocean, and atmospheric tides;
- to research the effects of the atmosphere and hydrology on gravity and other geodetic observations;
- to study the response of the Earth at tidal and non-tidal forcing frequencies;
- to study the interplay between tides and Earth rotation;

- to study tides on the planets;
- to study the effects of ocean loading and global water distribution;
- to establish and coordinate working groups on specific topics of interest and relevancy to the understanding of our planet;
- to develop, coordinate and promote international conferences, programs and workshops on data acquisition, analysis and interpretation related to the research fields mentioned above;
- to contribute to the definition and realization of the International Terrestrial Reference Frame via advanced geodynamic models at global, regional and local scales;
- to promote the systematic calibration and intercomparison of absolute and relative gravimeters (superconducting, MEMS as well as traditional spring instruments) ;
- to promote interdisciplinary research in Earth and planetary tides;
- to support the IAG Global Geodetic Observing System (GGOS) in the field of:
    - the integral effect on Earth rotation of all angular momentum exchanges inside the Earth, between land, ice, hydrosphere and atmosphere, and between the Earth, Sun, Moon, and planets,
    - the geometric shape of the Earth's surface (solid Earth, ice and oceans), globally or regionally, and its temporal variations, whether they are horizontal or vertical, secular, periodical or sudden,
    - the Earth's gravity field-stationary and time variable mass balance, fluxes and circulation.

Program of Activities

- Organization of International Symposium on Geodynamics and Earth Tide (GET Symposium held every four years) as well as other thematic conferences together with other Commission 3 SCs if possible.
- Awarding of the outstanding scientists with the Paul Melchior Medal, formerly known as the Earth Tides Commission Medal.
- Organization of special sessions at international meetings.
- Organization of the comprehensive SC meeting together with the IGETS.
- Publishing the outcome of the researches, either as stand-alone publications or as proceedings or special issues of scientific journals.
- Cooperating with other Joint Study Groups (JSG), Joint Working Groups (JWG) or Inter-Commission Projects (ICP) and Committees (ICC).
- Cooperate with GGOS, as mentioned above.

SC 3.2: Volcano Geodesy (joint with IAVCEI)

Chair: *Emily Montgomery-Brown* (USA)
Vice-Chair: *Alessandro Bonforte* (Italy)

Terms of Reference

Geodesy is an important tool for exploring the geometry and temporal evolution of magma plumbing systems, as well as for monitoring and hazards assessment during volcanic unrest and eruption. Geodetic techniques include measurements of both deformation (to determine the magnitude, location, and geometry of subsurface sources of pressure change) and gravity (to assess subsurface mass variations).

Recent decades have seen an explosion in the quality and quantity of volcano geodetic data, which has created a need for new approaches to data analysis, interpretation, and modeling. In addition, geodetic data can have different temporal and spatial resolutions, as well as different origins (ground-, air-, and space-based), and they are best utilized in conjunction with other non-geodetic datasets, like seismicity and gas emissions. New tools are therefore needed for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano monitoring results. This is especially relevant now given the expansion in GEO's Geohazard Supersites and Natural Laboratories initiative to volcanic sites around the globe.

We feel that an IAVCEI (International Association on Volcanology and Chemistry of the Earth's Interior) Commission on Volcano Geodesy is needed to organize the diverse community and promote a better understanding of magmatic processes through geodesy.

Objectives

Objectives of SC 3.2 include:

- foster communication within the volcano geodesy community, particularly between senior and early-career researchers, between scientists from different countries, and between volcano observatories;
- facilitate a coordinated geodetic response to volcanic unrest and eruptions around the world, including the acquisition of, and access to, satellite data;
- ensure high-level geodetic capability at the world's volcanoes through the sharing of best practices; development, testing, and distribution of open-source analysis and modeling tools; standardization of techniques for the measurement and interpretation of geodetic changes; exploitation of new technologies; and capacity-building activities;

- support the establishment and maintenance of databases for volcano geodetic observations, as well as the interoperability between these and other sources of geological, geochemical, and geophysical data related to volcanoes;
- promote volcano geodesy as a tool with broad implications and diverse applications in research, monitoring, and crisis response by serving as a bridge between geodesy and other branches of volcanology; connecting geodesists within the academic community, volcano observatories, space agencies, industry, government institutions, and other organizations; and advocating for the commitment of appropriate resources;
- encourage and enable collaborations between geodesy and other disciplines, given that interdisciplinary approaches to volcano research and hazards assessment offer the best prospects for improving overall understanding of volcanic processes and their impacts;
- implementation and dissemination of new standard approaches, protocols and best practices;
- promotion of common initiatives and projects with other IAG and IAVCEI entities.

Program of Activities

- Organize a scientific conference to define big scientific questions that could be addressed with Volcano Geodesy.
- Organize a scientific workshop with the goals of training early career volcano geodesists, sharing current research, and comparing codes on a standardized synthetic data set.
- Set up and use of social networks for advertising the activities and news and encourage people to use it widely.

SC 3.3: Earth Rotation and Geophysical Fluids

Chair: *Jianli Chen* (USA)
Vice-Chair: *Michael Schindelegger* (Germany)

Terms of Reference

Mass transport in the atmosphere-hydrosphere-mantle-core system, or the "global geophysical fluids", causes observable geodynamic effects on broad time scales. Although relatively small, these global geodynamic effects have been measured by space geodetic techniques to increasing, unprecedented accuracy, opening up important new avenues of research that will lead to a better understanding of global mass transport processes and of the Earth's dynamic response. Angular momenta and the related torques, gravitational field coefficients, and geocenter shifts for all geophysical fluids are the relevant quantities. They are observed using global-scale measurements and are studied theoretically as well as by applying state-of-the-art models; some of these models are already constrained by such geodetic measurements.

Objectives

The objective of the SC3.3 is to serve the scientific community by supporting research and data analysis devoted to variations in Earth rotation, gravitational field and geocenter, caused by mass redistribution within and mass exchange among the Earth's fluid sub-systems, i.e., the atmosphere, ocean, continental hydrosphere, cryosphere, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle. The SC complements and promotes the objectives of GGOS with its central theme "Global deformation and mass exchange processes in the Earth system" and the following areas of activities:

- quantification of angular momentum exchange and mass transfer;
- deformation due to mass transfer between solid Earth, atmosphere, and hydrosphere including ice.

Program of Activities

- To promote the exchange of ideas and results as well as of analysis and modeling strategies, sessions at international conferences and topical workshops will be organized.
- In addition, SC 3.3 interacts with the sister organizations and services, particularly with the IERS Global Geophysical Fluids Centre and its operational component with four Special Bureaus (atmosphere, hydrology, ocean, combination) and its nonoperational component for core, mantle, and tides.
- SC 3.3 will have close contacts to the GGOS activities, in particular to the activities of the newly established GGOS Committee "Contributions to Earth System Modelling".

SC 3.4: Cryospheric Deformation (joint with IACS)

IAG co-Chair: *Jeff Freymueller* (USA)
IACS co-chair: *Bert Wouters* (Netherlands)
Vice-Chair: *Natalya Gomez* (Canada)

Terms of Reference

Past and present changes in the mass balance of the Earth's glaciers and ice complexes induce present-day deformation of the solid Earth on a range of spatial scales, from the very local to global. Geodetic observations that validate, or may be assimilated into, models of glacial isostatic adjustment (GIA) and/or constrain models of changes in present-day ice masses through measurements of elastic rebound are of paramount importance, as are "paleo-geodetic" observations like the history of relative sea level.

Present-day ice mass changes induce an immediate elastic deformation of the Earth, while the integrated history of mass changes induces an additional viscoelastic deformation. Traditionally, these have been considered separately, which is a good approximation for long-ago load changes and regions of high mantle viscosity. In regions of low mantle viscosity (e.g. West Antarctica and Iceland), the present-day and recent past load changes must be modeled together as the rapid viscoelastic relaxation is substantial and not easily separated from the immediate elastic changes. In all cases, present-day geometric measurements (e.g., uplift rates) measure the sum of elastic and viscoelastic deformations, and these components cannot be separated without additional models or observations.

Present-day gravity changes have a different sensitivity to the elastic and viscoelastic components. In addition, it is now clear that 1-D Earth models are no longer sufficient for many problems, but 3-D models pose computational challenges, and careful inter-comparison of 3-D models is required to better understand model differences.

Reference frames of GIA models are likely computed in the center of mass of the solid Earth frame, while the International Terrestrial Reference Frame (ITRF) is defined with origin at the center of mass of Earth system (including all fluids). This means a frame origin transformation is required to allow direct comparison to measurements in ITRF and ambiguity currently exists over the exact transformation between the two.

This SC has a long history as part of IAG. At the Montreal IUGG, it was decided to make this a joint sub-commission with IACS. Within IAG, SC3.4 historically has focused on resolving technical measurement issues. With the new cross-Association sub-commission, we will have a better opportunity to enhance collaboration and dissemination of these measurements within the glaciological community.

Objectives

Objectives of SC 3.4 include:

- improvement of ice loading/unloading histories;
- improvement of Earth rheological models;
- assessment of elastic loading and viscoelastic GIA models using present day geodetic data of all types, or paleo-sea level data;
- assessing the impact of cryospheric deformation on geodetic reference frames and estimates of plate motions, and the differences between the frames of GIA models and the ITRF;
- assessing impact of lateral variations in Earth rheology on interpretations of geodetic and geological data.

Program of activities

- Organize a workshop focused on observation and modeling of cryospheric changes and GIA. There is an opportunity to organize what would likely be a 2-day workshop in conjunction with an upcoming WCRP Grand Challenge workshop, planned for November 2020 in Victoria BC, Canada. In terms of workshops, we will seek partners to enhance cross-disciplinary aspects of the workshops, and have begun discussions with the WRCP/CLIVAR program, the PALSEA program, and JSG 3.1: Geodetic, Seismic and Geodynamic Constraints on Glacial Isostatic Adjustment (*Rebekka Steffen*, Chair). We have approached IRIS about using their Earth Model Collaboration effort for the dissemination and inter-comparison of 3-D viscosity models, and they are eager to include these important Earth models.
- Organize a second workshop in 2022, possibly jointly with the PALSEA community on a topic such as GIA and past and present changes in sea level, geomorphology and landscape evolution. We have begun discussions with PALSEA on this, although their future activities will depend on a funding renewal.
- Organize a working group to analyze frame differences (especially frame origin) between GIA models and ITRF. It should be possible to transform global GIA model predictions into any reference frame, including Center of mass of Earth System and Center of Figure. We should encourage future modeling efforts to compute the needed frame transformations.
- Develop an online archive of 1D and 3D Earth rheological models to enhance dissemination and inter-comparison of these models. The IRIS Earth Models Collaboration (http://ds.iris.edu/ds/products/emc/) offers a promising suite of tools and archive capability, and they are eager to work with us. The IRIS EMC includes open-source software tools for dealing with their model format, and we will try to encourage development of tools to compare and use these viscosity models, and to transform seismic velocity models into effective viscosity models.
- Organize an effort to benchmark 3D GIA modeling approaches, similar to the benchmarking exercise done a few years ago for 1D codes.
- Encourage the completion of ongoing Activities from 2015-2019 that were approaching completion as of the last report (*Shfaqat Abbas Khan* and *Matt King*, leaders):
  - establish and publish a list of PSMSL tide gauges that are subject to large, time-variable elastic deformation associated with present-day glacier mass

change,

- compile a database of predictions for relative sea level changes at tide gauges, gravity field, and 3D deformation rates at geodetic sites and on global or regional grids for a set of reasonable GIA models, both for the deglaciation after LGM and more recent ice changes. While this database may not lead to consensus about the "best" model, it will clarify the range of predictions made by models that have some support within the broader community.

SC 3.5: Seismogeodesy (joint with IASPEI)

Chair: *Jean-Mathieu Nocquet* (France)
Vice-Chair: *Takuya Nishimura* (Japan)
Position replacement every 2 years.

Terms of Reference

Space and terrestrial geodetic techniques provide key observations to investigate a broad range of geophysical processes, thanks to their high accuracy, precision, and reliable georeferencing. Thanks to the technological evolution witnessed in the past decades, crustal movements of few millimeters can be now detected and monitored over time, opening new prospects for the study of Earth kinematics and geodynamics.

Among their many applications, geodetic measurements can now contribute to the study of the different phases of the seismic cycle, as they allow recording static and dynamic displacements during large earthquakes, as well as the slow postseismic and interseismic deformation. However, the foundation for fully exploiting the potential of geodetic measurements is the development of a multidisciplinary approach to their interpretation.

The joint IAG-IASPEI SC on Seismogeodesy aims to facilitate the cooperation between the geodetic and the seismological communities to improve our current understanding of the different seismic processes. The investigated phenomena range from large destructive events, to slow earthquakes and tremors. The works of the SC focus on both theoretical aspects and observational challenges. Particular effort is dedicated to identifying gaps of knowledge and opportunity for progress, particularly in the field of hazard assessment and early warning systems.

Objectives

Objectives of SC 3.5 include:

- to actively encourage the cooperation between all geoscientists studying the plate boundary deformation zones, by promoting the exploitation of synergies between different fields;
- to reinforce joint and integrated geodetic and seismological monitoring of seismically active areas by increasing and/or developing infrastructures dedicated to broadband observations from the seismic wave band to the permanent displacement;
- to be a reference group for the integration of the most advanced geodetic and geophysical techniques by developing consistent methodologies for data reduction, analysis, integration, and interpretation;
- to act as a forum for discussion and scientific support for international geoscientists investigating the kinematics and mechanics of the plate boundary deformation zone;
- to promote the use of standard procedures for geodetic data acquisition, quality evaluation, and processing, particularly GNSS data and InSAR data;
- to promote earthquake geodesy, the study of seismically active regions with large earthquake potential, and geodetic application to early warning system of earthquakes and tsunamis for hazard mitigation;
- to promote the role of geodesy in tectonic studies for understanding the seismic cycle, transient and instantaneous deformation, and creeping versus seismic slip on faults.

Program of Activities

- Building on the experience of the WEGENER Initiative, to continue as a framework for geodetic cooperation in the study of the plate boundary zones.
- To develop scientific programs in earthquake geodesy for subduction zones and possible occurrence of giant earthquakes and associated tsunamis.
- To foster the use of space-borne, airborne, marine and hybrid techniques such as GNSS, LIDAR, GNSS-Acoustic, seafloor pressure gauges, radar, optical, and gravity satellite missions including GOCE, GRACE, ENVISAT, SENTINELLE, ALOS, etc. for earth observation.
- To define effective integrated observational strategies for these techniques to reliably identify and monitor crustal movements and gravity variations over all time scales.
- To facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geo-processes.

- To organize periodic workshops and meetings with special emphasis on interdisciplinary research and interpretation and modeling issues.
- To organize special sessions at international meetings.
- To publish the outcome of the researches, either as stand-alone publications or as proceedings or special issues of scientific journals.

Joint Study Group 3.1: Geodetic, Seismic and Geodynamic Constraints on Glacial Isostatic Adjustment

(joint with IASPEI and IAG Commissions 1 and 2)

Chair: *Rebekka Steffen* (Sweden)
Vice-Chair: *Erik R. Ivins* (USA)

Terms of Reference

The solid Earth's memory of past glacial loading has been modelled throughout the past 100 years using much of the same formalism and attention to Earth structure that is found in the study of surface wave seismology. Glacial Isostatic Adjustment (GIA) models and geodynamics models use, as fundamental source of data, both seismologically based internal mantle structure models and geodetic time series. It is therefore the focus of this working group to allow cross fertilization of models, data and conceptual frameworks of these two communities, geodynamics and GIA, with the development of an interdisciplinary approach to better determination of the Earth's internal rheological structure.

The compatibility of the spatial and time scales over which rheological frameworks operate effectively is essential. This JSG shall also task itself with analysis of the currently applied GIA modelling parametrizations, data constraints and emerging geodetic data sets, such as GPS, gravity change, and both relative and absolute sea-level variations. In this interdisciplinary study it will be essential to improve the operative definition of the lithosphere.

We seek to identify critical assessments that can be performed to more tightly constrain the relationships between effective mantle viscosity for use in geodynamics and GIA models that are compatible with the results of advanced seismic imaging of 3-D mantle structure and geodetic time series. Consequently, this Study Group is joined between Commission 1 on Reference Frames, Commission 2 on Gravity Field and Commission 3 on Earth Rotation and Geodynamics with promising cooperation with IASPEI Commission on Earth Structure and Geodynamics.

Objectives

Objectives of JSG 3.1 include:

- to review the integration of geophysical, seismological, and geodynamical modelling as well as fundamental mineral physics into GIA models, with a special emphasizes on their model results (including gravity changes and GNSS rates);
- to formulate general principles for defining the lithosphere for GIA models and assessment of the rheological principles and geophysical observables relevant to that definition;
- to study the relative merits of GIA data types. These data types include GNSS horizontal and vertical motion, tide gauges, gravity changes, observed with both terrestrial and space, techniques, and seismicity, in form of paleo, historic and recent earthquakes. These data are especially powerful when combined with one another. Special emphasis should be placed on evaluating the spatial distribution of data and the length of time series required for GIA modelling;
- to assess the role of GIA model impact on products derived from modern space gravimetry (GRACE) for both ocean and hydrological sciences;
- to intercompare model based transient response of post-seismic relaxation following $M_w > 7.0$ earthquakes to the constitutive laws assumed valid in GIA models;

Program of Activities

- Organize a workshop discussing the objectives from above.
- Publishing a report on the definition of the GIA lithosphere.
- Organization of an international joint workshop in 2021 or 2022 (possibly in collaboration with SC 3.4 "Cryospheric Deformation", with JSG 0.21 "Dynamic modeling of deformation, rotation and gravity field variations", and even further related IAG (and IASPEI) working groups).
- Contribution to international meetings and conferences (e.g., EGU, AGU).
- Organization of a session at the IUGG meeting in Berlin in 2023.
- Common publications by JSG members.
- Managing a website with updates on the development of the JSG.

Members

Kristel Chanard (France)
Mark Hoggard (USA)
Paula Koelemeijer (UK)
Tanghua Li (Singapore)
Glenn Milne (Canada)
Bart Root (Netherlands)

Andrew Schaeffer (Canada)
Kate Selway (Australia)
Bernhard Steinberger (Germany)
Doug Wiens (USA)

Joint Working Group 3.1: Improving Theories and Models of the Earth's Rotation

(joint with IAU)

Chair: *José Ferrándiz* (Spain)
Vice-Chair: *Richard Gross* (USA)

Terms of Reference

The main purpose of this JWG is proposing consistent updates of the Earth rotation theories and models and their validation. The associated tasks will thus contribute to the implementation of the 2018 IAU Resolution B1 on Geocentric and International Terrestrial Reference Systems and Frames, and the 2019 IAG Resolution 5 on Improvement of the Earth's Rotation Theories and Models. The last resolution is the most specific for the WG assignment and mandates:

- to encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential EOPs;
- that the definition of all the EOPs, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG and its components;
- that the new models should be closer to the dynamically time-varying, actual Earth, and adaptable as much as possible to future updating of the reference frames and standards.

The work will be performed in close cooperation other IAG components, particularly GGOS, the IERS, and current WGs dealing with the Earth rotation and standards from specific perspectives, as well as with the IAU Commissions A2 and A3. Continuous coordination will be sought through common members and correspondents.

Program of Activities

At short term, intended as two years in this context, the JWG is committed to derive supplementary models for the Celestial Pole Offsets (CPO) evolution, in part of semi-empirical and semi-analytical nature, and able to increase significantly the explained variance of the current theories and models.

According to the recommendations of the 2019 GGOS-IERS Unified Analysis Workshop, the priority tasks of building such models will include:

- updating the amplitudes of the leading nutations of the IAU2000 theory and testing shortened series for certain operational purposes;
- correcting the inconsistencies found in the precession-nutation models;
- test the available FCN models (for explaining CPO variance) and consider whether the IERS should recommend FCN models or not.

The two years term being too short to develop and publish a fully dynamically consistent theoretical approach to support those models, that activity will likely continue till the end of the term. Theoretical developments must also address to advancing in all the aspects made explicit on resolution 5, like using a consistent framework for all the Earth Orientation Parameters, with regard to reference systems and frames, background models, standards, and adaptation of the developments to the current knowledge of the dynamic Earth, from its inner components to its outer layers. The chairing people may assign specific tasks with delimited scopes to volunteer members and correspondents, according to their expertise, availability and initiative.

Structure and operation

Taking into account the different methods and expertise required for the treatment of the different kinds of EOP and that their theoretical treatment must be as consistent as their determination from observations, we propose to structure the JWG in three Sub-WGs, which should work in parallel for the sake of efficiency. To guarantee that the SWGs are linked together as closely as the needs of consistency demand, the Chair and Vice-Chair of the WG, Ferrándiz and Gross, will be involved in all SWGs as will the President of the IAU Commission A2, F. Seitz, and the Vice-president of IAG Commission 3, C. Huang. Besides, a number of people will be affiliated to more than one SWG.

1. Precession/Nutation
Chair: *Alberto Escapa* ((Spain)
Members:
T. Baenas (Spain),
W. Chen (China),
V. Dehant (Belgium),
C. Huang (China),
J. Vondrak (Czech Republic)
Correspondents:
D. Angermannn (Germany),
C. Bizouard (France),
N. Capitaine (France),
J. Getino (Spain),
J. Hilton (USA),
G. Kaplan (USA),
J.C. Liu (China),

J.F. Navarro (Spain),
J. Ray (USA),
R. Ray (USA),
C. Ron (Czech Republic),
H. Schuh (Germany),
F. Seitz (Germany),
W.B. Shen (China),
D. Thaller (Germany).

2. Polar Motion and UT1
Chair: *Aleksander Brzezinski* (Poland)
Members:
S. Böhm (Austria),
B.F. Chao (Taipei),
J. Nastula (Poland),
F. Seitz (Germany),
W.B. Shen (China).
Correspondents:
D. Angermann (Germany),
C. Bizouard (France),
W. Chen (China),
R. Dill (Germany),
H. Dobslaw (Germany),
L. Fernández (Argentina),
Z. Malkin (Russia),
J. Ray (USA),
D. Salstein (USA),
H. Schuh (Germany),
J. Vondrak (Czech Republic),
L. Zotov (Russia)

3. Numerical Solutions and Validation
Chair: *Robert Heinkelmann* (Germany)
Members:
S. Belda (Spain),
C. Bizouard (France),
Z. Malkin (Russia),
M. Schindelegger (Austria),
B. Soja (USA).
Correspondents:
D. Angerman (Germany),
B.F. Chao (Taipei),
W. Chen (China),
J. Hilton (USA),
J. Mueller (Germany),
J. Ray (USA),
H. Schuh (Germany),
F. Seitz (Germany),
D. Thaller (Germany),
M. Thomas (Germany),
P. Zhu (Belgium).

JWG 3.2: Global combined GNSS velocity field (joint IAG Commissions 1 and 2)

Chair: *Alvaro Santamaría-Gómez* (France)
Vice-Chair: *Roelof Rietbroek* (Germany)

Terms of Reference

This Working Group aims at combining and comparing available GNSS velocity fields obtained by different groups from both network and PPP solutions. It continues the activities of former JWG3.2 "Constraining vertical land motion of tide gauges" with the inclusion of the last reprocessed solutions derived or related to the ITRF2020 realization while also extending the scope to the horizontal component of the velocity field.

GNSS velocities estimated by different groups usually differ due to the choices made concerning the GNSS data processing (corrections applied and noise level of the series), the completeness of the series, the removed position discontinuities and the alignment to a terrestrial reference frame. The position discontinuities that populate the GNSS time series have probably the biggest impact on the velocity estimates. Even when using exactly the same series, it is common that different groups provide different velocity estimates and uncertainties mainly due to the different choices of position discontinuities.

The main outcome of the Working Group will be a combined velocity field that takes into account the repeatability of the estimates by the different groups. It is expected that the combined GNSS velocity field will be useful for the scientific community in the areas of tectonics, sea-level change and GIA modeling among others.

The differences of the combined GNSS velocity field with respect to velocity fields obtained from other techniques (other space geodetic techniques, TGs, satellite altimetry) will be assessed. For instance, differences between tide gauge records and between tide gauges and satellite altimetry can provide constraints on the vertical velocities at the tide gauges. Observations from gravimeters, InSAR and other space geodetic techniques (e.g., DORIS) have the potential to provide valuable information on the velocities.

Program of Activities

- Collect velocity fields from GNSS and other techniques.
- Combine the GNSS velocity fields.
- Assess the differences between the combined GNSS velocity field and other velocity fields.

Members

Thomas Frederikse (USA),
Paul Rebischung (France).