Commission 3 - Earth Rotation and Geodynamics

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President: Rebekka Steffen (Sweden)
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Commission 3 website - www.com3.iag-aig.org

1 Terms of Reference

The Earth is a dynamic planet that can be explored through the analysis of geodetic data. Both space-based and terrestrial geodetic techniques, owing to their high accuracy, precision, and reliable georeferencing capabilities, offer invaluable observations for investigating a wide array of geophysical (geodynamic) processes. Spatial variations in the Earth's global static and temporal gravity field as well as global and local deformation (displacement) of the Earth's surface are used to learn more about the Earth's internal structure and dynamics. Phenomena associated with the Earth's rotation and orientation in space, such as polar motion, Universal Time (UT), Length of Day (LOD), precession/nutation, and (oceanic) pole tides, reveal insights into the dynamic behaviour of our planet. Precise measurements of these phenomena are pivotal for establishing the transformation between terrestrial and celestial reference frames. Commission 3 studies the entire range of physical processes associated with the movement and deformation of the Earth in response to both external and internal forces.

Modern geodesy effectively facilitates research and data analysis concerning variations in Earth's rotation, gravitational field, and geocenter motion, stemming from mass redistribution and exchange among the Earth's fluid sub-systems, including the atmosphere, oceans, continental hydrosphere, cryosphere, mantle, and core. This encompasses also geophysical phenomena related to tidal processes such as solid Earth and ocean loading tides as well as crustal and mantle deformation associated with tectonic motions, earthquakes, volcanic eruptions, hydrological events, isostatic adjustment, etc. Relevant quantities, such as angular momenta, associated torques, gravitational field coefficients and geocenter shifts, are observed using global-scale measurements and are compared to theoretical studies along with the application of advanced models, some of which have already been constrained using geodetic measurements.

Geodynamic modelling tools serve as foundation for comprehending geodetic observations and advancing our understanding of the dynamic Earth. Insights gained from these modelling studies can, in turn, assist in correcting geodetic time series, which are essential for tasks such as estimating reference frames, distinguishing between various changes in polar motion, and detecting other mass changes.

Geodesy plays a crucial role in monitoring and analyzing natural hazards. Through geodetic observations, researchers can study the geometry and temporal changes of volcanic systems, while playing a crucial role in monitoring and assessing hazards during volcanic unrest and eruptions. Moreover, geodetic data contribute significantly to the study of various phases of the seismic cycle, enabling the recording of static and dynamic displacements during large earthquakes, as well as the slow postseismic and interseismic deformation. Thus, the monitoring of seismic hazards and associated risks is greatly enhanced by geodetic observations. Additionally, geodetic observations serve as an essential tool for studying mass changes between and within the cryosphere and the hydrosphere. Mass changes of ice sheets contribute significantly to sea-level change, which can be mapped through the integration of geodetic observations with geodynamic models. The purpose of Commission 3 is to promote, disseminate, and where necessary, facilitate the coordination of research within this wide area.

Sub-Commission 3.1 (Earth Tides and Geodynamics) addresses both direct and indirect tidal phenomena, as well as non-tidal loading, that influence the positioning of fiducial sites. Correcting for these effects is essential to ensure accurate spatial referencing, which is critical for observing and accurately monitoring changes of the Earth's surface at global, regional and local scales. Consequently, tidal and surficial loading research significantly contributes to global geodynamics and climate change studies by providing key constraints to geophysical models.

Sub-Commission 3.2 (Volcano Geodesy) addresses the growing volume and quality of volcano-geodetic data, which has created a need for new approaches to data analysis, interpretation, and modelling. These approaches are crucial for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano-monitoring results.

Sub-Commission 3.3 (Earth Rotation and Geophysical Fluids) addresses the space-time variation of atmospheric pressure and winds, seafloor pressure, ocean currents, and flows in the Earth's liquid core. It also considers the surface loads associated with the hydrological cycle, and Earth's (mainly elastic) responses to these mass redistributions and particle flows.

Sub-Commission 3.4 (Cryospheric Deformation) addresses present-day deformations of the solid Earth induced by past and present changes in the mass balance of the Earth's glaciers and ice sheets. This includes improving the understanding of cryospheric deformation from local to global scales, both through observational measurements, and the use of these observations as constraint in the ongoing development of geophysical models.

Sub-Commission 3.5 (Seismogeodesy) addresses studies of plate boundary deformation zones and the integration of geodetic and seismological observations in seismically active regions to better understand the behaviour of faults. This involves enhancing and/or developing infrastructures dedicated to broadband observations from the time scale of seismic waves to decades-long displacement and promoting the joint seismological-geodetic analysis of these observations.

Commission 3 interacts with the GGOS, other Commissions, Inter-Commission Committees and Services of the IAG as well as with external organizations such as the IAU (International Astronomical Union, see https://www.iau.org/), IASPEI (International Association of Seismology and Physics of the Earth's Interior, see http://www.iaspei.org/), IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior, see https://www.iavceivolcano.org/), IACS (International Association of Cryospheric Sciences, see https://cryosphericsciences.org/), and the IUGG

Commission on the Study of the Earth's Deep Interior (SEDI) (https://hope.simons-rock.edu/~bergman/sedi/).

1.1 Objectives

Commission 3 will:

- promote cooperation and collaboration on the theory, modelling and observation of Earth rotation and geodynamics;
- support research on how geodesy contributes to studying natural hazards by maintaining interdisciplinary groups on volcanic deformations (with IAVCEI), present-day ice mass changes (with IACS), and phases of the seismic cycle (with IASPEI);
- identify uncertainties in geodetic time series introduced by local to regional background processes (e.g., due to glacial isostatic adjustment models and hydrological models);
- approach as close as possible the new models of Earth Orientation Parameters (EOPs) and other related parameters to the dynamically time-varying, actual Earth, to be adaptable to future updating of reference frames and standards;
- foster the development of increasingly consistent and accurate geodetic multi-technique solutions;
- encourage the exchange of ideas and data as well as the comparison of methods and results with the goal of improving accuracy, content, methods, theories, and understanding of Earth rotation and geodynamics;
- serve the geophysical community by facilitating interactions with organizations that provide the data needed to study Earth rotation and geodynamics.

1.2 Program of Activities

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

Commission 3 will involve under-represented groups into IAG activities.

1.3 Structure

Sub-Commissions

SC 3.1 Earth Tides and Geodynamics
Chair: Séverine Rosat (France)
SC 3.2 Volcano Geodesy (joint with IAVCEI)
Chair: Susanna Ebmeier (United Kingdom)
SC 3.3 Earth Rotation and Geophysical Fluids
Chair: Sigrid Böhm (Austria)
SC 3.4 Cryospheric Deformation (joint with IACS)
Chair: Karen Simon (Canada)

SC 3.5 Seismogeodesy (joint with IASPEI)
Chair: Jean-Mathieu Nocquet (France)

Working Groups

WG 3.1 Hydrologic signature in geodetic observations
Chair: Carla Braitenberg (Italy)

Joint Working Groups

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

In addition, Commission 3 jointly contributes to JWG established by other IAG components:

JWG 1.2.3 Impact of geophysical models on reference frames (led by Comm 1),
JWG 1.4.1 Improving and homogenisation of geophysical modeling for a better consistency of the reference frames (led by Comm 1),
JWG C.1 Climate Variability and Climate Change in EOP (led by ICCC),
JWG C.2 Polar geodesy for understanding climate change (led by ICCC),
JWG M.2 GNSS-Acoustic technologies and experiments (led by ICCM),
JWG M.3 Seafloor pressure- an essential variable for monitoring vertical deformation as well as ocean dynamics (led by ICCM),
JWG M.6 How marine geodesy can better contribute to coastal hazards assessment and mitigation (led by ICCM),
JWG Prediction of Earth Orientation Parameters (PEOP) - following the WG on the 2nd EOP Prediction Comparison Campaign (led by IERS).

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

Joint Study Groups

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

In addition, Commission 3 jointly contributes to JSG established by other IAG components:

JSG T.41 Geodetic quality/integrity modelling, monitoring and design (led by ICCT),
JSG T.42 Theoretical developments and applications of combined methods for a better understanding of the Earth's lithospheric formation, structure, and dynamics (led by ICCT),
JSG T.45 Dynamic gravity modelling of given distributions (led by ICCT),

JSG T.46 Deformation, rotation and gravity field modeling for Earth and space (led by ICCT),
JSG T.48 Theoretical Foundations of Machine and Deep Learning in Geodesy (led by ICCT),
GGOS.AI4G.JSG 3 AI for EOP Prediction (led by GGOS),
GGOS.AI4G.JSG 4 AI for Geodetic Deformation Monitoring (led by GGOS).

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

1.4 Steering Committee

- President Commission 3: Rebekka Steffen (Sweden)
- Vice President Comm. 3: José M. Ferrándiz (Spain)
- Chair Sub-Comm. 3.1: Séverine Rosat (France)
- Chair Sub-Comm. 3.2: Susanna Ebmeier (United Kingdom)
- Chair Sub-Comm. 3.3: Sigrid Böhm (Austria)
- Chair Sub-Comm. 3.4: Karen Simon (Canada)
- Chair Sub-Comm. 3.5: Jean-Mathieu Nocquet (France)
- Representative of IERS: Tonie van Dam (USA)
- Representative of IGFS: Pavel Novák (Czech Republic)
- Representative of IGETS: Ezequiel Antokoletz (Germany)
- Member-at-Large: Chikondi Chisenga (Malawi)
- Member-at-Large: Laura Fernández (Argentina)

Non-voting members

- Representative of GGOS: Laura Sánchez (Germany)
- Representative of IAU: Alberto Escapa (Spain)
- Representative of SEDI: Jérémy Rekier (Belgium)
- Representative of Early Career Scientists: Anna Riddell (Australia)

2 Sub-Commissions, Working Groups and Study Groups

SC 3.1: Earth Tides and Geodynamics

Chair: Séverine Rosat (France)
Vice-Chair: Xiaoming Cui (China)

Terms of Reference

SC 3.1 addresses the entire range of tidal phenomena, non-tidal loading and dynamics of the Earth, both at the theoretical as well as at the observational level. The Earth tide affects many types of high precision instrumentation, be it measurements of position, deformation, potential field or acceleration. The tidal phenomena influence both terrestrial and satellite-borne acquisitions. The tidal potential is a driving force that is accurately calculated. The tidal response observable as deformation and variations in Earth orientation and rotation parameters, gives information on Earth's rheology. Instruments sensitive enough to detect the tidal signal, record a large range of periodic and aperiodic phenomena such as ocean and atmospheric tidal loading, ocean, atmospheric and hydrospheric non-tidal effects, mass redistributions and deformation related to the earthquake cycle and even to gravitational waves, as well as plate tectonics and intraplate deformation. The periods range from seismic normal modes over to the Earth tides and the Chandler Wobble and beyond, ending at the long periods of nutation-precession. Thus, the time scales range from seconds to decennia, and for the spatial scales from local, continental to global dimensions. As tidal friction is affecting Earth's rotation, all the physical properties of the Earth contribute to the explanation of this phenomenon. Therefore, research on tidal deformation due to changes of the tidal potential as well as ocean and atmospheric loading is a prerequisite to constrain Earth's rheological properties. Further, direct and indirect tidal phenomena affect the position of fiducial sites and have to be corrected to provide accurate spatial referencing. Such referencing is needed for the observation and monitoring of changes of the Earth's surface at global, regional and local scales. Therefore, there is a considerable contribution of tidal research to global geodynamics and climate change by providing important constraints to geophysical models.

Modern instrumental developments for which tidal phenomena are relevant are gravimeters and gradiometers based on superconductivity, atom interferometry, microelectromechanical-system (MEMS) gravimeters, Inertial Measurement Units, gravitational wave antennas, satellite gravimetry and atomic clocks. Improvements in gravimetric instrumentation lead to the use of gravimetry as a tool to detect underground mass changes, as naturally occurring hydrologic draughts or fluids injected into the underground for the purpose of temporary storage for instance. The Earth is a complex dynamic system interacting with its fluid surficial layers. The Earth is studied in terms of its global gravity field and its temporal variations, as well as its surface deformation in order to characterize the Earth's internal structure and dynamics. In the next few years, instrumental developments in portable absolute gravimeters are expected, and further innovations can be envisaged from the atomic interferometry technology.

SC 3.1 will follow the instrumental developments and infer innovative applications. These geophysical observations together with other geodetic observations and geological information provide the means to better understand the structure, dynamics and evolution of the Earth system. The existence of a network of superconducting gravimeters (SGs) allows continuous monitoring of the gravity signal at selected stations with a precision of better than 10^{-10} m/s^2. The range of applications of SG measurements has become very wide and applicable not only to Earth tides investigations, but also to support studies on Earth's seismic cycle and hydrological mass estimates. The SG network has had scientifically close relation to the SC 3.1 and IGETS (International Geodynamics and Earth Tide Service), which distributes the data. Therefore, the Chair of SC 3.1 is responsible for the close cooperation with the IGETS to provide effective service-with science coupling.

Objectives

Objectives of SC 3.1 include:

- to study and implement new observational techniques and improve existing ones, including clinometric and extensometric techniques;
- to demonstrate the importance of long term geodetic stations;
- to predict the signals observable with space geodetic techniques based on high precision terrestrial long term time series;
- to advance tidal data analyses and prediction methods;
- to enhance the models on the interaction among solid Earth, ocean, and atmospheric tides;
- to research the effects of the atmosphere and hydrology on gravity and other geodetic observations;
- to study the response of the Earth at tidal and non-tidal forcing frequencies;
- to study the interplay between tides and Earth rotation;
- to study the effects of ocean loading and global water distribution;
- to study the seismic cycle in terms of deformation and normal modes;
- to establish and coordinate working groups on specific topics of interest and relevancy to the understanding of our planet;
- to develop, coordinate and promote international conferences, programs and workshops on data acquisition, analysis and interpretation related to the research fields mentioned above;
- to contribute to the definition and realization of the International Terrestrial Reference Frame via advanced geodynamic models at global, regional and local scales;
- to promote the systematic calibration and intercomparison of absolute and relative gravimeters (FG5, atomic gravimeter, SGs, MEMS as well as traditional spring instruments);
- to study planetary tides and dynamics;
- to promote interdisciplinary research in Earth and planetology;
- to support the GGOS in the field of:
  - the integral effect on Earth rotation of all angular momentum exchanges inside the Earth, between land, ice, hydrosphere and atmosphere, and between the Earth, Sun, Moon, and planets,

– the geometric shape of the Earth's surface (solid Earth, ice and oceans), globally or regionally, and its temporal variations, whether they are horizontal or vertical, secular, periodical or sudden,
– the Earth's gravity field-stationary and time variable mass balance, fluxes and circulation.

Program of Activities

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

SC 3.2: Volcano Geodesy (joint with IAVCEI)

Chair: Susanna Ebmeier (UK)
Vice-Chair: Matthew Head (USA)

Terms of Reference

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

Recent decades have seen an explosion in the quality and quantity of volcano geodetic data, especially from satellite instruments, which has created a need for new approaches to data analysis, interpretation, and modelling (Powell Centre Report, see www.usgs.gov/publications/optimizing-satellite-resources-global-assessment-and-mitigation-volcanic-hazards). Geodetic data can have different temporal and spatial resolutions, as well as different origins (ground-, air-, and space-based), and they are best utilized in conjunction with other non-geodetic datasets, like seismicity and gas emissions. New tools are therefore needed for data fusion and joint interpretation, both between geodetic datasets and with other types of volcano monitoring results. This is critical for volcano monitoring, and especially important where both multi-sensor constellation imagery and ground-based imagery is available, e.g., through volcanic sites in GEO's Geohazard Supersites (https://earthobservations.org/) and Natural Laboratories initiative GEO-GSNL (https://geo-gsnl.org) or through the CEOS (Committee on Earth Observations Satellites) Volcano Demonstrator (https://ceos.org/ourwork/workinggroups/disasters/volcanoes/) and related initiatives.

The IAG-IAVCEI Commission on Volcano Geodesy (https://volcgeodesy.iavceivolcano.org/) aims to support the diverse international research community, foster collaborations, and ultimately promote a better understanding of magmatic processes and volcanic hazards through the use of geodetic techniques and modelling.

Objectives

Objectives of SC 3.2 include:

- foster communication within the volcano geodesy community, particularly between senior and early-career researchers, between scientists from different countries, and between volcano observatories;
- support coordinated geodetic response to volcanic unrest and eruptions around the world, including the acquisition of, and access to, satellite data through collaboration with GEO, CEOS and individual members;
- encourage high-level geodetic capability at the world's volcanoes through the sharing of best practices; development, testing, and distribution of open-source analysis and modelling tools; standardization of techniques for the measurement and interpretation of geodetic changes; exploitation of new technologies; and capacity-building activities;
- support the establishment and maintenance of databases for volcano geodetic observations, as well as the interoperability between these and other sources of geological, geochemical, and geophysical data related to volcanoes;
- promote volcano geodesy as a tool with broad implications and diverse applications in research, monitoring, and crisis response by serving as a bridge between geodesy and other branches of volcanology; connecting geodesists within the academic community, volcano observatories, space agencies, industry, government institutions, and other organizations; and advocating for the commitment of appropriate resources;
- encourage and enable collaborations between geodesy and other disciplines, given that interdisciplinary approaches to volcano research and hazards assessment offer the best prospects for improving overall understanding of volcanic processes and their impacts;
- implementation and dissemination of new standard approaches, protocols and best practices;
- promotion of common initiatives and projects with other IAG and IAVCEI entities.

Program of Activities

- Organize a scientific conference to define big scientific questions that could be addressed with Volcano Geodesy.
- Organize a scientific workshop with the goals of training early-career volcano geodesists, sharing current research, and comparing codes on a standardized synthetic data set.

- Establish an accessible means of communicating regular updates (e.g., news, recent academic and observatory publications, conference sessions, job opportunities) to the volcano geodesy community, and promote the visibility of ongoing projects.
- Organize a quarterly virtual seminar for ongoing research in volcano geodesy, with at least one slot reserved for early-career/student volcano geodesists.

SC 3.3: Earth Rotation and Geophysical Fluids

Chair: Sigrid Böhm (Austria)
Vice-Chair: Christopher Dieck (USA)

Terms of Reference

Mass transport in the atmosphere-hydrosphere-mantle-core system, or the "global geophysical fluids", causes observable geodynamic effects on broad time scales. Although relatively small, these global geodynamic effects have been measured by space geodetic techniques to increasing, unprecedented accuracy, opening important new avenues of research that will lead to a better understanding of global mass transport processes and of the Earth's dynamic response. Angular momenta and the related torques, gravitational field coefficients, and geocenter shifts for all geophysical fluids are the relevant quantities. They are observed using global-scale measurements and are studied theoretically as well as by applying state-of-the-art models; some of these models are already constrained by geodetic measurements. Increasingly more efforts are also being made internationally to constitute future projections of mass transports in the geophysical fluid systems. These enable the investigation of global change impacts on Earth rotation variability, particularly considering possible consequences of human interaction with Earth's fluid systems.

Objectives

The objective of SC 3.3 is to serve the scientific community by supporting research and data analysis devoted to variations in Earth rotation, the gravitational field, and the geocenter caused by mass redistribution within and mass exchange among the Earth's fluid sub-systems, i.e., the atmosphere, ocean, continental hydrosphere, cryosphere, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle. The SC contributes to accomplishing the GGOS vision of "Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time" with the quantification of the following parameters for the past, present, and future:

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

Program of Activities

- To promote the exchange of ideas and results as well as of analysis and modelling strategies, sessions at international conferences and topical workshops will be organized.
- In addition, SC 3.3 interacts with the sister organizations and Services, particularly with the IERS components providing Earth rotation and geophysical fluids data (atmosphere, hydrology, ocean, combination).
- SC 3.3 will have close contacts to the GGOS activities, in particular to the activities of the GGOS Committee "Contribution to Earth System Modelling".
- The SC will foster the exchange and collaboration with the IAG Inter-Commission Committee on Geodesy for Climate Research (ICCC), for example to evaluate the potential of Earth system data from climate simulations for Earth rotation research.

SC 3.4: Cryospheric Deformation (joint with IACS)

Chair (IAG): Karen Simon (Canada)
Chair (IACS): Matthias Willen (Germany)
Vice-Chair: Carsten Ludwigsen (Denmark)

Terms of Reference

Past and present changes in the mass balance of the Earth's glaciers and ice sheets induce present-day deformation of the solid Earth on a wide range of spatial and temporal scales, from the very local to global and from immediate elastic deformations to millennial viscoelastic glacial isostatic adjustment (GIA) to past ice ages. This present-day deformation of the solid Earth is thus a window into glacial history and provides insights into the solid-Earth rheology, enabled by sophisticated GIA modeling. The geodetic observation of this deformation regarding changes in Earth's geometry, gravity field, and orientation is essential in validating or constraining GIA models. This holds true for direct information on the history of sea level and glaciation.

Present-day ice mass changes induce an immediate elastic deformation of the Earth, while the integrated history of mass changes induces an additional viscoelastic deformation. Traditionally, these responses have been considered separately, which is a good approximation for long-ago load changes and regions of high mantle viscosity. In regions of low upper-mantle viscosity (e. g. West Antarctica, Antarctic Peninsula, Patagonia, Iceland), the present-day and recent-past load changes must be modeled together as the rapid viscoelastic relaxation is substantial and not easily separated from the immediate elastic response. In all cases, present-day geometric measurements (e.g., bedrock motion rates) measure the sum of elastic and viscoelastic deformations, and these components cannot be separated without additional models or observations. Present-day gravity changes are useful because they have a different sensitivity to the elastic and viscoelastic components. During recent years, extensive efforts have been made in the GIA modeling community to represent the spatial heterogeneity of the solid-earth rheology in the models (3-D models) and to account for the different temporal response scales by implementing more sophisticated rheology models (e.g., extended Burgers material models). The careful inter-comparison and validation of these models, including consideration of the microphysical basis for transient models of deformation (creep processes), will help us unravel and understand the causes of the model differences.

Furthermore, the consideration of GIA-induced feedback effects in ice-sheet modeling (coupled GIA-ice sheet modeling) is increasingly being considered, for example, to better understand (de)stabilization effects due to bedrock motion and to be able to take them into account in projections. This applies in particular to the ice sheets in West Antarctica and Greenland, which have been identified as climate tipping elements.

This SC has a long history as part of IAG. Since 2022 this is a joint sub-commission with IACS. Within IAG, SC 3.4 historically has focused on resolving technical measurement issues. With this cross-Association sub-commission, we will continue to enhance the benefits obtained during the previous term through collaboration and sharing of data with the glaciological community.

Objectives

Objectives of SC 3.4 include:

- Connecting researchers working on cryospheric deformation by
  - Organizing 1-2 international workshop(s) that will continue the very successful series organized by this Sub-Commission over the last several years;
  - Co-organizing sessions at meetings of the AGU (American Geophysical Union, see https://www.agu.org/) and EGU (European Geosciences Union, see https://www.egu.eu/);
  - Organizing and continuation of online seminar series;
- Investigate the impact of reference frame differences (mainly origin) between GIA models and geodetic reference frames;
- Stimulate and support the inter-comparison, benchmarking, and validation of 1-D and especially 3-D Earth rheological models;
- Stimulate and encourage sharing model outputs, observational data, and distribution of open source software tools for modeling cryospheric deformation, and promote the inclusion of ice sheet-solid earth interactions in past and future ice sheet model runs;
- Stimulate discussion and promote the application of (future) Earth Observation techniques to research questions related to cryospheric deformation.

In terms of workshops and the online seminar series, we will seek partners to enhance cross-disciplinary aspects of the workshops (e.g., PALSEA-Next, see https://pastglobalchanges.org/science/wg/palsea/intro and SCAR INSTANT Theme 2, see https://www.scar-instant.org/index.php).

Program of Activities

- A session on GIA entitled “Glacial isostatic adjustment: observation, modelling, analysis, and interaction” will be co-convened at the EGU General Assembly in 2024.

- Co-organize an international workshop focusing on cryospheric deformation and GIA modeling and observables somewhere in Canada in the spring of 2025 (Sidney, British Columbia; 1st of June). This workshop will likely be a 4-day event and is a continuation of the successful series of workshops co-organized by the Sub-Commission and hosted in Reykjavik, Iceland in 2017, and Ottawa, Canada in 2019. We will continue to seek coordination with cross-disciplinary groups such as IAG, IACS, and PALSEA.
- If scheduling and means allow, co-organize a second workshop in 2027. We consider "assessing cryospheric deformations across time-scales" to be of particular interest as a possible focus topic for this workshop.
- Organize an online seminar series on key topics associated with cryospheric deformation. Even though the community continues to come together in face-to-face meetings after the Covid pandemic, we would like to initiate the opportunity for the community to regularly exchange scientific findings. Each seminar will focus on a single key topic and give a speaker the opportunity to present on a topic for around 20 to 30 minutes followed by a general discussion. We plan to start this series in 2024 and have 4-5 seminars throughout the year. This series continues the concept of the popular virtual seminar series which began in 2021 and had a second edition in 2022.
- We plan to create a worldwide overview of research activities regarding cryospheric deformation and thus a central point of reference. For example on the IAG website, we would like to provide the community with a comprehensive overview. This includes, for example, the listing of global and regional GIA modeling results and their sources, validation data sets of different observation methods, etc. This should also provide an overview of which research groups are working on which regions/questions. The maintenance of this information is the responsibility of SC 3.4 and will be continued and further developed in the future by those responsible for SC 3.4. We anticipate that this will make it easier for Early Career Scientist start working on this research topic. In particular, we intend to stipulate with this initiative that research results are made accessible. This initiative is to be coordinated with the community at the planned Workshop 2025.
- Develop an online archive of 1D and 3D Earth rheological models to enhance dissemination and inter-comparison of these models. The specific development of this archiving initiative will be a subject during the workshop in 2025.
- Organize an effort to benchmark 3D GIA modeling approaches, similar to the benchmarking exercise done a few years ago for 1D codes.
- Organize a working group to analyze frame differences (especially frame origin) between GIA models and ITRF (International Terrestrial Reference Frame). It should be possible to transform global GIA model predictions into any reference frame, including Center of mass of Earth System and Center of Figure. We want to encourage future modeling efforts to compute the needed frame transformations.

SC 3.5: Seismogeodesy (joint with IASPEI)

Chair: Jean-Mathieu Nocquet (France)
Vice-Chair: Masayuki Kano (Japan)

Terms of Reference

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

Seismogeodesy is an evolving discipline within earthquake-related research, seamlessly integrating seismology and geodesy to comprehensively monitor Earth's deformation across a broad range of timescales, spanning from hundreds of Hertz to several decades. Seismogeodesy includes the study of the phases of the earthquake cycle by quantifying the modes of accumulation and release of stress and strain before (inter-seismic phase), during (co-seismic phase), and after (post-seismic phase) seismic events. Among the current challenges, seismogeodesy aims at documenting transient aseismic slip at faults through their geodetic and seismological signatures to understand their dynamics and their significance in the earthquake cycle.

The foundation for fully exploiting the potential of the growing set of geodetic and seismological measurements is the development of a multidisciplinary approach. The joint IAG-IASPEI SC on Seismogeodesy aims to facilitate the cooperation between the geodetic and the seismological communities to improve our current understanding of the different seismic and aseismic processes. The works of the SC focus on both theoretical aspects and observational challenges. Particular effort is dedicated to identifying gaps of knowledge and opportunity for progress, particularly in the field of hazard assessment and early warning systems.

Objectives

Objectives of SC 3.5 include:

- to actively encourage the cooperation between all geoscientists studying the plate boundary deformation zones, by promoting the exploitation of synergies between different fields;
- to promote open science through open data policy, publicly available codes and algorithms;
- to reinforce joint and integrated geodetic and seismological monitoring of seismically active areas by increasing and/or developing infrastructures dedicated to broadband observations; from the seismic wave band to the permanent displacement;
- to be a reference group for the integration of the most advanced geodetic and geophysical techniques by developing consistent methodologies for data reduction, analysis, integration, and interpretation;

- to act as a forum for discussion and scientific support for international geoscientists investigating the kinematics and mechanics of the plate boundary deformation zone;
- to promote the use of standard procedures for geodetic data acquisition, quality evaluation, and processing, particularly GNSS data and InSAR (Interferometric Synthetic-Aperture Radar) data;
- to promote earthquake geodesy, the study of seismically active regions with large earthquake potential, and geodetic application to early warning system of earthquakes and tsunamis for hazard mitigation;
- to promote the role of geodesy in tectonic studies for understanding the relationship between short term versus long term deformation, documenting deformation of all phases of the seismic cycle, including steady and transient deformation, aseismic versus seismic slip on faults.

Program of Activities

- Building on the experience of the WEGENER (Working Group of European Geoscientists for the Establishment of Networks for Earth-science Research) initiative, to continue as a framework for geodetic cooperation in the study of the plate boundary zones.
- To develop scientific programs in earthquake geodesy for subduction zones and possible occurrence of giant earthquakes and associated tsunamis.
- To foster the use of space-borne, airborne, marine and hybrid techniques such as GNSS, LIDAR (Light detection and ranging), seafloor GNSS-Acoustic and pressure gauges.
- To support the development of new satellite mission aiming at providing new information of the Earth deformation through radar, optical, and gravity.
- To promote the emergence of new technologies to monitor both seismic and aseismic deformation such as optic fibers.
- To encourage effective integrated observational and analysis strategies for these techniques to reliably identify and monitor crustal movements and gravity variations over all time scales.
- To facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geo-processes.
- To organize periodic workshops and meetings with special emphasis on interdisciplinary research and interpretation and modeling issues.
- To organize special sessions at international meetings.
- To publish the outcome of the research, either as stand-alone publications or as proceedings or special issues of scientific journals.

WG 3.1: Hydrologic signature in geodetic observations

Chair: Carla Braitenberg (Italy)
Vice-Chair: Grace Carlson (USA)

Terms of Reference

Terrestrial and space geodetic observations have proven to be suitable for integrating studies of a multitude of time-varying processes. Hydrologic fluxes and volume changes can generate geodetic signals distributed in time from impulsive through seasonal to long term variations and in space at local to regional scales. Geodetic platforms such as satellite gravimetry and GNSS have improved our ability to track large-scale movements of water and are becoming increasingly essential in our ability to measure changes in freshwater storage due to extreme hydroclimate events such as droughts and floods, anthropogenic processes such as groundwater pumping, and climate change. However, these signals are overprinted and often difficult to disentangle from other signals of interest such as, for example, long-term tectonic signals. Therefore, isolating hydro-geodetic signals is important both for our ability to manage freshwater stores as well as to monitor other geophysical processes. To address this challenge, the working group aims to define best practices to identify hydrologic signatures in geodetic observations. Our objective is to support research and data analysis that allows us to gain a better understanding for the scales at which geodetic observations are sensitive to hydrologic processes, how these processes appear in geodetic observations, and how, if necessary, to eliminate these signals depending on the observation system and scale of interest.

Objectives

- Define the physical mechanisms that generate hydrologic signals in geodetic observations.
- Define best practices for forward modeling hydrologic effects that may be present in geodetic observations.
- Identify spatiotemporal scales at which geodetic observation may be sensitive to different hydrologic processes.
- Identify pitfalls to prevent the wrong identification of signals as for instance earthquake precursors or differentiating signals of man-made from natural fluid fluxes.

Program of Activities

- Organize a cycle of seminars to promote the exchange of ideas between hydrologists and geodesists.
- Organize a workshop for geodesists studying non-hydrology related signals to convey best practices for removing these signals from their observations.
- Publish a report detailing recommendations for isolating hydrologic signals in different geodetic datasets.
- Contribute publications and to scientific conferences such as meetings of the AGU and EGU.

Members

Carla Braitenberg (Italy); Chair
Grace Carlson (USA); Vice-Chair
Maite Benavent (Spain)
Wei Feng (China)
Manuela Girotto (USA)
Anna Klos (Poland)
Laurent Longuevergne (France)
Christian Massari (Italy)
Cristiano Mendel Martins (Brazil)
Tommaso Pivetta (Italy)
Umberto Riccardi (Italy)
Jose Arnoso Sampedro (Spain)

JWG 3.1: Consistent improvement of the Earth's rotation theory

(joint with IAU)
Chair: José M. Ferrándiz (Spain)
Vice-Chair: Cheng-li Huang (China)

Terms of Reference

To complete the development of the "2019 IAG Resolution 5" (https://iag-aig.org/doc/GH2020/209_IAG\%20Resolutions.pdf) and the "2021 IAU Resolution B2" (https://www.iau.org/static/archives/announcements/pdf/ann21040b.pdf) on Improvement of the Earth's Rotation Theories and Models, which mandates:

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

At present the development of the said Resolutions has arrived at the obtaining of some sets of semiempirical corrections to the IAU2000/IAU2006 nutation and precession models that allow a significant reduction of the inaccuracies of those theories, measured in terms of the variance of CPO (Celestial Pole Cffsets) time series, as well as at additional reductions associated to the improvement of FCN (Free Core Nutation) models. Theoretical advances have addressed the treatment of more realistic Earth models and some specific effects on the Earth rotation but have not been integrated yet in frameworks consistent both internally and with the procedures used in observational data analysis.

Objectives

- Solving an inconsistency issue at the foundation, so that the dynamical equations ruling the evolution of all EOP be consistent and referred to the same reference systems and frames - or alternatively to different frames but specifying the transformations among them.
- An improved and more accurate solution to the precession and forced nutations, consistent with state-of-the-art models of the tide-rising potential and the known geophysical forcing, and updatable to upcoming improvements of the auxiliary models in parallel to the procedures followed in data analysis.
- Continue advancing the modelling of the free core nutation.
- Furthering the understanding and implications of the relations between nutation and polar motion, in the light of the current capabilities to determine subdiurnal polar motion.
- An additional side benefit sought is to boost the interest and expertise of young researchers in Earth rotation theory and thus help the necessary generational replacement.

Program of Activities

Tasks are cast into two groups for the clarity's sake. Members and correspondents must participate in an interactive and coordinated way.

1. Core of Theory (chaired by Alberto Escapa)
   - Revision of the reference system and frames used in theoretical developments to ensure they are or can be made consistent with the reference frames used in observation processing, and that all EOP are referred to the same frames;
   - Extend the basic Earth model to get it closer to state of the art models and relaxing tight hypothesis on structure invariance (e.g., triaxial, updated tidal models for solid earth and oceans, possibility of accounting better for motion components of angular moment, time-varying gravity and realistic J2 variation, possibility of allowing for relative motions of the main layers. . .);
   - Update the tidal potential raised by external bodies;
   - Assess deeply the impact of relativity;
   - Recompute consistently second order effects and derive a solution for precession-nutation, accurate at the observation (or GGOS) level;
   - Revisit the problem of separation of nutations and polar motion, in particular at the sub-diurnal level.
2. Observations (chaired by Maria Karbon):
   - Ensure that hypothesis, equations and models used in the data analysis packages are consistent with those in theory and compliant with the IAU-IAG-IUGG resolutions;
   - Providing guidance and help to the potential update and revision of definitions;
   - Check the new theory and fit it to observations.

Members and corresponding members

1. Core of Theory
   Alberto Escapa (Spain); Chair
   Christian Bizouard (France)
   Tomás Baenas (Spain)
   Ben F. Chao (China-Taipei)
   Jolanta Nastula (Poland)
   Henryk Dobslaw (Germany)
   Pengshuo Duan (China)
   Wei Chen (China)
   Juan Getino (Spain); corresponding member
   Harald Schuh, Germany); corresponding member
   Richard S. Gross (USA); corresponding member
   David Salstein (USA); corresponding member
   Mian Zhang (China); corresponding member
   Xueqing Xu (China); corresponding member
   Wenbin Shen (China); corresponding member
   Nicolas Rambaux (France); corresponding member
   Jean Paul Boy (France); corresponding member
2. Observations
   Maria Karbon (Spain); Chair
   Santiago Belda (Spain)
   Sigrid Böhm (Austria)
   Kaho Hashimoto (Japan)
   Sebastien Lambert (France)
   Zinovy Malkin (Russia)
   Saho Matsumoto (Japan)
   Tobias Nilsson (Sweden)
   Lizheng Lian (China)
   Oleg Titov (Australia)
   Axel Nothnagel (Austria); corresponding member
   Hao Ding (China); corresponding member
   Yuanwei Wu (China); corresponding member
   Jiacheng Liu (China); corresponding member
   Laura Fernández (Argentina); corresponding member

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

(joint with Commission 1 and Commission 2)
Chair: Lambert Caron (USA)
Vice-Chair: Rebekka Steffen (Sweden)

Terms of Reference

The redistribution of mass at the Earth surface in the cryosphere, hydrosphere and ocean and the associated solid-Earth response create perturbations in the sea level, gravity field, bedrock topography, crustal stress field, geocenter motion, and rotation of the Earth. The geodetic signatures of these effects can be characterized in terms of amplitude, wavelength, and time-dependence. Our understanding of the underlying mechanisms controlling these characteristics currently relies on the model representation of the rheology of the Earth mantle and lithosphere, which is inferred by comparisons of model output to the observations.

Over the last decade, the community has put together several benchmarks and model inter-comparisons using numerical approaches to surface loading problems (including Glacial Isostatic Adjustement – GIA) for the case of an incompressible Maxwell Earth. However, an incompressible Maxwell Earth can no longer explain all geodetic signals observed by modern data missions and networks, and more advanced rheologies are increasingly becoming the norm across the community.

This study group tasks itself with organizing the community to extend such benchmarking and intercomparison efforts to the current state-of-the-art in mantle rheology modeling. We shall document the computation of compressible material and rheologies featuring transient relaxation for spherically symmetric Earth models. We will also assist ongoing efforts in benchmarking models with lateral viscosity variations. This effort aims to standardize the theory, computation, and error calibration in surface loading models for geodetic and geodynamic applications. We aim at expressing model results in a form that is applicable to common geodetic observational frameworks, in particular space gravimetry, GNSS, tide gauges, rotational data, and reference frames.

We seek to identify critical assessments that can be performed to constrain the relationships more tightly between effective mantle rheology for use in geodynamics and GIA models that are compatible with new advances in seismic tomography, rock laboratory experiments, post-seismic deformation and tidal dissipation. Consequently, this Study Group is joined between Commission 1 on Reference Frames, Commission 2 on Gravity Field and Commission 3 on Earth Rotation and Geodynamics with promising cooperation with SEDI (https://hope.simons-rock.edu/~bergman/sedi/).

Objectives

- Reviewing the established approaches to model surface loading problems, for spectral, grid-based and element-based modeling.
- Assessing the accuracy of and spread between existing modeling frameworks for standardized compressible and transient rheologies.
- Establishing and documenting standard tests and results that enable the community to calibrate current and future efforts to model surface loading problems.
- Encouraging open science and international collaboration for surface loading and geodetic science.

Program of Activities

- Creation of two benchmarks for modeling surface loading problems, the first one focusing on compressible Maxwell rheology and the second on linear transient rheology.
- Contribution to international meetings and conferences (e. g., by AGU and EGU).
- Co-organization of a session at the IUGG meeting in Incheon, South Korea, in 2027.
- Common publications by JSG members.
- Management of a website with updates on the development of the JSG and ensuring benchmark results remain perennially in open access for the community.

Members

Lambert Caron (USA); Chair
Rebekka Steffen (Sweden); Vice-Chair
Pingping Huang (UK)
Volker Klemann (Germany)
Harriet Lau (USA)
Tanghua Li (Singapore)
Andrew Lloyd (USA)
Anthony Purcell (Australia)
Daniele Melini (Italy)
Holger Steffen (Sweden)
Wouter van der Wal (Netherlands)
Doug Wiens (USA)

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