

## Commission 3 – Earth Rotation and Geodynamics

<http://euler.jpl.nasa.gov/IAG-C3>

*President: Richard Gross (USA)*

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### Overview

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 such as polar motion, length of day, precession and nutation, the observation and understanding of which are critical to the transformation between terrestrial and celestial reference frames. It includes tidal processes such as solid Earth and ocean loading tides, and crust and mantle deformation associated with tectonic motions and isostatic adjustment.

Commission 3 studies the entire range of physical processes associated with the motion and the deformation of the solid Earth. 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 the entire range of tidal phenomena including its effect on Earth rotation. Sub-Commission 3.2 (Crustal Deformation) addresses the entire range of global and regional crustal deformation including intraplate deformation, the earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. 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 the Earth's instantaneous and delayed responses to ice mass changes, including seasonal (cyclical) mass changes and progressive changes associated with climate change. This group also studies postglacial rebound at all spatial scales and the elastic deformation taking place in the near-field of existing ice sheets and glaciers. Sub-Commission 3.5 (Tectonics and Earthquake Geodesy) addresses the integration of space and terrestrial approaches for studying the kinematics and mechanics of tectonic plate boundary zones, and in particular of the Eurasian/African/Arabian boundary zone. Joint Study Group 3.1 is concerned with the comparison of ground and space gravity measurements with geometric measurements of surface deformation. IAU/IAG Joint Working Group 3.1 is concerned with developing fully consistent theories of the Earth's rotation that will meet the current and expected future accuracy requirements of the user community.

## **Sub-Commission 3.1: Earth Tides and Geodynamics**

*Chairs: Spiros Pagiatakis (Canada), Janusz Bogusz (Poland)*

Sub-Commission 3.1 addresses the entire range of Earth tidal phenomena, both on the experimental as well as on the theoretical level. Earth tide observations have a very long tradition. These observations led to the discovery of the Earth's elasticity which allows deformation and variations in Earth orientation and rotation parameters. The phenomena responsible for these variations include the full range of periodic and non-periodic phenomena such as Earth tides and ocean tidal loading, atmospheric dynamics 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. Thus, the time scales range from seconds to years and for the spatial scales from millimetres to continental dimensions.

### **17th International Symposium on Earth Tides**

Sub-Commission 3.1 organizes a symposium on Earth tides that is held every 4 years or so. The 17th International Symposium on Earth Tides was held in Warsaw, Poland during 15-19 April 2013. The theme of this Earth Tides Symposium (ETS) was "Understand the Earth". The Earth Tides Symposia are evolving to include all topics of interest to Commission 3 and ETS 2013 provided an opportunity to discuss not only tidal processes such as solid Earth and ocean loading tides but also crust and mantle deformations associated with tectonic motions, glacial isostatic adjustment, as well as the entire range of phenomena related to Earth rotation. There were 70 participants at the Symposium with 82 abstracts submitted and presented in 6 sessions. The proceedings of ETS 2013 are planned to be published as a special issue of the Journal of Geodynamics. More information about the symposium can be found at:  
<http://www.cgs.wat.edu.pl/ETS2013/>

### **Paul Melchior Medal**

The Paul Melchior Medal, formerly known as the Earth Tides Commission Medal, is awarded to a scientist for her/his outstanding contribution to international cooperation in Earth tides research. It was awarded for the fifth time to Houtze Hsu (China) and presented to him on April 18, 2013 at the 17th International Symposium on Earth Tides in Warsaw, Poland. Previous recipients of the medal have been Paul Melchior (Belgium), Hans-Georg Wenzel (Germany), John Goodkind (USA), and Bernard Ducarme (Belgium) and Tadahiro Sato (Japan).

## **Sub-Commission 3.2: Crustal Deformation**

<http://iagsc32.fgi.fi/>

*Chair: Markku Poutanen (Finland)*

There are many geodetic signals that can be observed and are representative of the deformation mechanisms of the Earth's crust at different spatial and temporal scales. These include the entire range of tectonic phenomena including plate tectonics, intraplate deformation, the earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. The time scales range from seconds to years and from millimetres to continental dimension for the spatial scales.

Space geodetic measurements provide nowadays the means to observe deformation and movements of the Earth's crust at global, regional and local scales. This is a considerable contribution to global geodynamics by supplying primary constraints for modeling the planet as a whole, but also for understanding geophysical phenomena occurring at smaller scales.

Gravimetry, absolute, relative and nowadays also spaceborne, is a powerful tool providing information to the global terrestrial gravity field and its temporal variations. Superconducting gravimeters allow a continuous acquisition of the gravity signal at a given site with a precision of  $10^{-10}$ . This is important in order to be able to detect and model environmental perturbing effects as well as the weak gravity signals associated with vertical crustal movements of the order of mm/yr. These geodetic observations together with other geophysical and geological sources of information provide the means to understanding the structure, dynamics and evolution of the Earth system.

Sub-Commission 3.2 addresses the entire range of global and regional crustal deformation including intraplate deformation, the earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. The Sub-Commission is divided into two Sub-Sub-Commissions, 3.2a on Global Crustal Deformation and 3.2b on Regional Crustal Deformation.

### **International Symposium on Geodesy for Earthquake and Natural Hazards**

Sub-Commission 3.2 is organizing an International Symposium on Geodesy for Earthquake and Natural Hazards that will be held in Matsushima, Japan during 22–25 July 2014. Various large-scale natural disasters, such as earthquakes, tsunamis, volcano eruptions, hurricanes, landslides, etc., repeatedly endanger human lives in many parts of the world. During the first decade of the 21st century, in spite of our developing technologies, more than 700 thousand people were killed by large earthquakes. The 2011 Tohoku earthquake and tsunami was one of those tragic events.

In order to mitigate natural hazards, monitoring changes in the Earth's lithosphere as well as the atmosphere is indispensable. Recent geodetic techniques, such as GNSS, SAR, satellite gravity missions, etc., have a significant contribution in that aspect.

In this symposium, researchers in related fields of geodesy will get together and discuss the role of geodesy in disaster mitigation and how groups with different techniques can collaborate toward such a goal. The symposium will be held in the Matsushima town on the Pacific coast of north-eastern Japan, which was heavily damaged by the 2011 tsunami.

## **Software Comparison Campaign**

Sub-Commission 3.2a is organizing a software comparison campaign to test different approaches for computing far-field co-seismic deformation. At least two distinct approaches have been used for these calculations in the past, but a careful software comparison has never been done before. We will use a common fault model and earthquake model, and assess how closely these approaches agree, and also how much accurate spherical layered models differ from the simple half space models commonly used by many. First comparison results are expected by the end of summer 2013. Assuming good agreement between software packages, we will then follow up with other tests to assess the sensitivity of different earth models and fault models, with a long-term goal of being able to provide realistic estimates and uncertainties of far-field co-seismic displacements from earthquakes on an ongoing basis.

### **Sub-Commission 3.3: Earth Rotation and Geophysical Fluids**

*Chairs: Maik Thomas (Germany), Jianli Chen (USA)*

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 geocentre 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.

The objective of the Sub-Commission 3.3 on Earth Rotation and Geophysical Fluids is to serve the scientific community by supporting research and data analysis in areas related to variations in Earth rotation, gravitational field and geocentre, caused by mass re-distribution 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.

#### **Activities during 2011–2013**

In order to promote the exchange of ideas and results as well as of analysis and modeling strategies, sessions at international conferences and topical workshops have been convened, including:

- Session G5.1 on “Observing and understanding Earth rotation variability and its geophysical excitation” at EGU 2012,
- Session G51A on “Earth Rotation: Past, Present, and Future” at the AGU 2012 Fall Meeting,
- Session G3.3 on “Observing and understanding Earth rotation variability and its geophysical excitation” at EGU 2013, and
- Theme 4 on “Science and Applications of Earth Rotation and Dynamics” at the IAG 2013 Scientific Assembly.

In addition, SC 3.3 has been active in preparing a physically consistent system model for simulation of Earth rotation and gravity field variability due to geophysical fluid dynamics. The current focus of this activity is the realization of mass conservation within the model and the improvement of model based short-term predictions of Earth rotation parameters.

### **Sub-Commission 3.4: Cryospheric Deformation**

*Chairs: Matt King (Australia), Shfaqat Abbas Khan (Denmark)*

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. Of principal interest is 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. Using geometric measurements alone, elastic and GIA deformations cannot be separated without additional models or observations. Reference frames of GIA models do not allow direct comparison to measurements in an International Terrestrial Reference Frame and ambiguity currently exists over the exact transformation between the two. Furthermore, there is no publicly available and easy-to-use tool for model computations of elastic effects based on observed elevation/mass changes over the spatial scales of interest (small valley glaciers to large ice streams) and including gravitational/rotational feedbacks. The focus of Sub-Commission 3.4 is on resolving these technical issues and working on dissemination of these measurements within the glaciological community.

#### **International Symposium on Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change**

Knowledge of present-day changes in the ice sheets and glaciers are critical to partitioning the individual sources of the well-observed global sea-level change. Similarly, knowledge of past changes is required to advance understanding of the paleo sea level budget and also provide the context for present-day changes. Both past and present changes in the mass balance of the Earth's glaciers and ice caps induce present-day deformation of the solid Earth on a range of spatial scales, from the very local to global. Observations of present-day changes in Earth's shape, gravity field and rotation are therefore sensitive to changes in ice load over a large range of time-scales.

Particularly relevant to this are data from GRACE, and proposed follow-on missions, which require accurate removal of glacial isostatic adjustment (GIA) to obtain present-day ice mass balance. Likewise, the increasing network of geodetic measurements, especially continuous GPS, in presently, or formerly, glaciated regions may validate, or be assimilated into, models of GIA and/or constrain models of present-day ice mass change through measurements of elastic rebound. Notable here are the International Polar Year POLENET networks of Greenland and Antarctica. It is impossible to interpret data or validate or improve models of the kind mentioned here without close interaction between a wide group of geophysicists.

Sub-Commission 3.4 organized an International Symposium on Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change with the objective of enabling this interaction and creating new collaborations through the discussion of the results of scientific studies focused on visco-elastic deformation of the solid Earth due to ice (un)loading. The symposium brought together those working on observation and modeling of cryospheric change and solid earth response to further our understanding of the Earth system. The symposium was held in Ilulissat, Greenland during 30 May – 2 June 2013. Over 50 abstracts were submitted and presented in 4 sessions. Nearly 60 scientists were in attendance across the fields of geodesy, seismology, GIA modeling and glaciology and about one third were early career scientists.

Significant funding was obtained from IAG, SCAR SERCE, EGU, NSF, DynaQlim and Danish Technical University which largely supported travel of early career researchers to the meeting.

## **Sub-Commission 3.5: Tectonics and Earthquake Geodesy**

*Chair: Haluk Özener (Turkey)*

Sub-Commission 3.5, Tectonics and Earthquake Geodesy (WEGENER group), aims to encourage cooperation between all geoscientists studying the Eurasian/African/Arabian plate boundary deformation zone with a focus on mitigating earthquake, tsunami, and volcanic hazards. Towards these ends, we organize periodic workshops and meetings with special emphasis on integrating the broadest range of Earth observations, sharing analysis and modelling approaches, and promoting the use of standard procedures for geodetic data acquisition, quality evaluation, and processing. WEGENER organizes dedicated meetings, arranges special sessions in other international meetings, organizes special issues in peer-reviewed journals, and takes initiative to promote and facilitate open access to geodetic databases.

### **Meetings Organized**

WEGENER organizes bi-annual conferences to serve as high-level international forums in which scientists from all over the world share results, and strengthen collaborations between countries in the greater Mediterranean region and beyond. In this respect, the 16<sup>th</sup> General Assembly of WEGENER was organized in Strasbourg, France between 17 and 20 September 2012. The meeting was hosted by Institut de Physique du Globe et Ecole et Observatoire des Sciences de la Terre of the University of Strasbourg.

Around 100 scientists from all around the world attended the meeting. A total of 57 oral and 37 poster presentations were made. The meeting was conducted on six different topics in six sessions. Each session had its own oral and poster presentations. This gave the attendees the chance to participate in the sessions covering their research interests.

Information and experience in the use of geodetic methods for geodynamic studies such as GPS, InSAR, and terrestrial methods were shared in a wide range of applications from large scale studies such as the studies of continental boundaries to small scale studies such as local observations focusing on single faults. Invited talks enabled the attendees to keep up with the latest research of world leading scientists and the latest technological developments in instrumentation, analysis, modeling, and interpretation. The meeting was carried out in a workshop form, including extensive and inclusive discussions of the results and the methods presented within each session.

Detailed information about the 16<sup>th</sup> General Assembly of WEGENER can be found at: <http://wegener2012.sciencesconf.org/>

### **WEGENER Sessions in other Scientific Meetings**

#### *EGU 2011*

During the EGU General Assembly 2011, a session titled “Geodesy and natural and induced hazards: Progress during 30 years of the WEGENER initiative” was convened by Susanna Zerbini, Robert Reilinger, and Mustapha Meghraoui. Eighteen oral talks were presented in two successive sessions. There were also 25 poster presentations presented. More detailed information can be found at:

<http://meetingorganizer.copernicus.org/EGU2011/session/7048>

## *AGU 2012*

The 45th Annual Fall Meeting of the American Geophysical Union (AGU) was held in San Francisco, CA, USA in 2012 between 3 and 7 December. Being the largest worldwide conference in the geophysical sciences, the AGU Fall Meeting attracted more than 23,000 earth and space scientists, educators, students, and other leaders. Nearly 14,000 posters and more than 6,800 oral presentations were given in parallel sessions. More than 270 exhibitors also took place during the meeting. Besides these, numerous workshops, town halls and social and networking events took place during the organization. Thus, this meeting provided an ideal opportunity to highlight WEGENER's accomplishments to the Earth science community, and to develop synergies with other organizations such as EPN/EUREF, EPOS, CEGRN, and UNAVCO to further our mutual objectives of mitigating natural and anthropomorphic hazards.

A dedicated session titled "Geodesy and Natural and Induced Hazards: Progress During 32 Years of the WEGENER Initiative" was held during the AGU meeting. The session consisted of eight oral and fifteen poster presentations and attracted many international scientists' interests. The topics of the presentations were broad ranging from studies that focused on a single fault to large-scale studies of continental boundaries. Invited talks also took place during this session. One of the invited talks was given by David E. Smith who was awarded the 2012 Charles A. Whitten Medal of the AGU. Information and experiences about the use of geodetic technologies in geodynamic studies was shared and discussed within the session thus giving the attendees the chance to be aware of recent studies of the world leading scientists. This session was chaired by Haluk Ozener, Susanna Zerbini and Robert Reilinger. Details can be found at:

<http://www.agu.org/cgi-bin/sessions5?meeting=fm12&part=G52A>

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## **Publications**

### *Journal of Geodynamics Special Issue*

A special issue of Journal of Geodynamics was arranged for WEGENER 2010. This special issue includes papers presented at the 15th General Assembly of WEGENER, held in Istanbul, Turkey, September 14–17, 2010. This biannual meeting was organized by the Bogazici University and hosted at the Albert Long Hall Conference Center. The 2010 WEGENER Conference brought together many experts from all around the world with a wide spectrum of Earth Sciences disciplines and provided an opportunity for the presentation of state-of-the-art results focusing on the "greater" Mediterranean region (Europe, Asia Minor, North Africa, and Arabia). There were 80 presentations at the meeting; this special issue includes a selection of 12 peer-reviewed manuscripts derived from these presentations. The papers in this volume reflect the application of new, as well as mature, space and terrestrial-based methods including, geodetic, gravimetric, radar technologies, environmental, and neo-tectonic observations and highlight the importance of integrated regional and global scale studies of the Earth System. A special paper describing the some of the accomplishments of WEGENER and our new focus on hazards was included in the Special Issue. Details can be found at:

<http://www.sciencedirect.com/science/journal/02643707/67>

## **Other Activities**

An effort to identify a “WEGENER Supersite” was initiated by SC 3.5 members, Susanna Zerbini and Meghan Miller, addressing one of the goals of SC 3.5. The supersite initiative is intended to solidify and extend international cooperation between WEGENER scientists, to provide broad access to invaluable data for constraining geodynamic processes, and to facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geo-processes.

Former WEGENER president, Susanna Zerbini was elected a member of the Scientific Advisory Committee for GEO-Supersites which will strengthen the ties between WEGENER and other international scientific organizations and reinforce cooperation with African and Arab countries as well as other international scientists studying these problems. We anticipate these developments will contribute to our understanding the kinematics and dynamics of the Eurasian/African/Arabian plate boundary zone providing an improved physical basis for hazard mitigation, and will promote the growth of such research and geodetic expertise in these countries.

## Joint Study Group 3.1: Gravity and Height Change Intercomparison

<http://www.srosat.com/iag-jsg/>

*Chair: Séverine Rosat (France)*

Surface deformations are continuously recorded from space or from the ground with increasing accuracy. Vertical displacements and time-varying gravity are representative of various deformation mechanisms of the Earth occurring at different spatial and temporal scales. We can quote for instance post-glacial rebound, tidal deformation, hydrologic loading, co-seismic deformation and volcanic deformation. The involved time scales range from seconds to years and the space scales range from millimetres to continental dimension. Large-scale deformations are well monitored by space geodetic measurements from monthly spatially averaged GRACE measurements while local deformation are precisely monitored by daily GPS or VLBI solution and sub-daily gravimeter data at a site. The intercomparison of the space- and ground-gravity measurements with vertical surface displacements enable to infer more information on the structure, dynamics and evolution of the Earth system. In particular, the transfer function of the Earth at various time-scales related to the elastic and visco-elastic properties of the Earth are a focus of activity.

Joint Study Group 3.1 on Gravity and Height Change Intercomparison is joint between Commission 1 on Reference Frames, Commission 2 on Gravity Field and Commission 3 on Earth Rotation and Geodynamics and is reporting to Commission 3. The activities of the Joint Study Group concern the comparison of ground and space gravity measurements with geometric measurements of surface deformation. The motivation of this Joint Study Group is to study surface deformation by comparing site displacement observations with both ground- and space-based gravity measurements. Issues that will arise when comparing site displacement with gravity measurements are differences in spatial and temporal scales and differences in sensitivity.

### Activities during 2011–2013

The Joint Study Group participated in the 17th Earth Tides Symposium that was held in Warsaw, Poland during 15–19 April 2013 by convening a session on *Gravity and Height Changes: Comparison with GPS*.

A review paper on the difficulties and techniques to compare space/ground gravity and height changes is in preparation. A talk on this subject was presented at the Earth Tides Symposium.

A bibliography of relevant papers has been compiled and is available at:

<http://www.srosat.com/iag-jsg/papers.php>

Load Love numbers for a PREM-like model (PREM with the ocean layer replaced by crust) have been computed and are available at:

<http://www.srosat.com/iag-jsg/loveNb.php>

## Joint Working Group 3.2: Theory of Earth Rotation

*Chair: Jose Ferrándiz (Spain)*

The purpose of the International Astronomical Union / International Association of Geodesy (IAU/IAG) Joint Working Group (JWG) on Theory of Earth Rotation is to promote the development of theories of Earth rotation that are fully consistent and that agree with observations and provide predictions of the Earth rotation parameters (ERPs) with the accuracy required to meet the needs of the near future as recommended by, for example, IAG's Global Geodetic Observing System. Recent efforts have not led to improvements in the accuracy of theoretical models of the Earth's rotation that approach the required millimetre level, so there is a strong need to develop such theories to meet the current and future accuracy of the observations.

A main objective of the JWG is to assess and ensure the level of consistency of ERP predictions derived from theories with the corresponding ERPs determined from analyses of the observational data provided by the various geodetic techniques. Consistency must be understood in its broader meaning, referring to models, processing standards, conventions etc. In addition, clearer definitions of polar motion and nutation are needed for both their separation in observational data analysis and for use in theoretical modelling.

The derivation of comprehensive theories accounting for all relevant astronomical and geophysical effects and able to predict all ERPs is sought. In case more than one theory is needed to accomplish this, their consistency should be ensured. Searching for potential sources of systematic differences between theory and observations is encouraged, including potential effects of differences in reference frame realization. Theoretical approaches must be consistent with IAU and IAG Resolutions concerning reference systems, frames and time scales.

There are no *a priori* preferred approaches or methods of solution, although solutions must be suitable for operational use and the simplicity of their adaptation to future improvements or changes in background models should be considered. The incorporation into current models of corrections stemming from newly studied effects or improvements of existing models may be recommended by the JWG when they lead to significant accuracy enhancements.

### Activities during 2011–2013

The JWG was established in 2013 and is just starting to organize its activities. Since the subject of the JWG is quite broad, three Sub-Working Groups (SWGs) have been formed: (1) Precession/Nutation chaired by Juan Getino of Spain, (2) Polar Motion and UT1 chaired by Aleksander Brzezinski of Poland, and (3) Numerical Solutions and Validation chaired by Robert Heinkelmann of Germany. The subjects of SWG 1 and 2 are self-explanatory. The subject of SWG 3 is numerical theories and solutions, relativity and new concepts, and validation by comparisons among theories and observational series.

Guidelines for the operation of the JWG have been drafted. A web site for the JWG is under development. The first meeting of the JWG will be held in conjunction with the IAG Scientific Assembly in Potsdam, Germany. A dedicated JWG workshop is being planned for 2014. Presentations about the JWG and its activities are being planned to be given at the IAG Scientific Assembly, the Journées 2013 Systèmes de Référence Spatio-Temporels in Paris, France, and the 2013 AGU Fall Meeting in San Francisco, California.