



# **International Association of Geodesy**

## **TRAVAUX**

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## **Introduction**

The reports of the International Association of Geodesy are published regularly since 1923 (Tome 1). They were called “Travaux de la Section de Géodésie de l'Union Géodésique et Géophysique Internationale” in the first years. In 1938 the name was changed to “Travaux de l'Association de Géodésie”. They were published on the occasion of the IUGG General Assemblies, which were held every three years until 1963, and since then every four years. These volumes serve as a comprehensive documentation of the work carried out during the past period of three or four years, respectively. The reports were published until 1995 (Volume 30) as printed volumes only, and since 1999 (Volume 31) in digital form as CD and/or in the Internet.

Since 2001 there are also midterm reports published on the occasion of the IAG Scientific Assemblies in between the General Assemblies. Usually they are presented before the Assembly to the IAG Executive Committee (EC) and are discussed in the EC meetings in order to receive and give advices for the future work. The present Volume 38 contains the midterm reports of all IAG components for the period 2011 to 2013 and is presented at the IAG Scientific Assembly in Potsdam, Germany, September 1-6, 2013.

The editors thank all the authors for their work. A feedback of the readers is welcome. The digital versions of this volume as well as the previous ones since 1999 may be found in the IAG Office homepage (<http://iag.dgfi.badw.de>). Printed versions are available on request.

Hermann Drewes  
IAG Secretary General

Helmut Hornik  
Assistant Secretary



## Commission 1 – Reference Frames

<http://iag.uni.lu>

*President: Tonie van Dam (Luxemburg)*  
*Vice President: Gary Johnston (Australia)*

### Structure

Sub-Commission 1.1:	Coordination of Space Techniques
Sub-Commission 1.2:	Global Reference Frames
Sub-Commission 1.3:	Regional Reference Frames
Sub-Commission 1.3 a:	Europe
Sub-Commission 1.3 b:	South and Central America
Sub-Commission 1.3 c:	North America
Sub-Commission 1.3 d:	Africa
Sub-Commission 1.3 e:	Asia-Pacific
Sub-Commission 1.3 f:	Antarctica
Sub-Commission 1.4:	Interaction of Celestial and Terrestrial Reference Frames
Joint Working Group 1.1:	Tie vectors and local ties to support integration of techniques
Joint Working Group 1.2:	Modelling environmental loading effects for reference frame realizations
Joint Working Group 1.3:	Understanding the relationship of terrestrial reference frames for GIA and sea-level studies
Joint Working Group 1.4:	Strategies for epoch reference frames

### Overview

Commission 1 deals with the theoretical aspects of 1) defining reference systems for geodetic and scientific applications; 2) the practical applications of reference frame realizations; and 2) applied research in reference frame development.

The main objectives of Commission 1 are:

- Definition, establishment, maintenance and improvement of the geodetic reference frames;
- Advanced terrestrial and space observation technique development for the above purposes;
- International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories;
- Theory and coordination of astrometric observation for reference frame purposes.
- Collaboration with space geodesy/reference frame related international services, agencies and organizations; and
- Promote the definition and establishment of vertical reference systems at global level, considering the advances in the regional sub-commissions.

## **Introduction**

The main activities of Commission 1 during the period 2011-2013 include the following:

- A dedicated web site was established immediately after the IUGG General Assembly in Melbourne, where the new Commission members were approved by the IAG Executive Committee. The Web site (<http://iag.uni.lu>) contains all the information related to the activities and objectives of the commission, its sub-commissions, projects and Working Groups. The Web site is regularly updated directly by the president; Sub-commissions and sub-components prefer to have control over their own websites; links to those websites can be found at the Commission 1 website.
- The terms of reference for the new Commission 1 were compiled
- Contributed to JWG 1.4 activities

## **Main highlights of the activities of Commission 1 Sub-components**

### *Sub-commission 1.1: Coordination of Space Techniques*

The activities of SC-1.1 where significant progress has been made since 2011 are the following:

- Studying the systematic effects of and between space geodetic techniques.
- Develop common modeling standards and processing strategies.
- The development of innovative combination aspects such as, e.g., GPS and VLBI measurements based on the same high-accuracy clock, VLBI observations to GNSS satellites, and the combination of atmospheric information (troposphere and ionosphere) of more than one technique.
- Validation of the GGFC fluid models
- An analysis of combining Synthetic Aperture Radar (InSAR), LIDAR and optical image analysis methods.

### *Sub-commission 1.2: Global Reference Frames*

Highlights of the activities of SC-1.2 include the following:

- A detailed article on ITRF2008 was prepared and published in 2011 in the Journal of Geodesy
- The estimation of a plate motion model consistent with ITRF2008
- Workshop on Site Surveys and Co-location, Paris, May 2013

### *Sub-commission 1.3: Regional Reference Frames*

The main activities of SC-1.3 are the following:

- Increase of the number of GNSS permanent stations within the 6 regional sub-commissions;
- The preparation for the future Galileo system and the development of the EPN towards a multi-system GNSS network started
- The number of continuously operating GNSS stations that support the SIRGAS Reference Frame is still growing. It is composed by about 300 stations, 140 of which with GLONASS capability, and 60 with real time data transfer;



- The densification of the ITRF and IGS network is made by weekly combinations of 5 regional weekly solutions using different GPS processing software;
- The increase of the number of stations of the CORS network (approximately 480 stations from 28 countries), whose data are processed by three Analysis Centres (ACs). The increase of the number of institutions contributing to APREF in several domains (analysis, archive and stations). The availability of a weekly combined regional solution, in SINEX format and a cumulative solution which includes velocity estimates.
- The realization of SCAR GPS Campaigns in 2012 and 2013. The data of 40 Antarctic sites are collected in the SCAR GPS database since 1995.

*Sub-commission 1.4: Interaction of Celestial and Terrestrial Reference Frames*

Together with the Working Group Chairs, Johannes Böhm, summarized the main challenges to be addressed in determining the terrestrial and celestial references in the proceedings paper for the IVS General Meeting 2012 in Madrid, Spain (Böhm et al., 2012).

The biggest challenge facing the group before the next ICRF will be to determine whether the contributions from geodetic techniques other than VLBI are significant to determining the ICRF or whether they degrade the product.

*Joint Working Group 1.1: Tie vectors and local ties to support integration of techniques*

JWG 1.1 organized a workshop on site surveys and co-location sites, May 2013 in Paris. One of the most important outcomes of the workshop is a list of recommendations that were identified in an open discussion with all the participants. The document sets out tasks with deadlines and assigns an individual to lead each task. The main tasks were outlined as follows:

- Define a clear nomenclature and terminology to be adopted for local tie discussions;
- Define the models to be adopted in the local tie survey data reduction;
- Propose a survey priority list for the next ITRF2013 computation;
- Recommend a surveying frequency;
- Create a local survey data archive; and
- Prepare of a draft document containing the site survey guidelines and specifications.

*Joint Working Group 1.2: Modelling environmental loading effects for reference frame realizations*

The activity of the working group has been dominated by the IERS campaign “for space geodetic solutions corrected for non-tidal atmospheric loading”, an action item defined at the Unified Analysis Workshop 2011. A call for participation was sent to the analysis technique coordinators of every service in the beginning of 2012. A 6-year loading data set has been generated at The Global Geophysical Fluid Center (GFC) to be used a priori in the data processing of the space geodetic technique observations. Analysis Centres from the four technique services have submitted 12 individual solutions from GNSS, Satellite Laser Ranging (SLR, Very Long Baseline Interferometry (VLBI) and Doppler Orbitography Integrated by satellite (DORIS). These solutions have been analyzed to determine:

- The effect of non-tidal atmospheric loading on the TRF datum and the Earth Orientation Parameters (EOPs);

- The effect of non-tidal atmospheric loading on individual averaged coordinates and velocities; and
- The level of agreement between a priori corrections and a posteriori corrections.

Preliminary results were presented at the EGU in 2013. They are of particular importance for the generation of future TRFs. This effort goes beyond just addressing the bullets above. The main success of this exercise is that it has catalyzed an open dialogue between modeling experts and technique ACs. A splinter meeting has been organized on Wednesday 10th of April 2013 at the EGU and another is planned in 2014.

*Joint Working Group 1.3: Understanding the relationship of terrestrial reference frames for GIA and sea-level studies*

The Working Group has been focusing on evaluating the effects of static- and time-varying orbits on the reference frame.

- They find that the time-variable coefficients in the gravity fields map into apparent changes in sea-level.

*Joint Working Group 1.4: Strategies for epoch reference frames*

The results of the research activities of this JWG demonstrate that:

- The time series of weekly epoch reference frames approximate the complete station motion (linear and non-linear part) very well;
- Neglecting non-linear station motions in long-term reference frames affects the consistently estimated EOP-series by annual and semi-annual signals (Bloßfeld et al, submitted to J Geod). EOP's of epoch reference frames are not affected, because the station motions are fully considered by the highly resolved station position parameters; and
- Epoch reference frames do not provide as strong of a long-term stability as long-term reference frames do. Further research is needed to improve the long-term stability of the epoch reference frames. The weekly combination at the observation level of GNSS and SLR (via satellite co-location) leads to very promising results, which allow (i) the transfer of the SLR-derived centre-of-mass of the Earth to GNSS station network with very high accuracy and (ii) for a validation of the local ties at ground sites.

## **Sub-Commission 1.1: Coordination of Space Techniques**

*Chair: Tom Herring (USA)*

The space geodetic observation techniques, including Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR/LLR), Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS, GALILEO, and COMPASS, and the DORIS system, as well as altimetry, InSAR, LIDAR, and the gravity missions, contribute significantly to the knowledge about and the understanding of the three major pillars of geodesy: the Earth's geometry (point coordinates and deformation), Earth orientation and rotation, and the gravity field as well as its time variations. These three fields interact in various ways and they all contribute to the description of processes in the Earth System. Each of the space geodetic techniques contributes in a different and unique way to these three pillars and, therefore, their contributions are critical to the Global Geodetic Observing System (GGOS).

Sub-Commission 1.1 coordinates efforts that are common to more than one space geodetic technique, such as models, standards and formats. It shall study combination methods and approaches concerning links between techniques co-located at fundamental sites, links between techniques co-located onboard satellites, common modeling and parameterization standards, and perform analyses from the combination of a single parameter type up to a rigorous combination on the normal equation (or variance-covariance matrices) as well as at the observation level. The list of interesting parameters includes site coordinates (e.g. time series of combined solutions), Earth orientation parameters, satellite orbits (combined orbits from SLR, GPS, DORIS, altimetry), atmospheric refraction (troposphere and ionosphere), gravity field coefficients, geocentre coordinates, and others. One important goal of SC1.1 will be the development of a much better understanding of the interactions between the parameters describing geometry, Earth rotation, and the gravity field as well as developing methods to validate combination results, e.g., by comparing them with independent geophysical information.

To the extent possible SC1.1 should also encourage research groups to develop new observation techniques connecting or complementing the existing set of measurements.

Sub-Commission 1.1 has the task to coordinate the activities in the field of the space geodetic techniques in close cooperation with GGOS, all of the IAG Services, and with COSPAR.

### **Objectives**

The principal objectives of the scientific work of Sub-Commission 1.1 in collaboration with GGOS are the following:

- Study systematic effects of and between space geodetic techniques.
- Develop common modeling standards and processing strategies.
- Comparison and combination of orbits derived from different space geodetic techniques.
- Explore and develop innovative combination aspects such as, e.g., GPS and VLBI measurements based on the same high-accuracy clock, VLBI observations to GNSS satellites, and the combination of atmospheric information (troposphere and ionosphere) of more than one technique.
- Establish methods to validate the combination results (e.g., with global geophysical fluids data).

- Explore, theoretically and practically, the interactions between the gravity field parameters, EOPs, and reference frames (site coordinates and velocities plus extended models), improve the consistency between these parameter groups, and assess, how a correct combination could be performed.
- Study combination aspects of new geodetic methods such as Synthetic Aperture Radar (InSAR), LIDAR and optical image analysis methods.
- Additional objectives of Sub-Commission 1.1 are:
- Promotion of international scientific cooperation.
- Coordination of common efforts of the space geodetic techniques concerning standards and formats (together with the IERS and GGOS).
- Organization of workshops and sessions at meetings to promote research. - Establish bridges and common activities between SC1.1 and the IAG Services.

### **Links to Services**

Sub-Commission 1.1 will establish close links to the relevant services for reference frames, namely Global Geodetic Observing System (GGOS), International Earth Rotation and Reference Systems Service (IERS), International GPS Service (IGS), International Laser Ranging Service (ILRS), International VLBI Service for Geodesy and Astrometry (IVS), and International DORIS Service (IDS) and the International gravity services.

### **Working Groups:**

#### **WG 1.1.1: Creation of common geodetic coordinate time series**

**Chair:** Laurant Soudarin (Laurent.Soudarin@cls.fr)

#### **Members**

- Bernd Richter (BKG) GGOS portal manager
- Thomas Herring (MIT) IERS Analysis Coordinator
- Xavier Collilieux (IGN) ITRS Combination Center
- Manuela Seitz (DGFI) ITRS Combination Center
- Laurent Soudarin (CLS) IDS representative
- Paul Rebischung (IGN) IGS representative
- Erricos Pavlis (Univ. of Maryland, Baltimore County) ILRS representative
- Alexis Nothnagel (Uni. Bonn) IVS representative
- Médéric Gravelle (Uni. La Rochelle) user (SONEL)
- Yehuda Bock (Scripps Institution of Oceanography) user (SOPAC GPS webservice)
- Simon Williams (Proudman Oceanographic Laboratory) user (CATS software)
- Xiaoping Wu (JPL) user

The temporal variations of the position of points on the Earth's surface are useful observations to monitor geophysical process (land deformation, post-glacial rebound, seismic activity...). The IAG services that distribute GNSS, SLR, VLBI and DORIS data and products proposes plots and/or files of coordinates time series for the stations of the tracking networks, as well as web services to display these time series. However, the time series, when available, are proposed in different formats and give position series under various forms (residuals, trended or detrended, cartesian or geographic coordinates...).

One of the outcomes of the Unified Analysis Workshop 2011 (UAW 2011) in Zurich was the action item to establish an IERS Working Group on site coordinates time series to define a common exchange format for coordinates time series for the geodetic techniques.

The format should provide a user-friendly presentation of coordinate time-series results for a potentially broader community of users. One of the objectives of the group is to define the data and meta-data to be included so that the format is self-described and can be easily used or converted for, at least, the existing web tools of the IAG Services (GGOS, IERS, IDS, IGS, ILRS, IVS). The group will ensure that comparisons of time series can so be possible between GNSS, SLR, VLBI and DORIS, but also with other techniques such as tide gauges records. Some of the issues that should also be addressed are, e.g., reference system, time unit, content description etc.

### **Goals and objectives**

The major goals and objectives of the WG are:

- Define a common exchange format for coordinate time series of all geodetic techniques (DORIS, GNSS, SLR, VLBI...).
- Examine what type of time series is required (geocentric, detrended, reference frame,...)
- Define the data and meta-data that should be included in the format
- Ensure that the format contains the necessary information to be easily used or converted for the web tools of the IAG Services (GGOS, IERS, IDS, IGS, ILRS, IVS)

#### **WG 1.1.2: Investigate methods for merging geodetic imaging systems (InSAR, LIDAR and optical methods) into a geodetic reference system.**

- Chair Lead: Sebastien Leprince, California Institute of Technology
- Members: Francois Ayoub, California Institute of Technology
- Jean-Philippe Avouac, California Institute of Technology
- Bruno Conejo, California Institute of Technology
- Jiao Lin, California Institute of Technology
- Sang-Ho Yun, NASA/JPL
- Piyush Shanker Agram, NASA/JPL
- Mark Simons, California Institute of Technology

With the development of new methods for studying surface deformations, such as InSAR, LIDAR and optical methods, this working group will explore the methods that should be used to ensure that these deformation measurements are made in a well-defined geodetic reference frame. Issues to be addressed include how to establish the reference frame for these classes of measurements, how to ensure the long-term stability of the reference frame, and to make recommendations for changes in future systems that would allow more robust frame realization.

Activities of this geodesy group have focused around five main activities dedicated to producing dense and precise observations of ground deformation and changes using remote sensing systems. Group members have been meeting regularly and have been working in close collaboration on these topics:

### **3D estimation of ground motion using multi-temporal optical acquisitions**

Participants: Sebastien Leprince, Francois Ayoub, Jean-Philippe Avouac

This topic aims at taking advantage of the newly available high-resolution stereoscopic acquisitions from optical pushbroom satellites such as Worldview, Quickbird, or Pleiades. Using multi-temporal stereoscopic acquisitions, ground motion can be observed in three-dimension, with accuracy within tens of centimetres, and measurement density of one observation distributed every couple meters or so. This group aims at improving this technique to make it reliable and current study areas involve the 2010 El-Mayor Cucapah earthquake in Baja California, Mexico, and the observation of fast flowing alpine glaciers in New-Zealand, in particular the Franz Josef and the Fox Glaciers.

### **3D matching of 3D point clouds**

Participants: Bruno Conejo, Sebastien Leprince, Francois Ayoub, Jean-Philippe Avouac

This topic aims at providing a new framework to extract three-dimensional measurement of deformation from point cloud data of surfaces. Point cloud data of surfaces can be generated from stereoscopic acquisition of optical imagery, or directly from LiDAR imaging technology. It has appeared to us that the computer vision community is indeed lacking such expertise providing precise measurements of surface deformation. The work currently involves formulating a regularized matching function of 3D point clouds, assuming a continuous deformation field, with potentially high deformation gradients. Test cases are currently being investigated using airborne LiDAR time series of the migrating White Sand Dunes in New Mexico.

### **Development of InSAR time-series analysis tools**

Piyush Shanker Agram, Mark Simons

The project involves the development of a multi-scale wavelet-based InSAR time-series technique to extend the current MInTS processor, based on Short Baseline and Persistent Scatterer techniques.

A new simple covariance model has been developed for time-series techniques. Simple analytical models for decorrelation and atmospheric inhomogeneities in individual interferograms have been around for the last decade, but no work has been undertaken to model the covariance structure of interferometric phase - both in space and in time. Understanding the structure of the covariance matrix is key to designing optimal interferogram networks and to quantify the errors in the estimated time-series.

### **Damage detection of buildings combining multi-temporal stereo imagery and SAR decorrelation maps**

Participants: Sebastien Leprince, Jiao Lin, Sang-Ho Yun, Mark Simons

This topic aims at merging information from optical satellite and SAR satellite sensors to provide rapid estimate of damages following large disasters around urban areas. Our approach relies on producing accurate maps of building heights using optical stereoscopic acquisitions.

The challenge is to provide an automatic and reliable technique to produce 3D maps of buildings from space. Comparing building heights before and after an event provides good estimate of potential building collapse. In addition, the study of the phase decorrelation of SAR images acquired before and after an event has been found to be a reliable proxy to estimate zones affected by large disasters. This group is currently working on merging both techniques (stereo optical and SAR decorrelation) to produce more accurate damage maps estimation. On-going studies are currently focused on data that were collected during the 2010 earthquake near the city of Christchurch, New Zealand.

### **Datum inconsistencies in the processing of satellite imagery on Mars**

Participants: Francois Ayoub, Sebastien Leprince, Jean-Philippe Avouac

Planetary bodies such as Mars have very few reference surfaces and projections available compared to Earth. This should be an advantage to limit the confusion surrounding the projections and datum conversions. On Mars, the traditional map projections used by the imagery community are the equirectangular and polar stereographic. However, the equirectangular projection is defined for a spheroid and not an ellipsoid reference surface. The spheroid radius is chosen arbitrarily by the user to best match the local radius of the area of interest. With the multiplication of imagery available and the increasing needs to put in a common projection system various source of imagery, this poses the immediate problem of potential different radius for the same area. For instance, the MOLA geoid reference is defined with respect to a spheroid of radius 3396 km, and the USGS is delivering DEMs and orthophotos of MRO imagery with respect to a spheroid whose radius is defined locally (unique radius per 5 degrees latitude increment). To avoid much of the confusion it would be convenient to define a cartographic projection that relies on an ellipsoidal reference surface, for instance the one defined by IAU 2000, in order to remove the arbitrarily-chosen spheroid radius issue and have a unique projection system, which would allow faster and easier merging and comparison of all the data now being collected on Mars.

The studies of this group have been supported by the Keck Institute of Space Studies, The Gordon and Betty Moore Foundation through Grant GBM 2808 to the Advanced Earth Observation Project at Caltech, by the NASA MDAP# 11-MDAP11-0013 grant, and by the NASA/JPL R&TD grant to the ARIA project.

## **Sub-Commission 1.2: Global Reference Frames**

*Chair: Claude Boucher (France)*

IAG Sub-Commission 1.2 was created in 2003 as a part of the new structure of the International Association of Geodesy (IAG). It is engaged in scientific research and practical aspects of the global reference frames. It investigates the requirements for the definition and realization of the terrestrial reference systems and frames, addresses fundamental issues, such as global geodetic observatories or methods for the combined processing of heterogeneous observation data.

Numerous activities are actually realized in other IAG-related structures, mainly:

- Sub-commission 1. On Regional reference frames, including EUREF, SIRGAS...
- International Earth Rotation and Reference Systems Service (IERS)
- Other relevant IAG services (IGS, ILRS, IVS, IDS)
- IAG Global Geodetic Observing System (GGOS)
- Inter-Commission Committee on Theory.

We therefore encourage to refer to their individual reports.

Beyond IAG, cooperation with other relevant international organizations such as IAU, FIG or ISO are also developed.

This report is not intended to be a comprehensive survey of these activities. This will be realized by the final report for 2011-2014. This report selected several topics where progresses were achieved or conversely need to be done. For each one, a short summary report is given, with a list of meetings in which sessions were devoted to the topic and a bibliography.

### **1. Relativistic modelling**

This topic is of great interest and was identified as one of the goals of the sub-commission. Two specific points were identified:

- Extension of the IAU model to geodesy
- Investigations on the use of emission coordinate systems

Detailed report on IAU model will be published in the final report.

### **Emission coordinates and relativistic reference frames**

The development of the concept of emission coordinates (Coll and Morales 1991, Rovelli 2002, Blagojevic, Garecki, Hehl, and Obukhov 2002, Lachize-Rey 2006) led to new ideas about the realization of global reference frames. Clocks combined with time transfer techniques are powerful tools for positioning in the 4 dimensional space-time, and it has been suggested to use a constellation of clocks linked one to another with a time transfer technology, so called Inter-Satellite Links (ISLs), in order to build a satellite-based dynamical reference frame (Coll 2002). Such constellations are already a reality with GNSS (GPS, Galileo, GLONASS, Beidou), and the last generation of GPS implemented such links (NAVSTAR). It is planned to be implemented on the second generation of Galileo satellites (2020).



Inter-satellite links (ISLs) allow to directly synchronize the satellite clocks in space, and determine orbits using ISLs pseudo-ranges. This realizes an autonomous, four-dimensional, dynamical and relativistic reference frame, so-called the ABC (Autonomous Basis of Coordinate) frame (Delva et al 2011 bis, Gombac et al 2013). The benefit of such a reference system compare to the actual GNSS process is to separate the realization of the frame from the determination of Earth-specific parameters, such as the ground station coordinates, Earth rotation parameters and atmospheric parameters. Indeed the realization of the frame relies only on ISLs observables. Such a frame would be decoupled from an Earth fixed frame and even from a celestial frame. It would shine a new light on the space-time geometry around the Earth. Indeed, the space ensemble of clocks can be used to monitor Earth based clocks and determine their trajectories and the Earth gravity field (thanks to the redshift effect), and therefore link the ABC dynamical frame to an Earth fixed frame. Clock accuracies regarding the gravitational potential determination and height determinations begin to be competitive with classical techniques, e.g. in the sub-decimeter range for the determination of the geoid.

Several teams are developing concepts around relativistic positioning systems, and a workshop has been organized to exchange and foster new ideas: "Relativistic Positioning Systems and their Scientific Applications". It took place in Brdo near Kranj, Slovenia 19-21 September 2012. Proceedings have been published in Acta Futura in 2013 (<http://dx.doi.org/10.2420/ACT-BOK-AF07>).

## **2. ITRF**

More details can be found in the report from the IERS ITRS Product Center. In general research activities related to ITRF are developed by three groups in the frame of IERS: DGFI, IGN and JPL.

### **ITRF2008 results**

The ITRF2008 solution was released in May 2010. A dedicated website has been established ([http://itrf.ign.fr/ITRF\\_solutions/2008/](http://itrf.ign.fr/ITRF_solutions/2008/)) providing full description of ITRF2008 solution, together with all associated products: station positions and velocities of the 920 stations (located at 580 sites) in SINEX as well as in simple table formats; Earth Orientation Parameters in different formats; plots of technique origin and scale time variations and station position residuals. The website also provides synthesized summary descriptions of the IERS Technique Centres (TC) solutions used in the ITRF2008 elaboration. All the submitted solutions were combined solutions by the Combination Center of each TC and based on reprocessed individual solution generated by the Analysis Centers of each one of the four techniques (VLBI, SLR, GNSS/GPS and DORIS). The submitted solutions cover the full history of observations, except for the GNSS/GPS series which start in 1997. These solutions are archived by the ITRS Center and the Central Bureau and were analysed by the two IERS Combination Centers (IGN and DGFI). Interaction and communication between the IERS Center and the TCs were operated as necessary and as a function of the ITRF2008 analysis conducted by the IERS CCs. The following table summarizes the final time series of station positions and EOPs submitted by the TCs.

Table 1.2.1: Final time series of station positions and EOP's submitted by the TC's for ITRF08

TC	Span	Solution type	EOPs
IVS	1980.0–2009.0	Normal Equation	Full set
ILRS	1983.0–2009.0	Variance-Covariance	Polar Motion, LOD
IGS	1997.0–2009.5	Variance-Covariance	Polar motion, rate, LOD
IDS	1993.0–2009.0	Variance-Covariance	Polar motion, rate, LOD

A detailed article on ITRF2008 results was prepared and published in 2011 in Journal of Geodesy with open access so that the ITRF2008 users have full and free access to the details of the ITRF2008 analysis and results (Altamimi Z., Collilieux X., and Métivier L. 2011).

### ITRF2008 Plate Motion Model

Detailed analyses of the ITRF2008 velocity field were undertaken in order to estimate a plate motion model consistent with ITRF2008. Indeed, for various geodetic and geophysical applications of ITRF2008, the aim of this study is to provide users with the most precise plate motion model derived from and consistent with the ITRF2008. The analysis consisted in simultaneously estimating angular velocities for 14 plates, together with an origin rate bias of the selected velocity field of 206 sites. The obtained results provide a model for 14 plates, with a global WRMS of 0.3 mm/yr. (Altamimi Z., Métivier L. and Collilieux X. (2012), ) The article details also the comparisons between ITRF2008 PMM and the geophysical models NN-NUVEL-1A and NNR-MORVEL56. Results show in particular a large angular velocity residual of about 4 mm/yr for the Australian plate between ITRF2008 PMM and NNR-MORVEL56, as illustrated by Figure 1. This bias is not observed in the comparison with NNR-NUVEL-1A and suggests that the Australian plate is probably mis-modelled in NNR-MORVEL56.

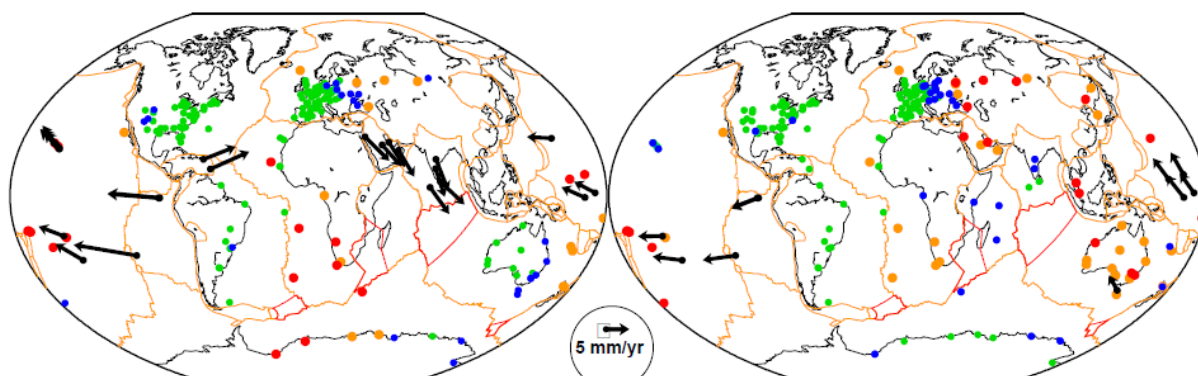


Figure 1.2.1: Velocity differences between ITRF2008 and (left) NNR-NUVEL-1A and (right) NNR-MORVEL56, after rotation rate transformation. In mm/yr, Green: less than 2 mm/a. Blue: between 2–3 mm/a. Orange: between 3–4 mm/a. Red: between 4–5 mm/a. Black: larger than 5 mm/a, and rates of velocity differences are shown only in this case.

### Research and development activities

#### IGN

The IGN group, often in cooperation with other scientists, conduct research and developments activities relating to the ITRF in particular and reference frames in general. R&D activities include ITRF accuracy evaluation, mean sea level, loading effects, combination strategies,

and maintenance and update of CATREF software. Scientific results of specific data analysis and combination are published in peer-reviewed journals, as listed in the references' section, but also presented at international scientific meetings.

### **DGFI**

In the report period, the DGFI group published the general paper about the computation of the DTRF2008 solution (Seitz et al. 2012). In a second publication DGFI compared the two reference frames DTRF2008 and ITRF2008 in order to assess the accuracy of the reference frames (Seitz et al. 2013). The agreement is between 7 and 10 mm and between 0.2 and 2.0 mm/a for the station positions and velocities, respectively, depending on the technique and if only core stations are considered.

In addition, DGFI performed various research and development activities in the field of global geodetic reference frames. This includes basic research related to the definition and realization of global terrestrial reference system and to the datum definition (Drewes 2012; Drewes et al. 2013). Other research topics were the common adjustment of the celestial and terrestrial reference frame together with the Earth Orientation Parameters (Seitz et al. in press) and the development of strategies for the computation of epoch reference frames (Bloßfeld et al. 2011; Bloßfeld et al. 2013).

### **JPL**

The JPL group has also started activities related to ITRF. CATREF, the software package used at IGN France to produce the well-known ITRFs, has been installed at JPL and has been used to reproduce ITRF2005. A Kalman filter and smoother algorithm has been developed and coupled to the CATREF software. This Kalman filter-based software package, KALREF, has been used to produce ITRF2005-like and ITRF2008-like reference frames that compare favorably with ITRF2005 and ITRF2008, respectively. It has also been used to solve for time-variable weekly coordinates, as well as a model of secular, periodical and stochastic motion components. In addition, KALREF has been used to define a nearly instantaneous reference frame by specifying constant frame parameters and combining different technique data weekly. Descriptions of KALREF and its use to produce secular and nearly instantaneous reference frames were given at the 2012 EGU General Assembly and at the 2012 AGU Fall Meeting. Journal articles describing the theory behind the use of a Kalman filter to produce combined terrestrial reference frames like ITRF2008 and applications of this Kalman filter to produce nearly instantaneous, rather than secular, reference frames are in preparation.

In December 2012 at its Directing Board meeting, the International Earth Rotation and Reference Systems Service (IERS) certified JPL as an International Terrestrial Reference System (ITRS) Combination Center. Only two other organizations in the world, IGN in France and DGFI in Germany, are similarly certified.

A simulation tool to study the effect of network geometry on reference frame determination is being developed. The tool is based on synthetic station position and reference frame parameter (geocenter, scale) data. It has been used to study the effect of station distribution, number of stations, availability of site tie measurements, etc. on the reference frame. Preliminary conclusions indicate that reasonable TRFs can be determined from a network of about 30-40 well-distributed, co-located stations as long as accurate site ties are available at each site.

A postdoctoral research associate, Claudio Abbondanza, has been using CATREF to examine the sensitivity of ITRF-like reference frames to different input data sets including the

accuracy of co-location tie vectors. Claudio has also been applying the Three Corner Hat (TCH) technique to estimate the uncertainties of estimates of positions of stations at co-located sites. Results of this TCH analysis using station positions in the ITRF2005 frame were presented at the 2012 EGU General Assembly. Updated results using station positions in the ITRF2008 frame were presented at the 2012 AGU Fall Meeting and a journal article on these results is in preparation.

### **3. TRF activities in IAG services**

#### **IGS**

Since February 2010, IGN France has replaced Natural Resources Canada (NRCan) as coordinator of the IGS Reference Frame Working Group. On the operational side, this coordination consists in combining the SINEX solutions provided by the IGS final Analysis Centers (ACs) and updating a long-term cumulative solution each week. The switch from NRCan to IGN was the opportunity to bring some changes to the SINEX combination strategy (Rebischung and Garayt, 2013). But the formats and contents of all products were kept unchanged so as to ensure a smooth transition. Besides a continuous monitoring of the SINEX combination results, the main achievements of the Reference Frame Working Group since 2010 were:

- the publication of IGS08 (Rebischung et al., 2012), a new IGS reference frame based on ITRF2008;
- the generation of a homogeneous set of weekly solutions based on the IGN combination strategy back to 1994 and of a new, modernized IGS cumulative solution;
- the switch from weekly to daily terrestrial frame combinations in August 2012.

More details on the recent IGS Reference Frame Working Group activities can be found in the 2011 and 2012 IGS Technical reports available at <ftp://igs.org/pub/resource/pubs/>

#### **IDS**

Several TRF related activities can be found in references below, in particular Altamimi and Collilieux 2010, Angermann, Seitz and Drewes 2010, Govind et al 2010.

### **4. ISO standardization**

A project has been established within the International Standardization Organization (ISO) Technical Committee ISO TC 211 (geographical information) dealing with geodetic references. This project 19161 is chaired by Claude Boucher (France). Its objective is to write a report showing the importance of geodetic references for geo-information and to propose some specific items relevant to an ISO standard. The ITRS has been proposed as one of them. IAG which is already a liaison organization with ISO TC211 should appoint a representative to this project.

## **Working Groups:**

### **WG 1.2.1: External evaluation of TRF**

**Chair:** Xavier Collilieux (France)

An accurate Terrestrial Reference Frame (TRF) is fundamental for Earth science applications. To constrain the error budget of some geoscience products such as the determination of sea level variations from space, the uncertainty of tracking geodetic station coordinates should be known reliably. The scope of this task force is to enumerate and assess all the methods that provide an evaluation of the Terrestrial Reference Frame accuracy, especially in terms of origin and scale.

This activity has started in 2011. First results have been discussed in Collilieux and Altamimi (2013). During the previous term of the IAG commission 1, the task force has written a report that has been finalized during this term (Collilieux et al., 2014). It establishes that the accuracy of the ITRF2008 in terms of origin rate is likely to be less than 0.5 mm/yr on the three components while the scale rate error is smaller than 0.3 mm/yr. In the meantime, Argus (2013) revisited the TRF origin and scale accuracy by relying on the assessment of space geodetic data. Post-glacial rebound models have been further investigated for evaluation purpose by several authors. King et al. (2011, 2012) have shown that models and observed station vertical velocities can not be reconciled by shifting the origin of the TRF. However, their accuracy is sufficient to discriminate different modeling of the rotational feedback (Métivier et al., 2012). Finally, we mention that Earthquake co-seismic models have been used globally to assess discontinuities and effect on station velocities on a global set of station. Such an approach in the future is likely to improve the accuracy of the TRF.

Too few activity of this working group has been reported during these first two years. For this reason, it is more reasonable not to continue this effort for the next two years.

### **WG 1.2.2: Global Geodetic Observatories**

**Chair:** Pierguido Sarti (Italy)

Works on concepts and practical implementation are under progress. Detailed results with references will be provided in the final report. We must mention the specific activities of the working group *Site Survey and Co-location* (jointly with IERS) chaired by Pierguido Sarti (Italy).

The Joint Working Group has focussed on the provision of accurate tie vectors for ITRF computation and the assessment of their accuracy. It is a rather complex process as it must rely on the extent of (dis)agreement with the space geodetic solutions and the analysis of any possible cause, either on the local survey or the space geodetic observation side. The ITRF combination residuals do not often agree with the magnitude of the tie vector formal precisions, these latter usually being at the mm or sub-mm level. In addition, the WG has focussed on the definition and validation of new methodologies for the surveying and computation of the tie vectors and the definition of standards and guidelines. Finally, the creation of a central repository for local surveys data has been discussed and evaluated during a meeting held in Paris on May 21-22, 2013. This two days meeting was organized as an official IERS workshop and brought together more than 40 experts that had the opportunity to discuss different issues related to surveying methods and approach, tie vector estimation

strategies, nomenclature, guidelines, documentation, data archiving and more. The workshop was a success in terms of participation and results. 25 oral contributions were presented during the meeting. All relevant information can be found at the workshop web page: <http://iersworkshop2013.ign.fr/?page=scope>

### **Workshops, meetings, invited talks (2010-2013)**

#### **Convening activity:**

Dec. 2013: Session convener American Geophysical Union Fall meeting G012: Reference Frames: Determination, Usage and Application, San Francisco, CA, USA, <https://fallmeeting.agu.org/2013/scientific-program/session-search/sessions/g019-reference-frames-determination-usage-and-application-2/>

May 2013: Chair of the Scientific Organizing Committee - International Earth rotation and Reference systems Service Workshop on Local Surveys and Co-locations, Paris, France, <http://iersworkshop2013.ign.fr/?page=soc>

Apr. 2010: Session convener, European Geosciences Union G2: The Global Geodetic Observing System: tying and integrating geodetic techniques for research and applications, Vienna, Austria, <http://meetingorganizer.copernicus.org/EGU2010/sessionprogramme/G>

#### **Invited/solicited talks:**

2011: 37<sup>th</sup> course of the International School of Geophysics; Interdisciplinary Workshop on Earth expansion evidence: a challenge for geology, geophysics and astronomy, Erice, Italy. The consistency between local and space geodetic observations – Accuracy of the global terrestrial reference frame.

2010: IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010); Theory and realization of global terrestrial reference systems, Marne-La-Vallée, France. A review on local ties and co-location issues

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## **Sub-Commission 1.3: Regional Reference Frames**

*Chair: João Torres (Portugal)*

### **Introduction**

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

In addition to specific objectives of each regional sub-commission, the main objectives of SC1.3 as a whole are:

- Develop specifications for the definition and realization of regional reference frames, including the vertical component with special consideration of gravity data and other data.
- Coordinate activities of the regional sub-commissions focusing on exchange and share of competences and results.
- Develop and promote operation of GNSS permanent stations, in connection with IGS whenever appropriate, to be the basis for the long-term maintenance of regional reference frames.
- Promote the actions for the densification of regional velocity fields.
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations.
- Encourage and assist, within each regional sub-commission, countries to re-define and modernize their national geodetic systems, compatible with the ITRF.

Six regional Sub-Commissions compose the Sub-Commission 1.3:

- Sub-Commission 1.3 a: Europe
- Sub-Commission 1.3 b: South and Central America
- Sub-Commission 1.3 c: North America
- Sub-Commission 1.3 d: Africa
- Sub-Commission 1.3 e: Asia-Pacific
- Sub-Commission 1.3 f: Antarctica

Furthermore, two Working Groups (WG) were created within SC 1.3:

- WG 1.3.1: Integration of Dense Velocity Fields into the ITRF
  - The main task of this WG is to study and promote consistent specifications for the generation of GNSS-based velocity field solutions and their combination in order to derive a unified dense velocity field in a common global reference frame.
- WG 1.3.2: Deformation Models for Reference Frames
  - The primary aim of the WG is to develop tectonic deformation models that will enable transformation of locations within a defined reference frame between different epochs. Such deformation models are essential to support precise point positioning applications and CORS/NRTK operations within deforming zones

## Overview

The activities of each of the regional Sub-Commissions - with the exception of AFREF - and Working Groups “Integration of Dense Velocity Fields into the ITRF” and “Deformation Models for Reference Frames” are reported hereafter. A summary of those activities and the main results achieved is given below.

### *Sub-Commission 1.3 a: Europe*

- The number of permanent GNSS tracking sites in Europe is still growing, with almost 250 EPN stations operating by mid-2013. The number of site, switch record GLONASS data simultaneously to GPS data is steadily increasing (70 %).
- The preparation for the future Galileo system and the development of the EPN towards a multi-system GNSS network started.
- The results of the first reprocessing of the EPN (EPN-REPRO1) were endorsed by the EUREF TWG, allowing the generation of a new cumulative EPN position/velocity solution including the EPN-REPRO1 results.
- The document on “Guidelines for EUREF Densifications” was published. In this context, several countries and CERGN provide weekly SINEX solutions to obtain consistent cumulative position/velocity solutions. The “EUREF Serbia 2010” (Serbia), “EUREF-MAKPOS 2010” (Macedonia), “EUREF Faroe Islands 2007” (Faroe Islands), and “EUREF BE 2011” (Belgium national GNSS campaigns were accepted by the plenary as EUREF densification campaign.
- The EPN Project on “Real-time Analysis” is still developing. Based on orbit and clock corrections broadcasted in ETRS89 (realization ETRF2000), users can directly derive real-time coordinates referred to ETRS89 at few dm-level.
- The EUREF TWG set up two new Working Groups. One is on “Multi GNSS” to prepare recommendations on the use of the new signals within the EPN. The other one is on “Deformation Models”, to improve the knowledge of surface deformations in Eurasia and adjacent areas.
- The UELN was enhanced by additional or updated leveling data. These data make possible to close the loop around the Baltic Sea. Some countries announced to provide their leveling data and join the UELN.
- The promotion of the ETRS89 (European Terrestrial Reference System) and the EVRS (European Vertical Reference System) continued, following the adoption by INSPIRE of these systems as the basis for georeferencing in Europe.
- The symposia in 2012 (Saint-Mandé) and 2013 (Budapest) and 6 meetings of the Technical Working Group constituted benchmarks the activity of EUREF.

### *Sub-Commission 1.3 b: South and Central America*

- The number of continuously operating GNSS stations that support the SIRGAS Reference Frame is still growing. It is composed by about 300 stations, 140 of which with GLONASS capability, and 60 with real time data transfer. The SIRGAS Reference Frame includes 58 formal IGS stations.
- The IGS Global Analysis Centres process 40 SIRGAS stations since January 2012 in order to improve the distribution of the ITRF sites in this region. These stations are included in the IGS Reprocessing 2.
- The 4 sub-networks are independently processed by 10 SIRGAS Analysis Centres (AC). The AC follow the same guidelines for the computation of loosely constrained weekly

solutions and they are aligning the computation procedures to the new standards released by the IGS for the Reprocessing 2. It is expected that the second reprocessing of the SIRGAS Reference Frame starts in the last quarter of 2013.

- The computation of the cumulative solution is performed every year, providing epoch positions and constant velocities for stations operating longer than two years. For the moment, the computation of multi-year solutions is stopped until the entire network is totally reprocessed with respect to the IGS08 (IGb08) Reference Frame.
- The support of the countries interested on adopting SIRGAS as official reference frame continued. During the last two years, significant advances were achieved in Bolivia, Costa Rica, Guatemala, and Honduras.
- The installation of the service "Experimental SIRGAS Caster" with the goal to promote the availability of the SIRGAS Reference Frame in real time showed major advances, reported by several countries.
- The increase of the availability of epoch station positions to detect deformations of the reference frame, especially in those areas affected by earthquakes, is being achieved through the coordination of local GNSS campaigns on passive points.
- The efforts needed towards the definition and realisation of a gravity field-related vertical reference system in Latin America and the Caribbean have been identified. The work has started in collecting and validating the existing databases, performing levelling field works to connect the fundamental points of the vertical networks with the SIRGAS reference station and with the main national tide gauges and levelling connections between neighbouring countries.
- The signature of the "2013-2015 Action Plan to Expedite the Development of Spatial Data Infrastructure of the Americas" constitutes a strategy for the adoption of SIRGAS as the official reference frame for Geodesy and Cartography, according to the recommendation issued in 2001 by the "United Nations Cartographic Conference for the Americas".
- The development of actions for capacity building and the promotion of SIRGAS in the member countries, in particular the SIRGAS Workshop on Vertical Networks Unification, the SIRGAS School on Reference System, the SIRGAS School on Real Time GNSS Positioning and training courses on precise GNSS data processing, under the sponsorship of several international organizations and national institutions.
- The SIRGAS General Meetings took place in Costa Rica (2011) and Chile (2012).

#### *Sub-Commission 1.3 c: North America*

- The densification of the ITRF and IGS network is made by weekly combinations of 5 regional weekly solutions using different GPS processing software.
- The implementation of PPP solutions by NRCan is being performed to provide redundant solutions.
- The release of the first enhanced version of the software to allow the weekly combinations of the large number of stations that stopped in GPS week 1583 due to great number of stations.
- The reprocessing of the regional networks is planned in conjunction with the IGS08 repro2 effort, with the exception of INEGI, who has just completed their own reprocessing with repro1 orbits.
- The analysis of the best method of fixing the new NAD system to the North American plate, which is expected to occur in 2022, when it is also planned to replace the vertical datum in the USA with a geoid-based datum.

- The continuation of the activities related to the definition and maintenance of the relationships between international and North American reference frames/datums. Transformations from/to subsequent versions of ITRF96 are obtained by updating the NAD83-ITRF transformation with the official incremental fourteen parameter transformations between ITRF versions as published by the IERS.
- The working groups dedicated to the different tasks met when appropriate.

*Sub-Commission 1.3 e: Asia-Pacific*

- The increase of the number of stations of the CORS network (approximately 480 stations from 28 countries), whose data are processed by three Analysis Centres (ACs).
- The increase of the number of institutions contributing to APREF in several domains (analysis, archive and stations).
- The availability of a weekly combined regional solution, in SINEX format and a cumulative solution which includes velocity estimates.
- The publications of the weekly ITRF coordinate estimates in SINEX format, coordinates time series and velocity solutions for the APREF stations on the APREF website.
- The coordination of annual geodetic observation campaigns in order to densify the ITRF in the Asia-Pacific Region in countries without Continuously Operating Reference Stations (CORS), the last one carried out from 9th September 2012 to 15th September 2012 (GPS week 1705).

*Sub-Commission 1.3 f: Antarctica*

- The realization of SCAR GPS Campaigns in 2012 and 2013. The data of 40 Antarctic sites are collected in the SCAR GPS database since 1995.
- The continuation of data analyses and presentation of the results at the XXXII SCAR Meeting (2012).
- The establishment of the working plan of the SCAR Group of Experts on Geodetic Infrastructure in Antarctica (GIANT) for the years 2012-2014 during the meeting that took place on the occasion of the XXXII SCAR Meeting.

*Working Group 1.3.1: Integration of Dense Velocity Fields into the ITRF*

- The decision to start with the combination of weekly position solutions allowing the mitigation of biases, as a result of tests concluding that the level of agreement between the several multi-year solutions submitted before was not satisfactory.
- The submission of regional and global solutions containing 2396 selected stations.
- The realization of preliminary combinations of stations with more than 3 years observations, present in at least 104 weekly SINEX and present in at least 50% of the weekly SINEXs within the data span.
- The solution obtained from the stacking of the weekly combined solutions should be finalized by the fall of 2013. A second combination will have to be performed based on new reprocessed submissions compliant with the IGS repro 2 standards.

*Working Group 1.3.2: Deformation Models for Reference Frames*

- The realization of considerable research on deformation modelling completed by WG members in Japan, South America, Australia, New Zealand and the USA.

- The improvement of crustal deformation models (post-seismic deformation), the release of deformation patches which model the co-seismic and post-seismic deformation in Japan (Tōhoku earthquakes) and New Zealand (Canterbury earthquake sequence).
- The development of localised deformation models to support land surveying activities in zones where significant earthquakes occurred.
- The development of next-generation geodetic datums using deformation models.
- The activity of the WG members is being developed in the majority of the areas covered by the regional Sub-commissions.

## Conclusion

The activities developed by each of the regional Sub-Commissions and Working Groups (Integration of Dense Velocity Fields into the ITRF and Deformation Models for Reference Frames) make evident that all the components of the structure are working according to the main objectives of the SC 1.3, even in the case of AFREF, for which no report is presented.

Some general aspects deserve to be mentioned:

- The activities are contributing to the scientific and technical development in several topics such as GNSS analysis and processing, precise reference frame establishment, use of new GNSS signals, among others.
- The stronger involvement of the regional components in the global scientific goals of the IAG, especially their contribution to the ITRF solutions.
- The emphasis that all the regional Sub-commissions and both Working Groups are giving to the modelling of non-linear changes in the coordinates due mainly to geophysical phenomena.
- The recognition of the role of the WG on “Integration of Dense Velocity Fields into the ITRF” and the WG on “Deformation Models for Reference Frames” in the identification of problems and solutions when going from regional to global analysis, that is encouraged.
- The effort to bring together different types of institutions (R&D structures, National Mapping Agencies, political and economic agencies, etc.) to support and contribute to the activities related to the geospatial reference frames.
- The organizational and outreach aspects play a more and more important role and are crucial for the efficient achievement of results and their use by the geospatial community.
- The concern to develop education and training events, especially in less developed regions and countries. In this context, it's worth to mention the combined IAG, FIG and ICG workshop "Reference Frames in Practice" held in Rome prior to the FIG Working Week in May 2012. This effort must be continued and supported by the IAG.

Finally, please note that the reports presented here reinforce the strategic decision to keep and develop this kind of regional organization within the IAG, since each region of the world has its own way to proceed, considering all the variables involved in this kind of work.

## **Sub-Commission 1.3a: Regional Reference Frame for Europe (EUREF)**

*Chair: Johannes Ihde (Germany)*

### **Introduction**

The long-term objective of EUREF, as defined in its Terms of Reference is “the definition, realization and maintenance of the European Reference Systems, in close cooperation with the pertinent IAG components (Services, Commissions, and Inter-Commission projects) as well as EuroGeographics”. For more information see <http://www.euref.eu>.

The results and recommendations issued by the EUREF sub-commission support the use of the European Reference Systems in all scientific and practical activities related to precise georeferencing and navigation, Earth sciences research and multi-disciplinary applications. EUREF applies the most accurate and reliable terrestrial and space-borne geodetic techniques available, and develops the necessary scientific principles and methodology. Its activities are focused on a continuous innovation and on evolving user needs, as well as on the maintenance of an active network of people and organizations, and may be summarized as follows:

- Maintenance of the ETRS89 (European Terrestrial Reference System) and the EVRS (European Vertical Reference System) and upgrade of the respective realizations;
- Refining the EUREF Permanent Network (EPN) in close cooperation with the International GNSS Service (IGS);
- Improvement of the European Vertical Reference System (EVRS);
- Contribution to the IAG Project GGOS (Global Geodetic Observing System) using the installed infrastructures managed by the EUREF members.

These activities are reported and discussed at the meetings of the EUREF Technical Working Group (TWG) and annual EUREF Symposia, an event that occurs every year since 1990, with an attendance of about 100-150 participants coming from more than 30 European countries and other continents, representing Universities, Research Centres and NMCA (National Mapping and Cadastre Agencies). The organization of the EUREF Symposia is supported by EuroGeographics, the consortium of the European National Mapping and Cadastral Agencies, reflecting the importance of EUREF for practical purposes.

The latest EUREF symposia took place in Saint-Mandé, France (2012) and in Budapest, Hungary (2013). Meetings of the EUREF Technical Working Group have been held three times a year. In addition a EUREF retreat was held in Nov. 2012 with the goal to review EUREF key themes and organizational structures and derive a plan to achieve the EUREF objectives for the next 4-8 years.

### **Members:**

- Z. Altamimi
- E. Brockmann
- C. Bruyninx (TWG chair)
- A. Caporali (EUREF secretary)
- R. Dach,
- J. Dousa
- R. Fernandes

- H. Habrich
- J. Ihde (EUREF chair)
- A. Kenyeres
- M. Lidberg
- R. Pacione
- M. Poutanen
- K. Szafranek
- W. Söhne
- G. Stangl
- J. Torres

In addition to the already existing partnerships with EUMETNET and EuroGeographics, EUREF and CERGOP (Central European GPS Geodynamic Network Consortium) signed a Memorandum of Understanding (MoU) at EUREF symposium at Chisinau, Moldova in 2011. The general goal of the MoU is to create the conditions to facilitate data exchange and promote the co-operation between EUREF and CERGOP in order to improve the densification of the European GNSS network for reference frame definition and geodynamical applications, and support the ECGN (European Combined Geodetic Network) project.

EUREF is an associated member of the International Committee on Global Navigation Satellite Systems (ICG) since 2009. The main ICG objective is to promote greater compatibility and interoperability among current and future providers of the Global Navigation Satellite Systems (GNSS). The annual ICG meetings review and discuss progress towards the realization of its main objective, as well as developments in GNSS where contributions from ICG members, associate members and GNSS user community are considered.

### **EUREF Permanent GNSS Network (EPN)**

The EPN is the permanent GNSS network created by EUREF (Fig 1.3a.1). Its primary objective is to maintain and provide access to the ETRS89. The EUREF TWG is responsible for the general management of the EPN. The EPN Coordination Group and the EPN Central Bureau implement the operational policies of the EUREF TWG.

The EPN is based on a well-determined structure including GNSS tracking stations, operational centres, local and regional data centres, local analysis centres, combination centres and a Central Bureau (Bruyninx et al, 2011). These different EPN components (all based on voluntary contributions) follow specific guidelines set up by the EUREF TWG.

The EPN is the European densification of the International GNSS Service (IGS) network. Therefore, the EPN uses the same standards and exchange formats as the IGS.

Almost 250 EPN stations are operated today by NMCA and other scientific and technical institutions. The number of sites that record GLONASS data simultaneously with GPS data is steadily increasing (70 %).

To prepare for the Galileo system, already some EPN station operators make available GNSS observation data in RINEX version 3 format in addition to their routine data submissions in the RINEX 2.11 format. The goal is to support developers preparing for the future Galileo system and to foster the development of the EPN towards a multi-system GNSS network. Instructions for becoming an EPN station are available at [http://www.epncb.oma.be/\\_organisation/guidelines/procedure\\_becoming\\_station.pdf](http://www.epncb.oma.be/_organisation/guidelines/procedure_becoming_station.pdf).





Figure 1.3a.1: EUREF Permanent GNSS Network (EPN), status June 2013

### EPN reprocessing activities

Since the start of the EPN operations, its data are routinely analyzed by the EPN Local Analysis Centres in order to derive precise station coordinates and tropospheric zenith path delays. Throughout the years, the EPN has become more precise and reliable thanks to historical improvements of modeling parameters affecting the satellites (orbits, reference frame, and antenna calibration model), the propagation media (troposphere and ionosphere), the receiver units (e.g. elevation cut-off, antenna calibration model), geophysical phenomena (e.g. tidal forces, loading related to ocean, ground water and atmospheric pressure variations) and the reference frames. The EUREF TWG has therefore decided to reprocess all historical EPN data using present-day state-of-the-art models and to obtain improved and consistent coordinates, position time series and tropospheric parameters for each EPN site.

This first reprocessing (known as EPN-REPRO1) was done in 2011 for EPN observations gathered between Jan. 1996 and Jan. 2007. Different software packages, namely BERNESSE, GIPSY/OASIS and GAMIT were used for the analysis (Habrigh, 2011 and Völksen, 2011). The reprocessing was done using the `epn_05.atx` antenna calibration model, which is derived from the `igs05.atx` model. The reprocessed EPN results were used for weekly combined positions (in SINEX format) and tropospheric delays generated by the EPN Analysis Coordinator and EPN Troposphere Coordinator, respectively. At its fall meeting in Oct. 2011, the EUREF TWG endorsed the EPN-REPRO1 results and gave the green light to the EPN Reference Frame Coordinator for the generation of a new cumulative EPN position/velocity solution including the EPN-REPRO1 results.

### EUREF Densification of the ITRS

#### *Using the EPN*

Because the number of permanent GNSS tracking sites in Europe has grown considerably, only a selection of these sites (mostly those belonging to the IGS) are included in recent realizations of the ITRS. The latest realization of the ITRS, the ITRF2008, is based on

observations from space geodetic techniques (GNSS, DORIS, VLBI, and SLR) up to December 2009.5 and does not take into account any of the IGS/EPN data gathered after that date. Consequently, it cannot reflect the most recent status of the EPN (due to e.g. antenna changes). The limited number of stations and the lack of frequent updates limit therefore the use of the ITRF for national densifications of the ETRS89.

The EUREF TWG decided at its meeting of Nov. 3-4, 2008 in Munich, to release regularly recomputed cumulative official updates of the ITRS/ETRS89 coordinates/velocities of the EPN stations. Using the 15-weekly updates of the EPN site coordinates, the EPN sites are classified in two classes:

- Class A stations with positions at 1 cm accuracy during the time span of the used observations (thanks to providing accurate station velocity estimates);
- Class B stations with positions at 1 cm accuracy at the epoch of minimal variance of each station.

Following the EUREF “Guidelines for EUREF Densifications” (Bruyninx et al., 2013), only Class A EPN stations can be used for EUREF densifications.

Table 1.3a.1 gives an overview of the weekly EPN SINEX files available for the computation of a new EPN cumulative position/velocity solution:

Table 1.3a.1: Overview of the weekly EPN SINEX files including the antenna calibration model used in the analysis.

Solution	GPS week Start / End	Antenna Calibration Model
EPN-REPRO1	835 / 1399	e pn_05.atx
Routine	1400 / 1631	e pn_05.atx
Routine	1632 / Now	e pn_08.atx

In order to have a consistent set of weekly SINEX solutions, the EUREF TWG asked the ROB (Royal Observatory of Belgium, see Baire et al. 2011) to correct the solutions before week 1632 to make them consistent with the e pn\_08.atx antenna calibration model. Using these corrected SINEX files, complemented with the present-day EPN weekly SINEX files, a new cumulative EPN position/velocity solution has been created and tied to the IGS08/IGb08 reference frame (see Kenyeres, 2011; Kenyeres, 2012). The computations were done using the CATREF software (Altamimi et al., 2007) and are again updated each 15-weeks. The resulting station coordinates are available from [http://www.epncb.oma.be/\\_productsservices/coordinates/](http://www.epncb.oma.be/_productsservices/coordinates/). Figure 1.3a.2 shows the map of Class A and Class B stations outcome of the latest cumulative EPN solution.

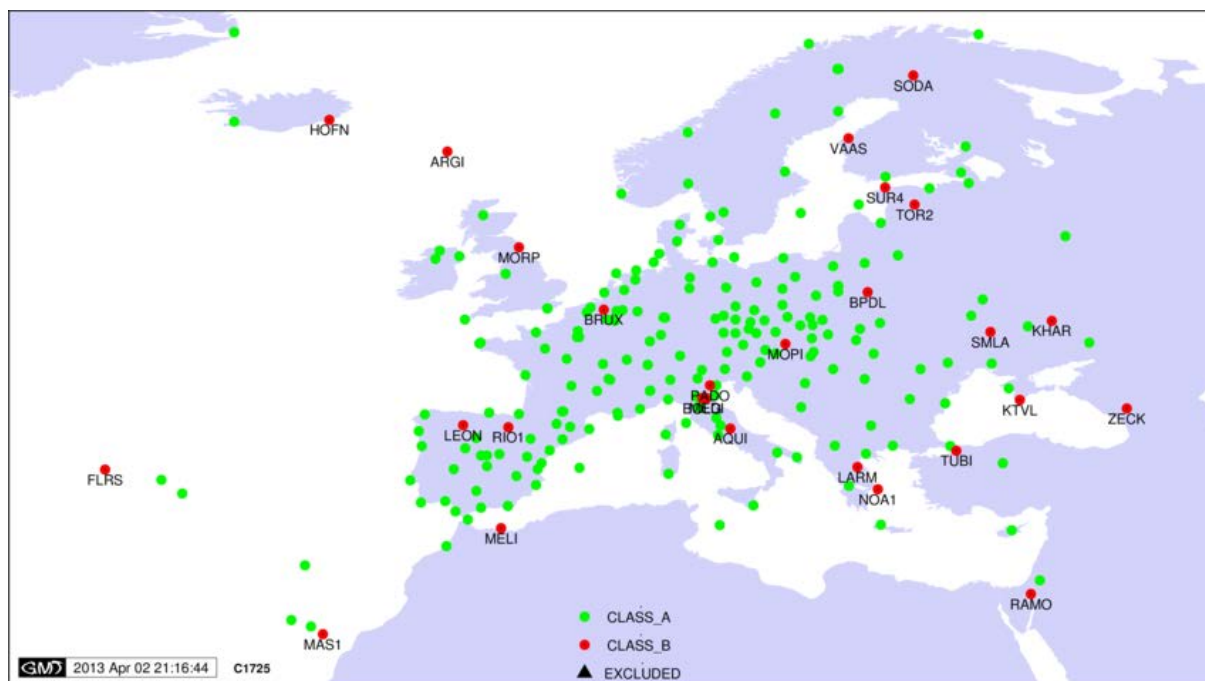


Figure 1.3a.2: EPN site categorization, status April 2013. In green: Class A stations; in red: class B stations.

### *Using the National GNSS Densification Networks*

Many European countries operate national dense GNSS networks, whose stations are not all included in the EPN. In order to take advantage of these data for creating a dense European velocity field, EUREF invited these countries to routinely analyze these data following EUREF guidelines and to submit the weekly positions to EUREF. Several countries (Poland, Estonia, Latvia, Slovakia, Hungary, Austria, Bulgaria, Czech Republic, and Italy) responded positively and provide now weekly SINEX solutions to the EPN Reference Frame Coordinator who combines these solutions with the weekly EPN solution and then stacks them to get consistent cumulative position/velocity solutions for the resulting densified EPN network (containing today already about a 1000 sites). Thanks to EUREF's Memorandum of Understanding with CERGN, also a CERGN solution (bi-annual campaigns) was submitted. This work is still in progress (see Kenyeres et al, 2012) and it will be an important input for the new EUREF Working Group on "Deformation Modeling" (see below).

### *Using Densification Campaigns*

EUREF continued the validation of national GNSS campaigns. A report including the necessary information about the measurements, the processing and the validation of the results is delivered to the TWG. After successful evaluation by the TWG the following projects were accepted by the plenary as EUREF densification campaign between 2011 and 2013: "EUREF Serbia 2010" (Serbia), "EUREF-MAKPOS 2010" (Macedonia), "EUREF Faroe Islands 2007" (Faroe Islands), and "EUREF BE 2011" (Belgium).

### **EPN Real-time Analysis Project**

The EPN Project on "Real-time Analysis" ([http://epncb.oma.be/\\_organisation/projects/RT\\_analysis](http://epncb.oma.be/_organisation/projects/RT_analysis)) focuses on the processing of the EPN real-time data to derive and disseminate real-time GNSS products.

The EPN regional broadcaster at BKG (Federal Agency for Cartography and Geodesy, <http://www.euref-ip.net>) is broadcasting satellite orbits in the ETRS89 (realization ETRF2000). Based on these orbit and clock corrections, users can directly derive real-time coordinates referred to ETRS89 at few dm-level (Fig. 1.3a.3; more details are given in Söhne, 2011). Additional solutions for other regional datums, e.g. for SIRGAS95 or SIRGAS 2000, are implemented and could be found at <http://products.igs-ip.net>.

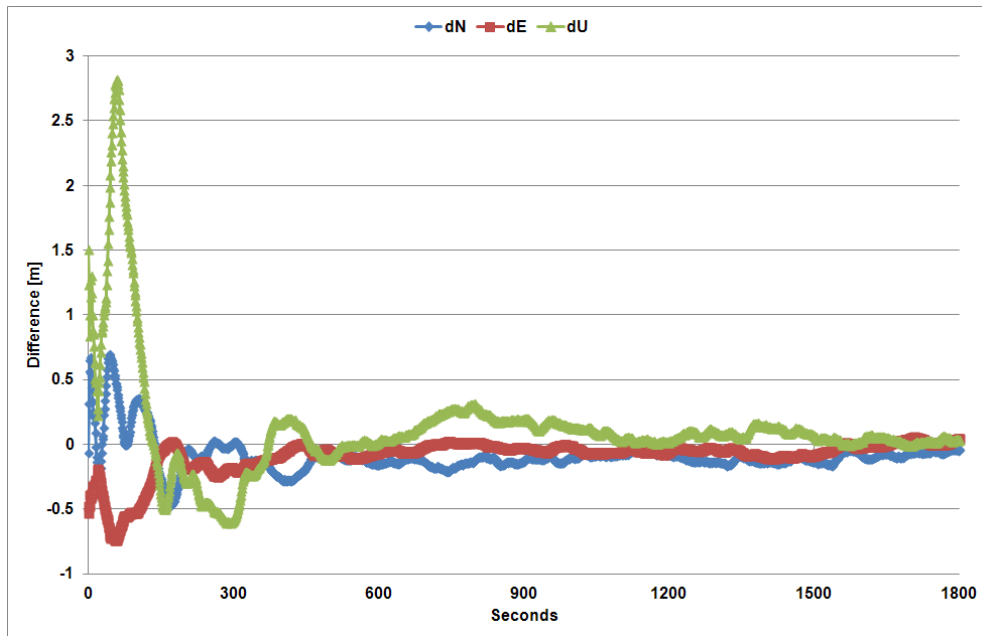


Figure 1.3a.3: Differences of real-time coordinates using the BKG Ntrip Client (BNC) with ETRS89-related satellite and orbit corrections for station ZIM2 w.r.t. the ETRS89 coordinates

One aim of the project is to increase the reliability of the EPN real-time data flow and to minimize the possibility of data and products outage. For this purpose, two additional regional broadcasters have been put in operation, one at ASI (Italian Space Agency, <http://euref-ip.asi.it/>) and one at ROB (<http://www.euref-ip.be/>). Based on the existence of three regional broadcasters, several stations and national broadcasters started uploading their data in parallel to all of the broadcasters.

To ensure the product generation without interruption and without jumps, it is necessary to have a back-up processing running in an identical environment. This scheme could be implemented on a second computer at the same facility or, to overcome problems at the facility itself, at another place. In case of an outage in the production scheme at the master facility the broadcaster will switch to the backup solution using the same source table entry (mount point). Therefore the user will notice neither any interruption nor any change in the origin of the streamed data.

While for the first step of the estimation of parameter corrections, i.e. satellite orbits and clocks, a globally distributed network (50-60 stations) is sufficient, any further steps, e.g. improved ambiguity fixing, ionosphere and troposphere corrections which go for an improved accuracy of the real-time Precise Point Positioning (PPP), require a denser network of real-time stations like the EPN or SIRGAS could provide.

## **New EUREF Working Groups**

### *Multi-GNSS Working Group*

In 2012 the EUREF TWG set up a new Working Group on “Multi GNSS”. As written above, a number of station managers provide GNSS signals on top of the GPS and GLONASS L1 and L2 signals. Before introducing Galileo, BeiDou or new GPS signals into EPN routine operation they must be carefully checked. One goal of the WG is to test and evaluate the new formats (RINEX 3, RTCM Multi Signal Messages) on content and data quality. New processing techniques have to be used or even developed for analysis of the new signals. Finally, recommendations must be prepared which of the new signals should be declared as mandatory for further use within the EPN.

### *Deformation Modeling Working Group*

In 2012 the EUREF TWG set up a new Working Group on “Deformation Models”. The objective of this WG is to create a crustal deformation model for Europe to 1) improve the knowledge of surface deformations in Eurasia and adjacent areas and 2) manage and use the national realizations of the ETRS89 by studying the behaviour of geodetic reference frames in the presence of crustal deformations. The Working Group aims at making more precise the concept of ‘Stable part of Europe’ underlying the definition of ETRS89. At the mm/yr level, areas of departure from the rigid rotation model of ITRS velocities about an Eurasian Eulerian pole are clearly visible in the Mediterranean area (Greece, Southern Italy, for example). Vertical motion due to Glacial Isostatic Adjustment (GIA) is clearly observed in the Fennoscandia, causing the vertical datum to be accordingly adjusted periodically. The Working Group attempts a geophysical understanding of the non rigid behaviour of the European crust, with the objective to monitor the evolution of the deformation of national coordinate grids caused by geophysical phenomena, and predict when the deformation exceeds a certain tolerance. When this occurs, the NMCA’s are recommended to generate an update of the National realization of the ETRS89 and/or EVRS.

## **European Vertical Reference System (EVRS)**

In 1994 the IAG Sub-commission for Europe (EUREF) started the work on the Unified European Leveling Network (UELN) and resumed and enhanced previous projects, which existed in the Western and Eastern part of Europe separately. A European Vertical Reference System (EVRS) was defined in 2000 and the associated realization was named EVRF2000.

During the following years about 50 % of the participating countries provided new national leveling data to the UELN data centre. Therefore a new realization of the EVRS was computed and published under the name EVRF2007. The datum of EVRF2007 is realized by 13 datum points distributed evenly over the stable part of Europe. The measurements have been reduced to the common epoch 2000 by applying corrections for the glacial isostatic adjustment (land uplift) in Fenno-Scandinavia, which are provided by the Nordic Geodetic Commission (NKG). The results of the adjustment are given in geopotential numbers and normal heights, which are reduced to the zero tidal system. At the EUREF symposium June 2008 in Brussels, Resolution No. 3 was approved proposing to the European Commission the adoption of the EVRF2007 (Figure 1.3a.4) as the mandatory vertical reference for pan-European geo-information.

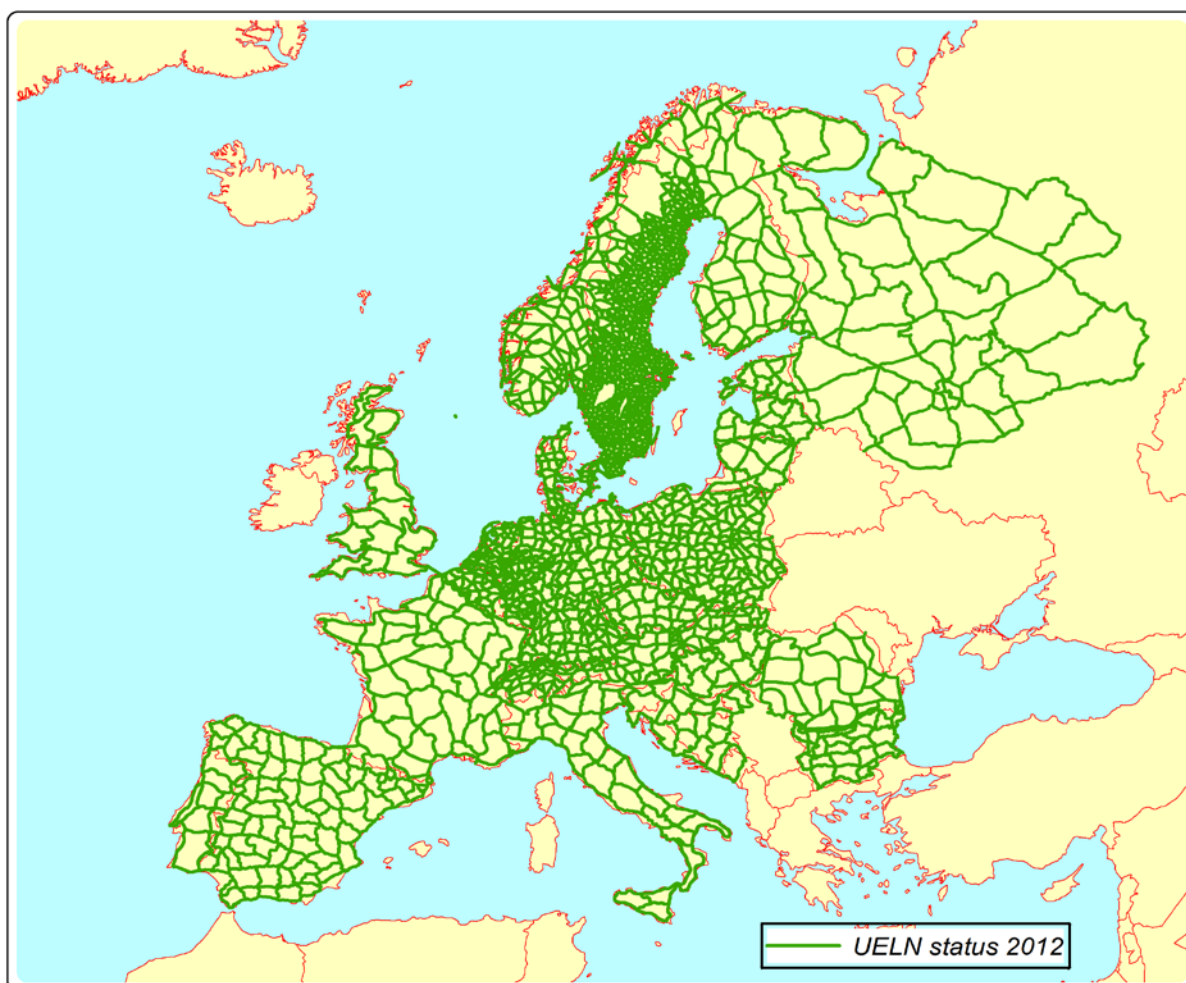


Figure 1.3a.4: EVRF2007 including extensions

The availability of EVRF2007 forced an update of the Geodetic Information and Service System. Transformation parameters between national height systems and EVRF2007 were estimated and are provided at <http://www.crs-geo.eu/> since April 2010. Furthermore the transformation parameters to EVRF2000 are available. Additionally the online-transformation for heights of single points was implemented.

In the meantime, the UELN is continuously enhanced using additional or updated leveling data submitted by different countries. EUREF received in 2009 the European part of first order leveling network of Russia. Together with connection measurements between the national networks of Finland and Russia it was possible to close the loop around the Baltic Sea and strengthen the adjustment process. In addition, the new first order leveling data of Latvia (2011), and Spain (2012) were received by EUREF. For the next years Belarus and Ukraine announced to provide their leveling data and join the UELN. A new UELN adjustment will be computed after receiving the new data.

### Promotion and Adoption of the ETRS89 and EVRS

Since 1989, many European countries have defined their national reference frames in ETRS89 by calculating national ETRS89 coordinates following the EUREF guidelines. The difference of the ETRS89 coordinates adopted in each country for a set of EPN stations with

respect to the ETRS89 coordinates recently estimated by the EPN is now monitored on a regular basis by EUREF (Brockmann, 2010). These national ETRS89 coordinates can differ from the latest cumulative EPN coordinates due to e.g. differences in datum definition (different ETRFyy frames) and differences in used observation periods.

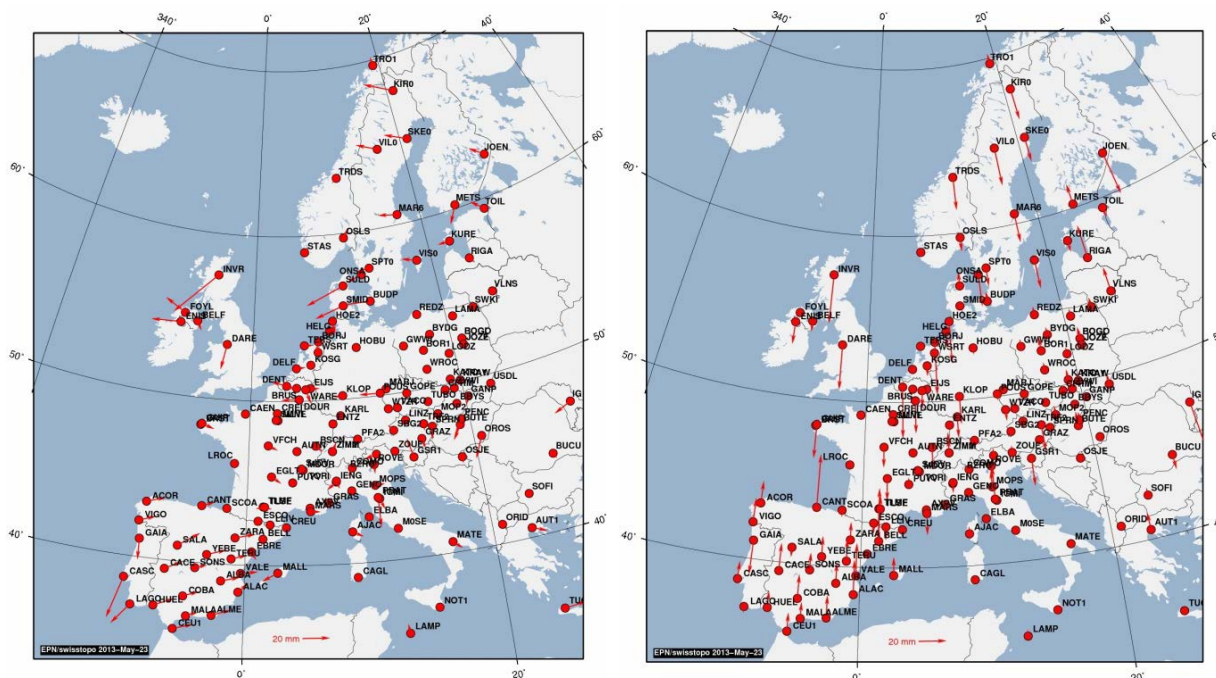


Figure 1.3a.5: Difference between official ETRS89 coordinates adopted in the different countries and the latest EPN cumulative coordinate solution

The results of the comparison show an agreement of a few cm (see Figure 1.3a.5). In addition, EUREF recently provided a new questionnaire to the NMCA on the utilization of the ETRS89 and EUREF products in their country and the first results were presented by Ihde et al. (2011). Up to now, 60% of the contacted countries replied to the questionnaire. About 85% stated that they adopted the ETRS89 in their country while other 10% were still working on this issue.

INSPIRE (Infrastructure for Spatial Information in Europe) was adopted in March 2007 by the Directive 2007/2/EC of the European Parliament and the Council. The goal of INSPIRE is to deliver an interoperable and integrated European spatial information service to users from different communities. The INSPIRE Directive addresses 34 spatial data themes needed for environmental applications, with key components specified through technical implementing rules. “Coordinate Reference Systems” (CRS) is one of the important themes. It establishes the geographical reference for many other themes. This makes INSPIRE a unique example of a legislative “regional” approach.

To ensure that the spatial data infrastructures of the member states are compatible and usable in a trans-boundary context, the Directive requires that common Implementing Rules (IR) are defined and applied in a number of specific areas (metadata, data specifications, network services, data and service sharing and monitoring and reporting).

These IRs are adopted as Commission decisions or regulations and are binding in their entirety. The Commission is assisted in this process by a regulatory committee composed of representatives of the member states and chaired by a representative of the Commission

(known as the comitology procedure). Thanks to the efforts of the EUREF TWG, the ETRS89 and the EVRS, defined by EUREF, play now a fundamental role in the CRS IR.

The descriptions of national and pan-European geodetic reference systems are available by a Service System for European Coordinate Reference Systems (CRS). Transformation parameters between national geodetic reference systems and the European ETRS89 and EVRF2007 were calculated and provided. Additionally, an online-transformation capability for coordinates and heights of single points is implemented.

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## **1.3b: Regional Sub-Commission for South and Central America (SIRGAS)**

*Chair: Claudio Brunini (Argentina)*

*Vice-chair: Laura Sánchez (Germany)*

### **Structure**

SC1.3b-Working Group I: Reference system, *chair: Virginia Mackern (Argentina)*

SC1.3b-Working Group II: SIRGAS at national level, *chair: William Martínez (Colombia)*

SC1.3b-Working Group III: Vertical datum, *chair: Roberto Luz (Brazil)*

### **Overview**

The IAG Sub-commission 1.3b (South and Central America) encompasses the activities developed by the "Geocentric Reference System for the Americas" (SIRGAS). Its main objective is the definition, realisation and maintenance of a state-of-the-art geodetic reference frame in Latin America and the Caribbean, including both, the geometrical and physical components. The present SIRGAS activities concentrate on:

- Maintenance and improvement of the ITRF densification in the SIRGAS Region;
- Contribution to the IGS through the operation of the IGS–RNAAC–SIR;
- Definition and realization of a gravity field-related vertical reference system in Latin America and the Caribbean;
- Promotion, coordination and support of national activities oriented to the use of SIRGAS as official reference frame in the individual countries;
- Measuring and modelling non-linear changes in the position of the reference stations;
- Monitoring vertical movements of tide gauges with GNSS;
- Expanding SIRGAS capabilities for real time GNSS positioning;
- Monitoring the ionosphere and neutral atmosphere with GNSS;
- Exploring the usefulness of GLONASS for the SIRGAS realisation;
- Organising and developing capacity building activities;
- Outreach through focused symposia, conferences, lectures, and articles.

In addition to being a Sub-commission of the IAG Commission 1, SIRGAS is at the same time a Working Group of the Cartographic Commission of the Pan American Institute for Geography and History (PAIGH). The linkage with the IAG ensures compliance with the policies of the Association and facilitates the access of the region to the IAG components. The interaction with PAIGH ensures agreement with the targets of the "2013-2015 Action Plan to Expedite the Development of Spatial Data Infrastructure of the Americas" that SIRGAS signed with PAIGH and other Pan American organizations in November 2012<sup>1</sup>. Thanks to the common work with the IAG and the PAIGH, 14 countries in the region have already adopted SIRGAS as the official reference frame for Geodesy and Cartography, according to the recommendation issued in 2001 by the "United Nations Cartographic Conference for the Americas" (New York, USA, January 22-26, 2001).

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<sup>1</sup> Borrero S., Brunini C., Fortes L. and Van Prag E. (2013): 2013-2015 PAIGH, SIRGAS, PC-IDEA, GeoSUR Joint Action Plan to Expedite the Development of Spatial Data Infrastructure of the Americas. PAIGH, Mexico City ([www.ipgh.org/Iniciativas/JointActionPlan.pdf](http://www.ipgh.org/Iniciativas/JointActionPlan.pdf)).

At present, more than 50 institutions from 19 countries, including the national mapping agencies of Latin America, are committed to SIRGAS in a voluntary partnership. The main body of the organization is a Directing Council composed by one representative of each member country, one of IAG and one of PAIGH. This Council states the fundamental policies whose accomplishment is under the responsibility of an Executive Committee and the corresponding activities are conducted by the three working groups described in the following.

### **SC1.3b-WGI: Reference System**

This WG is responsible for the analysis of the SIRGAS Reference Frame. This frame is composed of approximately 300 continuously operating GNSS stations, 140 of which with GLONASS capability, and 60 with real time data transfer. The SIRGAS Reference Frame includes 58 formal IGS stations; however, in order to improve the distribution of the ITRF sites in this region, 40 additional SIRGAS stations are being processed by the IGS Global Analysis Centres since January 2012 and they are also included in the IGS Reprocessing 2. GNSS data are produced, archived, and processed according to the international standards to generate:

- Loosely constrained weekly solutions as input for the computation of cumulative (multi-year) solutions and to be integrated into the IGS polyhedron;
- Weekly station positions aligned to the ITRF to be as reference for surveying applications in Latin America;
- Multi-year solutions with station positions for a given epoch and constant velocities to estimate the kinematics of the reference frame.

Due to the large number of stations, the SIRGAS network is divided in 4 sub-networks: one core network with ~120 stations distributed over the whole continent, and three sub-networks distributed regionally on the northern, middle, and southern part of the continent. These sub-networks are independently processed by 10 SIRGAS Analysis Centres: the core network is computed by DGFI in Germany (responsible for the IGS RNAAC SIR), and the others by CEPGE (Ecuador), CIMA (Argentina), CPAGS-LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM (Chile), IGN (Argentina), INEGI (Mexico), and SGM (Uruguay). INEGI and IGN use the GAMIT/GLOBK software<sup>2</sup>, while the others use the Bernese GPS Software V. 5.0<sup>3</sup>. The distribution of the stations among the Processing Centres guarantees that each station is included in three solutions. Those solutions are integrated in a unified solution by the SIRGAS Combination Centres: DGFI and IBGE. The accuracy of the final SIRGAS coordinates is estimated to be  $\pm 2,0$  mm in the North and the East, and  $\pm 4,0$  mm in the height. All Analysis Centres follow the same guidelines for the computation of loosely constrained weekly solutions and presently, they are aligning the computation procedures to the new standards released by the IGS for the Reprocessing 2. It is expected that the second reprocessing of the SIRGAS Reference Frame starts in the last quarter of 2013.

As already mentioned, to estimate the kinematics of the SIRGAS Reference Frame, a cumulative solution is computed (updated) every year, providing epoch positions and constant velocities for stations operating longer than two years. The coordinates of the multi-year solutions refer to the latest available ITRF and to a specified epoch, e.g. the most recent SIRGAS-CON multi-year solution SIR11P01 refers to ITRF2008, epoch 2005.0. It includes 230 stations with 269 occupations and its precision was estimated to be  $\pm 1,0$  mm (horizontal)

<sup>2</sup> Herring T.A., King R.W. and McClusky S.C. (2010): Introduction to GAMIT/GLOBK. Department of Earth, Atmospheric and Planetary Sciences, MIT ([www-gpsg.mit.edu/~simon/gtgk/index.htm](http://www-gpsg.mit.edu/~simon/gtgk/index.htm)).

<sup>3</sup> Dach R., Hugentobler U., Fridez P. and Meindl M. (Eds.) (2007): Bernese GPS Software Version 5.0 Documentation. Astronomical Institute, University of Berne ([www.bernese.unibe.ch/](http://www.bernese.unibe.ch/)).

and  $\pm 2,4$  mm (vertical) for the station positions, and  $\pm 0,7$  mm/a (horizontal) and  $\pm 1,1$  mm/a (vertical) for the constant velocities. For the moment, the computation of multi-year solutions is stopped until the entire network is totally reprocessed with respect to the IGS08 (IGb08) Reference Frame.

The loosely constrained weekly solutions as well as the weekly SIRGAS station positions and the multi-year solutions are available at <ftp://ftp.sirgas.org/pub/gps/SIRGAS/> or at [www.sirgas.org](http://www.sirgas.org).

### **SC1.3b-WGII: SIRGAS at national level**

After the determination of the first SIRGAS realisation in 1995, the South American countries concentrated on the modernization of their local geodetic datums through national densifications of the continental network and the determination of transformation parameters to migrate the existing geo-data from the old reference systems to SIRGAS. At the beginning, these densifications were realised by passive networks (i.e. pillars); today, most of the countries are installing continuously operating GNSS stations, which serve not only as local reference frame, but also as referential for daily applications based on satellite navigation and positioning. From 2000, the Central American countries started also to face these activities. The current undertakings of the SC1.3b-WGII concentrate on:

- Supporting those countries interested on adopting SIRGAS as official reference frame. It includes advice on the establishment and processing of national GNSS reference networks, determination of transformation parameters between the classical geodetic datums and SIRGAS, alignment of the existing geo-data into SIRGAS, and generation of documents of guidance to orientate local users approaching SIRGAS. During the last two years, significant advances were achieved in Bolivia, Costa Rica, Guatemala, and Honduras.
- Promoting the availability of the SIRGAS Reference Frame in real time by improving the transfer facilities at the reference stations and by installing a service called "Experimental SIRGAS Caster"<sup>4</sup>. Argentina, Brazil, Chile, Colombia, Uruguay, and Venezuela report major advances in this field.
- Coordinating local GNSS campaigns on passive points (where no continuously operating stations exist) to increase the availability of epoch station positions to detect deformations of the reference frame, especially in those areas affected by earthquakes (Argentina, Chile, Colombia, Costa Rica, Honduras, Guatemala, México, Peru, and Venezuela).

### **SC1.3b-WGIII: Vertical datum**

Through this WG, SIRGAS is committed to the definition and realisation (and further maintenance) of a gravity field-related vertical reference system in Latin America and the Caribbean, following the advice of the IAG Joint Working Group 0.1.1 on Vertical Datum Standardization. On-going tasks include

- Continental adjustment of the first order vertical networks in terms of geopotential numbers referred to a common  $W_0$  value;
- Determination of a unified (quasi)geoid model for the region (under the responsibility of the IAG SC 2.4b, 'Gravity and Geoid in South America');
- Transformation (unifications) of the existing height systems into the new one.

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<sup>4</sup> This caster is hosted by the Universidad Nacional de Rosario, Argentina ([www.fceia.unr.edu.ar/gps/caster](http://www.fceia.unr.edu.ar/gps/caster)).

Great efforts have been dedicated, and have still to be dedicated, to

- The collection and validation of the existing databases containing levelling and gravity data as well as tide gauge registrations;
- Transcription of old field notebooks to digital format;
- Levelling field works to connect the fundamental points of the vertical networks with the SIRGAS reference station and with the main national tide gauges;
- More levelling connections between neighbouring countries.

A great advance towards the continental adjustment of geopotential numbers have been recently achieved with the realization of the "SIRGAS Workshop on Vertical Networks Unification", carried out in December 2012, in Río de Janeiro (Brazil), with the local support of the IBGE and economical support from the IUGG, the IAG, and the PAIGH.

### **Outreach and capacity building activities**

- **SIRGAS 2011 General Meeting** hosted by the Universidad Nacional in Heredia, Costa Rica, between August 8 and 10, 2011. It was attended by 116 participants from 17 countries.
- **SIRGAS 2012 General Meeting and technical visit to the Geodetic Observatory TIGO** carried out in Concepción, Chile from October 29 to October 31, 2012. It was organised by the Universidad de Concepción and the Instituto Geográfico Militar of Chile.
- **Third SIRGAS/IAG/PAIGH School on Geodetic Reference Systems:** it took place together with the SIRGAS 2011 General Meeting in August 3-5, 2011 in Heredia, Costa Rica. It was attended by 116 participants from 17 countries.
- **Fourth SIRGAS/IAG/PAIGH School was devoted to the Real Time GNSS Positioning** and was carried out between October 24 and 26, 2012. It was hosted by the Universidad de Concepción and the Instituto Geográfico Militar of Chile and was attended by 50 colleagues from 16 countries. This School was possible thanks to the support of the Federal Agency for Cartography and Geodesy (BKG) of Germany.
- **Capacity building on Geodetic Reference Systems** in Santiago de Chile, Chile, between September 26 and 30, 2011. It was organised by the Instituto Geográfico Militar of Chile with the support of the Deutsches Geodätisches Forschungsinstitut (DGFI, Germany) and the IAG. It was attended by 120 Chileans.
- **Training courses on precise GNSS data processing.** This activity is possible thanks to the agreement between the University of Bern and the DGFI to provide with the Bernese Software Latin American institutions intending to establish a SIRGAS Analysis Centre. In this period, three courses were carried out:
  - Instituto Geográfico Militar of Chile, Santiago de Chile, Chile, between September 26 and 30, 2011. 5 attendants.
  - Escuela de Topografía, Catastro y Geodesia, Universidad Nacional, Heredia, Costa Rica from December 3 to December 7, 2012. 15 attendants.
  - Instituto Geográfico Militar of Bolivia, La Paz, Bolivia, between May 27 and 31, 2013. 15 attendants.
- Participation in the following meetings:
  - IUGG General Assembly. Melbourne, Australia. June 2011.
  - Latin American Geospatial Forum. Rio de Janeiro, Brazil. August 2011.

- VII Colóquio Brasileiro de Ciências Geodésicas, Sessão Especial sobre a Rede Vertical Brasileira. Curitiba. Brasil. September 2011.
- Curso avanzado de posicionamiento por satélites. Madrid, Spain. October 2011.
- International Symposium on Global Navigation Satellite Systems, Space-Based and Ground-Based Augmentation Systems and Applications. Berlin, Germany. October 2011.
- Jornada técnica acerca del Marco de Referencia Vertical de Argentina. Rosario, Argentina. November 2011.
- STSE-GOCE+Height System Unification Progress Meeting 2, Frankfurt am Main, Germany. December 2011.
- XI Congreso Nacional y VIII Latinoamericano de Agrimensura. Villa Carlos Paz, Argentina. May 2012.
  - Congreso Internacional Geomática Andina 2012. Bogota, Colombia. June 2012.
  - IGS Workshop 2012. Olsztyn, Poland. July 2012.
  - AOGS-AGU (WPGM) Joint Assembly. Singapore. August 2012.
  - XII Congreso Internacional de Topografía, Catastro, Geodesia y Geomática. San Jose, Costa Rica. September 2012.
  - 8th FIG Regional Conference. Montevideo, Uruguay. November 2012.
  - AGU Meeting of the Americas. Cancun, Mexico, May 2013.

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## Acknowledgments

The operational infrastructure and results described in this report are possible thanks to the active participation of many Latin American and Caribbean colleagues, who not only make the measurements of the stations available, but also operate SIRGAS Analysis Centres processing the observational data on a routine basis. This support and that provided by the International Association of Geodesy (IAG) and the Pan-American Institute for Geography and History (PAIGH) is highly appreciated.

More details about the activities and new challenges of SIRGAS, as well as institutions and colleagues working on can be found at [www.sirgas.org](http://www.sirgas.org).

## **Sub-Commission 1.3c: Regional Reference Frame for North America (NAREF)**

*Co-Chairs: Michael Craymer (Canada), Jake Griffiths (USA)*

### **Introduction**

The objective of this sub-commission is to provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, including Central America, the Caribbean and Greenland (Denmark).

The Sub-Commission is currently composed of three working groups:

- SC1.3c-WG1: North American Reference Frame (NAREF)
- SC1.3c-WG2: Plate-Fixed North American Reference Frame
- SC1.3c-WG3: Reference Frame Transformations

The following summarizes the activities of each working group. For more information and publications related to these working groups, see the regional Sub-Commission web site at <http://www.naref.org/>.

### **SC1.3c-WG1: North American Reference Frame (NAREF)**

The objective of this working group is to densify the ITRF and IGS global networks in the North American region. Meetings of the working group were held in 2011 and 2012 during the AGU Fall Meeting in San Francisco.

The regional densification of the ITRF and IGS network consists of weekly combinations of different regional weekly solutions across the entire North American continent using different GPS processing software. Current contributors and some details of their solutions are given in the Table 1.3c.1 (below). In addition to these contributions, NRCan is in the process of implementing PPP solutions for the same set of stations in their Bernese contribution. This will provide redundant solutions for all NRCan stations.

Table 1.3c.1: Current NAREF weekly regional contributions

<b>Contributor</b>	<b>Software</b>	<b>Region</b>	<b>No. Stations (total/used)</b>
NGS	PAGES	USA & territories (CORS network)	1853
Scripps	GAMIT	North America	1291
MIT	GIPSY+Bernese Combination	Western North America	1373
NRCan	Bernese	Canada, Greenland & northern USA	485
INEGI	GAMIT	Mexico	44

Not all stations in the Scripps and MIT solutions are being used because of the very high density of sites in southern California and some local areas of the Plate Boundary Observatory network. Presently, only those stations in the U.S. common with the NGS CORS solution will be included in the combinations.

Because of the increasing number of stations, no weekly combinations have been performed since GPS week 1583 due to the limitations of the SINEX combination software at that time. An enhanced version of the software is under development by NRCan to handle thousands of stations with greatly improved processing efficiency. The first version of the software has just been released and will be used to restart the weekly NAREF combinations by the Summer of 2013.

With the exception of INEGI, reprocessing of the regional networks are planned in conjunction with the IGS08 repro2 effort. Most contributors (NGS, NRCan, Scripps) plan to create their regional solutions as densifications of their global contributions to repro2 using their own orbits submitted to the IGS. INEGI has just completed their own reprocessing with repro1 orbits and has no immediately plans to reprocess again.

### **SC1.3c-WG2: Plate-Fixed North American Reference Frame**

The objective of this working group is to establish a high-accuracy, geocentric reference frame, including velocity models, procedures and transformations, tied to the stable part of the North American tectonic plate which would replace the existing, non-geocentric NAD83 reference system and serve the broad scientific and geomatics communities by providing a consistent, mm-accuracy, stable reference with which scientific and geomatics results (e.g., positioning in tectonically active areas) can be produced and compared.

It is not expected that NAD83 will not be replaced until 2022 when it is also planned to replace the vertical datum in the USA with a geoid-based datum. It has generally been agreed that the new NAD system will be aligned exactly with the current realization of ITRF at that time at some specific epoch. In the meantime, discussions are underway on the best method of fixing such a frame to the North American plate.

### **SC1.3c-WG3: Reference Frame Transformations in North America**

The objective of this working group is to determine consistent relationships between international, regional and national reference frames/datums in North America, to maintain (update) these relationships as needed and to provide tools for implementing these relationships.

This work primarily involves maintaining the officially adopted relationship between ITRF and NAD83 in Canada and the U.S. The NAD83 frame is now defined in terms of a time-dependent 7-parameter Helmert transformation from ITRF96. Transformations from/to other subsequent versions of ITRF are obtained by updating the NAD83-ITRF transformation with the official incremental fourteen parameter transformations between ITRF versions as published by the IERS. The last update to the NAD83-ITRF transformation was for ITRF2008 in late 2010.



## **Sub-Commission 1.3d: Regional Reference Frame for Africa (AFREF)**

*Chair: Richard Wonnacott (South Africa)*

### **Introduction**

This report summarizes the main activities related to the IAG action plans, developed during 2011 – 2013 in Africa under Sub-Commission 1.3d Africa. Many persons and institutions have contributed, either directly or indirectly, to the activities of the Sub-Commission. The author wishes to thank all those who have contributed and at the same time apologize in advance for credits that may have been inadvertently omitted in this report.

### **Reference Frame**

The major activity within Africa in relation to the activities of Commission 1 Reference Frames and in particular SC 1.3d Africa is the establishment of a network of permanent GNSS base stations in support of an effort to unify the reference frames in Africa. The project is known as the Africa Reference Frame project (AFREF) and has the support of the United Nations Committee for Development Information, Science and Technology (CODIST).

Four of the seven major objectives of AFREF relative to this report are to:

- Define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF;
- Establish continuous, permanent GPS stations such that each nation or each user has free access to, and is at most 500km from, such stations;
- Determine the relationship between the existing national reference frames and the ITRF to preserve legacy information based on existing frames; and
- Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

In pursuance of these objectives, permanent GNSS base stations are being set-up through most of Africa. Approximately 70 stations have been installed and an Operational Data Centre has been installed to download and archive data from these stations. On average, 40 stations provide data daily albeit not always the same 40.

The stations have been installed by a variety of agencies, organizations and projects such as the Africa Array (seismology), AMMA-GPS (meteorology) and SCINDA (ionosphere) projects. A number of countries have also established CORS networks by the National Mapping Authorities.

A two-week period was identified in Dec 2012 during which data from an average of 50 stations were downloaded per day. This data, together with a further 50 global stations, was processed by 5 processing centres and combined by the IGN, Paris to provide a set of static co-ordinates based on ITRF to be used for everyday surveying and mapping operations.

The five processing centres were:

- Ardhi Univesity, Tanzania / University of Purdue, USA
- Centre for Geodesy and Geodynamics, Nigeria

- Hartebeesthoek Radio Astronomy Observatory, South Africa
- Surveying and Mapping Division, Ministry of Lands, Tanzania
- University of Beira Interior, Portugal

The second phase will be routine processing of the network to provide a velocity field. Data from the stations currently in place is being processed and used by IAG Working Group on Regional Dense Velocity Fields

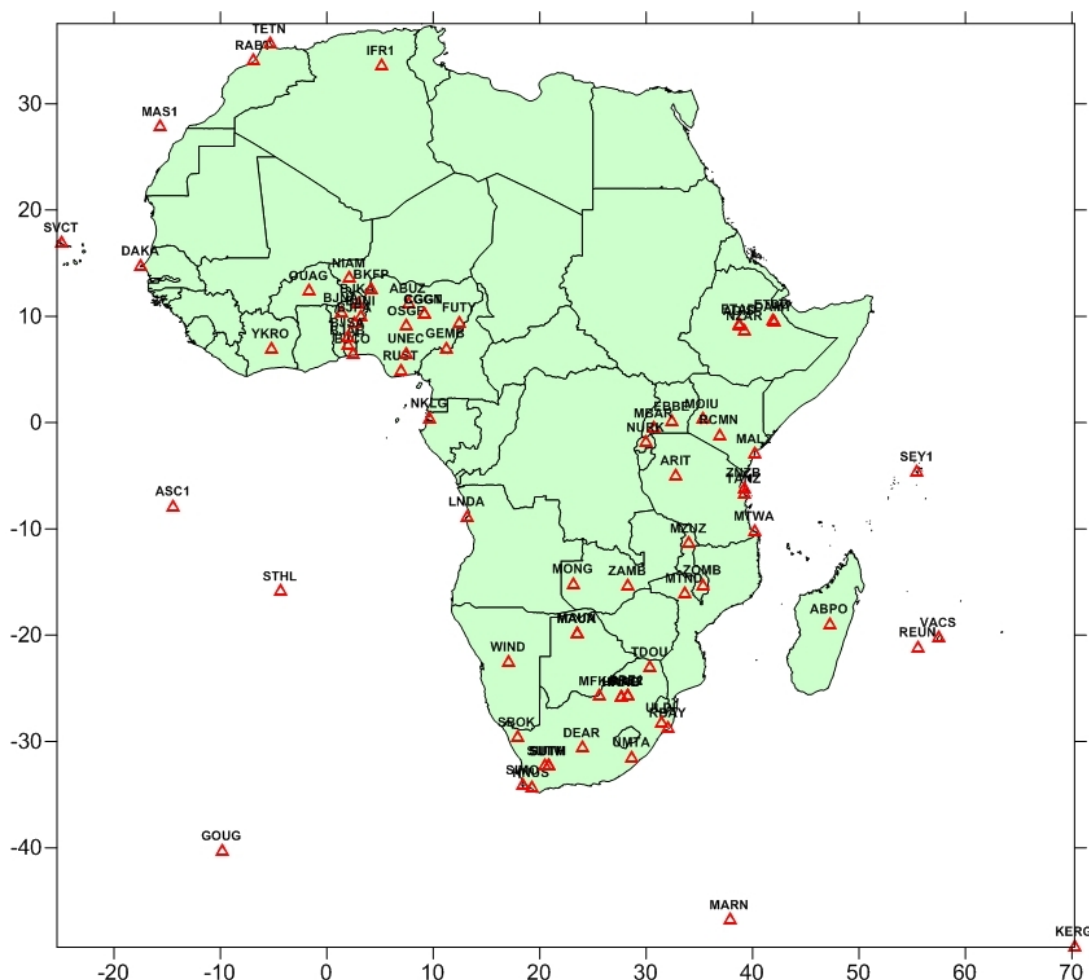


Figure 1: Stations for which data is archived in the AFREF ODC as at 4 January 2013. The lack of freely available CORS data in the area from Angola through Central Africa, Sudan and Sahara and North African countries is of concern.

Once the set of static co-ordinates has been published, the National Mapping Authorities will have to commence with determining the relationship between the new ITRF based AFREF reference frame and the existing in-country reference in order to preserve the legacy of all historical geospatial data and reference material.

### Capacity Building

Workshops on the establishment and processing of permanent GNSS stations and networks are held annually at the Regional Centre for Mapping of Resources for Development in Nairobi, Kenya. Partially as a result of these workshops, a number of countries have either established or have commenced with the establishment of in-country CORS networks.

## **Sub-Commission 1.3e: Regional Reference Frame for South-East Asia and Pacific (APREF)**

*Chair: John Dawson (Australia)*

### **Overview**

To improve regional cooperation that supports the realisation and densification of the International Terrestrial Reference frame (ITRF). This activity is carried out in close collaboration with the United Nations Global Geospatial Information Management (UN-GGIM) Asia Pacific - Geodesy Working Group (formerly known as the Geodetic Technologies and Applications Working Group of the Permanent Committee for GIS Infrastructure in Asia and the Pacific - PCGIAP).

The objectives of the Sub-commission 1.3e are:

- The densification of the ITRF and promotion of its use in the Asia Pacific region.
- To encourage the sharing of GNSS data from Continuously Operating Reference Stations (CORS) in the region.
- To develop a better understanding of crustal motion in the region.
- To promote the collocation of different measurement techniques, such as GPS, VLBI, SLR, DORIS and tide gauges, and the maintenance of precise local geodetic ties at these sites.
- To outreach to developing countries through symposia, workshops, training courses, and technology transfer activities.

### **Activities**

The activities of sub-commission 1.3e have focussed on the Asia Pacific Reference Frame (APREF) project. Table 1.3e.1 summarizes the current commitments to APREF.

APREF products presently consist of a weekly combined regional solution, in SINEX format and a cumulative solution, which includes velocity estimates.

In addition to those stations contributed by participating agencies, the APREF analysis also incorporates data from the International GNSS Tracking Network including stations in the Russian Federation (16), China (10), India (3), French Polynesia (2), Kazakhstan (1), Thailand (1), South Korea (3), Uzbekistan (1), New Caledonia (1), Marshall Islands (1), Philippines (1), Fiji (1), and Mongolia (1).

GNSS data from a CORS network of approximately 480 stations, contributed by 28 countries is now available and processed by three Analysis Centres (ACs): Geoscience Australia, the Curtin University, and the Department of Sustainability and Environment in Victoria, Australia.

The APREF project websites was established as <http://www.ga.gov.au/earth-monitoring/geodesy/asia-pacific-reference-frame.html>. The weekly ITRF coordinate estimates in SINEX format, coordinates time series and velocity solutions for the APREF stations are published on the APREF website.

Table 1.3e.1: Responses to the APREF Call For Participation. Responding agencies have indicated whether they would undertake analysis, provide data archive and product distribution or supply data from GNSS stations

Country/Locality	Responding Agency	Proposed Contribution		
		Analysis	Archive	Stations
Afghanistan	National Geospatial-Intelligence Agency, USA			2
Alaska, USA	National Geodetic Survey (USA)			90
American Samoa	National Geodetic Survey (USA)			1
Australia	Geoscience Australia	x	x	97
Australia	Curtin University of Technology	x		1
Australia	University of New South Wales	x		1
Australia	Department of Environment and Resource Management, Queensland			10
Australia	Department of Sustainability and Environment, Victoria	x		55
Australia	Department of Lands and Planning, Northern Territory			5
Australia	Department of Primary Industries, Parks, Water & Environment, Tasmania			2
Australia	Radio and Space Weather Services, Bureau of Meteorology			3
Australia	Land and Property Management Authority, New South Wales			89
Brunei	Survey Department, Negara Brunei Darussalam			1
Cook Islands	Geoscience Australia			1
Cook Islands	Geospatial Information Authority of Japan			1
Ethiopia	Ethiopian Mapping Agency			3
Federated States of Micronesia	Geoscience Australia			1
Fiji	Geoscience Australia			1
French Polynesia	Geospatial Information Authority of Japan			1
Guam, USA	National Geodetic Survey (USA)			1
Hawaii, USA	National Geodetic Survey (USA)			19
Hong Kong, China	Survey and Mapping Office			7
Indonesia	Bakosurtanal			4
Iran	National Cartographic Center, Iran			6
Iraq	Iraqi Ministry of Water Resource General Directorate for Survey			6
Japan	Geospatial Information Authority of Japan	x	x	10
Kazakhstan	Kazakhstan Gharysh Sapary			2
Kiribati	Geoscience Australia			1
Kiribati	Geospatial Information Authority of Japan			2
Macau, China	Macao Cartography and Cadastre Bureau			3
Manus Island	Geoscience Australia			1
Marshall Islands	Geoscience Australia			1
Micronesia	Geoscience Australia			1

Mongolia	Administration of Land Affairs, Construction, Geodesy and Cartography (ALACGaC)			8
Nauru	Geoscience Australia			1
New Zealand	Land Information New Zealand	x	x	38
Northern Mariana Islands	National Geodetic Survey (USA)			1
Papua New Guinea	National Mapping Bureau, Papua New Guinea, and Geoscience Australia			2
Philippines	Department of Environment and Natural Resources, National Mapping and Resource Information Authority	x	x	4
Samoa	Geoscience Australia			1
Solomon Islands	Geoscience Australia			1
Tonga	Geoscience Australia			1
Tuvalu	Geoscience Australia			1
Vanuatu	Geoscience Australia			1

In addition to APREF, the sub-commission has and will continue to coordinate an annual GNSS campaigns along with APREF so that countries without Continuously Operating Reference Stations (CORS) can connect their national geodetic infrastructure to the regional/global network.

In 2012 a GNSS Campaign (APRGP2012) was carried out from 9th September 2012 to 15th September 2012 (GPS week 1705). This campaign was coordinated by Geoscience Australia (GA). Data were contributed from eleven countries and regions, i.e., Brunei, Cambodia, Hong Kong, Japan, Korea, Lao, Malaysia, Nepal, Philippine, Singapore and Vietnam. The analysis report for this campaign will be distributed through the participant member countries after finalization.

## **Sub-Commission 1.3f: Regional Reference Frame for Antarctica (SCAR)**

*Chair: Reinhard Dietrich (Germany)*

### **Observation Campaigns**

The SCAR GPS Campaigns 2012 and 2013 were carried out in the austral summers 2012 and 2013. All together, the data of about 40 Antarctic sites are now collected in the SCAR GPS database beginning with the year 1995.

### **Data Analysis**

The data analysis has been continued. All data analyses were carried out with the Bernese GNSS Software, version 5.0. The results were presented at the XXXII SCAR Meeting in Portland/USA in July 2012.

### **Meetings**

During the XXXII SCAR Meeting in Portland the members of SC1.3f met and the working plan of the SCAR Group of Experts on Geodetic Infrastructure in Antarctica (GIANT) was discussed and fixed for the years 2012-2014. M. Scheinert (Germany) was elected as the new chairman of GIANT Project “Crustal Movements from GNSS observations”, which will focus also on the regional reference frame in Antarctica. The members of GIANT represent the SC1.3f.

## **Working Group 1.3.1: Integration of Dense Velocity Fields into the ITRF**

*Chair: Carine Bruyninx (Belgium), co-chair: J. Legrand (Belgium)*

### **Introduction**

The Working Group (WG) “Integration of Dense Velocity Fields into the ITRF” is the follow up of the IAG WG “Regional Dense Velocity Fields” (Bruyninx et al. 2012, 2013).

The objective of the WG is to provide a GNSS-based dense, unified and reliable velocity field globally referenced in the ITRF (International Terrestrial Reference Frame) and useful for geodynamical and geophysical interpretations.

The WG is embedded in IAG sub-commission 1.3 “Regional Reference Frames” where it coexists with the Regional Reference Frame sub-commissions AFREF (Africa), APREF (Asia & Pacific), EUREF (Europe), NAREF (North America), SCAR (Antarctica), SIRGAS (Latin America & Caribbean). These IAG Regional Reference Frame sub-commissions are responsible to provide the GNSS-based densified solutions for their region.

### **Working Group Members**

- Zuheir Altamimi
- Carine Bruyninx
- Mike Craymer
- John Dawson
- Jake Griffiths
- Ambrus Kenyeres
- Juliette Legrand
- Laura Sanchez
- Álvaro Santamaría Gómez
- Elifuraha Saria

### **Activities**

The WG originally started by combining several multi-year position/velocity solutions submitted by the IAG regional reference frame sub-commissions (APREF, EUREF, SIRGAS, NAREF) and global (ULR, (Santamaría-Gómez et al. 2011)) analysis centres. However, the regional and global multi-year solutions showed discrepancies. An attempt was made to find the origin of these differences by analysing position time series, position/velocity solutions, and metadata. In case of disagreements, the wrong positions and velocities were removed prior to perform the combination of the cumulative ITRF2008 solution with some of the submitted solutions. As the level of agreement between the solutions was not satisfactory, these combinations demonstrated the limitations of the ‘cumulative’ approach, which was affected by geographically correlated biases.

In 2012, the WG therefore decided to start with the combination of weekly position solutions allowing to mitigate the biases. All initial contributors agreed with this approach and in addition, AFREF also started to submit its first solutions. They submitted: weekly SINEXs (cleaned or with a list of the outliers to be removed), a cumulative solution and associated

residual position time series, position and velocity discontinuities that should be used for the cumulative solution, and station site logs (if available).

The list of submitted solutions is shown in Table 1.3.1.1. The solutions contain more than two thousand stations (Figure 1.3.1.1).

Table 1.3.1.1: List of the weekly solutions submitted to the WG in 2012

	AC	Solution	Data span (year)	Antenna calibrations	# stations (raw)	# stations (selected)	# new stations wrt ITRF2008
IGS	IGS	Global	1996.0-2011.3	igs05	1030	724	187
AFREF	AFR	Global	1996.0-2011.3	igs08	197	158	103
APREF	APR	Global	2004.0-2011.3	igs08	492	308	82
EUREF	EUR	Regional	1996.0-2011.3	igs05 + indiv	290	254	134
NAREF	GSB	Global	2000.0-2011.3	igs05	592	568	455
	NGS	Global	2000.0-2011.3	igs05	2506	1359	1005
SIRGAS	SIR	Regional	2000.0-2011.3	igs05	266	203	145
ULR	ULR	Global	1996.0-2011.3	igs05 or igs08	317	260	57
<b>Total</b>			<b>1996.0-2011.3</b>		<b>3669</b>	<b>2396</b>	<b>1831</b>

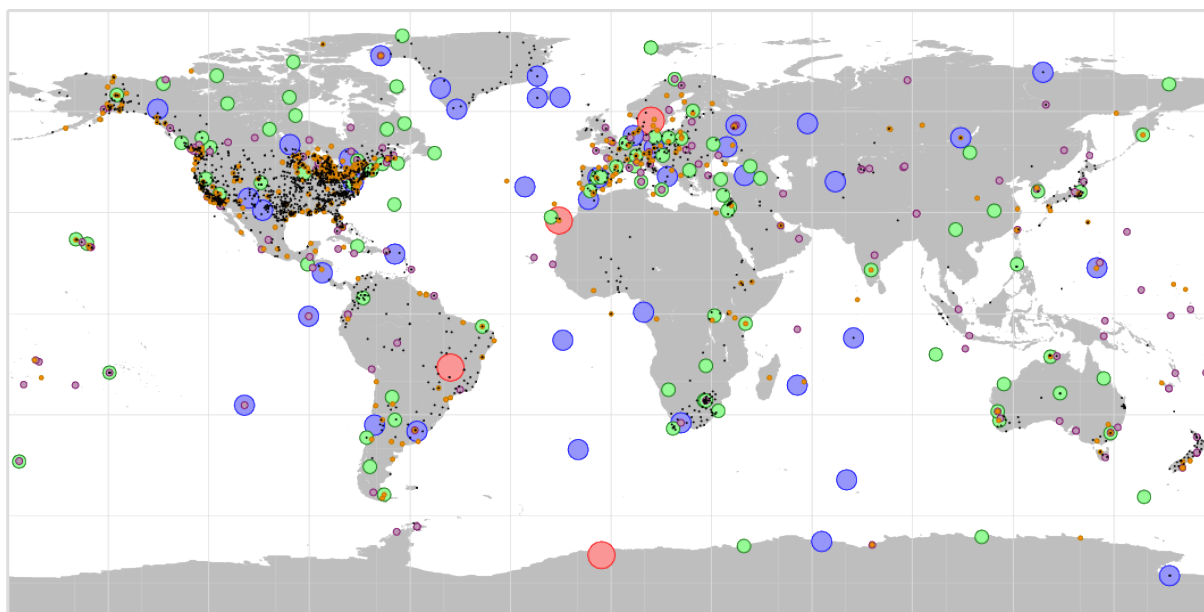


Figure 1.3.1.1: Map of the network, stations common to: 6 solutions in red, 5 solutions in blue, 4 solutions in green, 3 solutions in purple, 2 solutions in orange and 1 solution in black.

Preliminary combinations have been performed. For this, each week, the available individual SINEXs are combined with the CATREF Software (Altamimi et al., 2007). The IGS weekly solution is used as reference and the “regional” individual weekly solutions are aligned to it using 7 Helmert parameters.

For these combinations, only stations having enough observations were estimated (data span > 3 year, present in at least 104 weekly SINEX and present in at least 50% of the weekly



SINEXs within the data span). So far, only a gross data cleaning was done rejecting outliers larger than 10 cm. The resulting 3D weekly RMS of these preliminary combinations ranged between 2 mm and 8 mm (Figure 1.3.1.2).

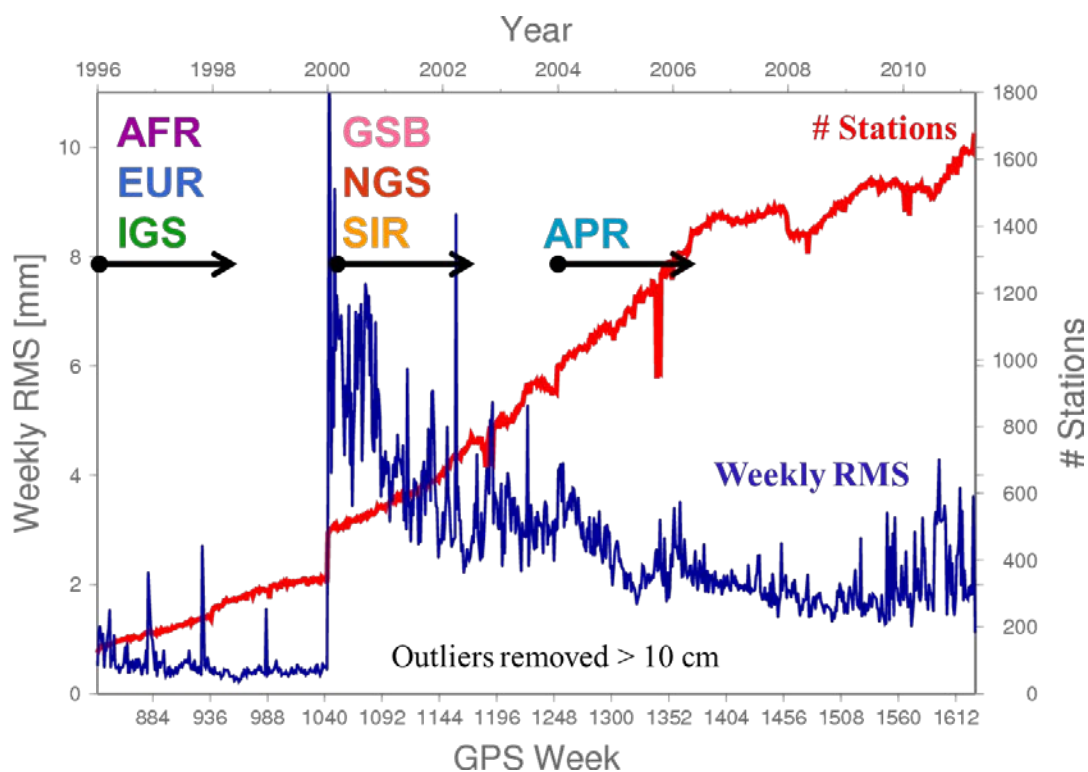


Figure 1.2.3.2: 3D Weekly RMS [in mm] and number of stations in the weekly combinations as a function of GPS weeks.

The large RMS increase occurring in 2000.0 is linked with the increasing number of common solutions and stations and to remaining large disagreements between solutions, mainly caused by inconsistencies at the GNSS data modeling and metadata level. Indeed, as shown in table 1, some solutions used the antenna calibration model igs05.atx before week 1631 and igs08.atx after week 1632 (IGS, EUR, GSB, NGS, SIR), while others used already igs08.atx (APR, AFR) for the whole period. In addition, the EUREF solution also used individual antenna calibrations when available. This situation entailed systematic biases affecting some stations. A possible way to mitigate these biases is to apply the Rebischung (et al. 2012) model. However, we showed that, so far, the use of this model does not significantly improve the agreement between solutions based on different antenna calibration models. One of the reasons for this lies in the fact that some of the antenna metadata included in the submitted weekly SINEXs are erroneous, e.g. not agreeing with information in the site log (when available) or not agreeing with the antenna information used during the analysis. The identified cases will be treated by the exclusion of the inaccurate position.

The stacking of the weekly combined solutions will be performed in order to derive a dense velocity field. First, we will harmonize the discontinuities introduced in each individual solution to derive the individual velocity field. Then, we will refine the stacking and check the residual position time series to detect remaining discontinuities. This solution should be finalized by the fall of 2013.

## Conclusion and Future Work

The preliminary weekly combinations performed in 2013, contain 1830 additional stations compared to the ITRF2008 and include 7 individual solutions. The agreement between the solutions is promising and leads to weekly RMS values ranging from 2 to 8 mm. This combined cumulative solution will be finalised by the fall of 2013. Unfortunately, this solution will be a mix of igs05.atx, igs08.atx and individual antenna models and will therefore not be optimal. In addition, systematic biases (few mm to several m) caused by the usage of incorrect (antenna) metadata were found between the different solutions. Feedback will be sent to the contributors in order to correct these issues in a next reprocessing.

For these reasons, a second combination will have to be done in 2014-2015 based on new reprocessed submissions. It was agreed that these future submissions would be compliant with the IGS repro 2 standards (IERS 2010 conventions); they are expected within the year 2014.

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## **Working Group 1.3.2: Deformation Models for Reference Frames**

*Chair: Richard Stanaway (Australia)*

### **Introduction**

WG 1.3.2 on Deformation Models for Reference Frames was formed after the IUGG in Melbourne, Australia in July 2011. The main aim of the WG is to focus research in deformation modelling into the rapidly emerging field of regional reference frames used in applied geodesy. Deformation models provide linkages between global reference frames such as ITRF, regional reference frames and local reference frames commonly used for land surveying and mapping. Presently there is no consistent approach and methodology to perform high precision transformations between these reference frames.

The IAG WG is working closely with FIG Commission 5 (Positioning and Measurement), specifically FIG Working Group 5.2 (Reference Frames) as there is a great deal in common with the aims of both working groups. The members of WG 1.3.2 comprise a wide spectrum of researchers from different fields of geophysics, geodesy, land surveying and GIS.

### **Working Group members**

- Richard Stanaway, University of New South Wales, Sydney, Australia
- Christopher Pearson, University of Otago, Dunedin, New Zealand
- Paul Denys, University of Otago, Dunedin, New Zealand
- Kevin Kelly, ESRI, Redlands, California, USA
- Rui Fernandes, University of Beira Interior, Covilhã, Portugal
- Craig Roberts, University of New South Wales, Sydney, Australia
- Graeme Blick, Land Information New Zealand, Wellington, New Zealand
- Chris Crook, Land Information New Zealand, Wellington, New Zealand
- John Dawson, Geoscience Australia, Canberra, Australia
- Mikael Lilje, Lantmäteriet, Gävle, Sweden
- Laura Sánchez, Deutsches Geodätisches Forschungsinstitut, München, Germany
- Rob McCaffrey, Portland State University, Portland, Oregon, USA
- Yoshiyuki Tanaka, Earthquake Research Institute, University of Tokyo, Japan
- Sonia Alves, Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Brazil
- Norman Teferle, University of Luxembourg, Luxembourg
- Laura Wallace, University of Texas, Austin, Texas, USA
- Yasushi Harada, Tokai University, Shizuoka, Japan

### **Brief summary of WG activities from 2011 to 2013**

During 2012 and early 2013 considerable research on deformation modelling has been completed by WG members in Japan, South America, Australia, New Zealand and the USA. Recent significant earthquakes such as those in Chile, Japan and New Zealand have resulted in localised deformation models being developed to support land surveying activities necessary for recovery and reconstruction in those countries.

WG members from Japan (Yoshiyuki Tanaka and Yasushi Harada) have been analysing data from the dense GEONET CORS network in Japan in order to improve Japanese crustal

deformation models, particularly post-seismic deformation in the aftermath of the great Tōhoku earthquakes of March 2011. Related work in Japan has been conducted by Atsushi Yamagiwa and Yohei Hiyama of the Geospatial Information Authority of Japan to develop deformation models for use with the Japanese Geodetic Datum JGD2000 (Figure 1.3.2.1), (Kato et al., 2011; Tanaka et al., 2011; Yamagiwa and Hiyama, 2013).

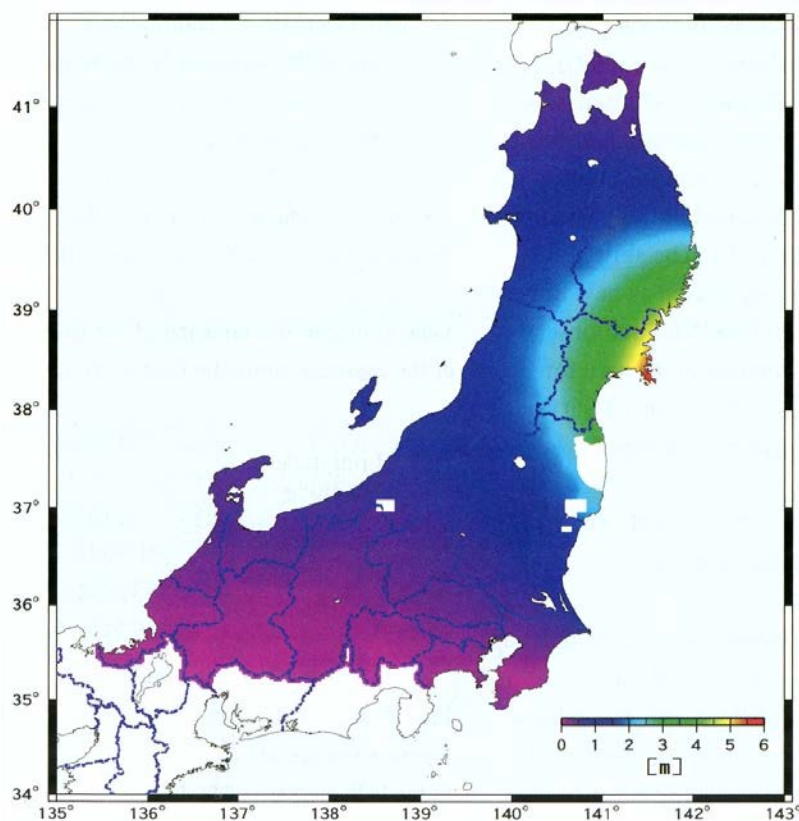


Figure 1.3.2.1. Correction parameters developed for coordinates in Japan - Horizontal component

Development of geodetic deformation models is well advanced in New Zealand, particularly after the Canterbury earthquake sequence between 2010 to 2012. Chris Crook and Nic Donnelly from Land Information New Zealand (LINZ) have revised the New Zealand Deformation Model, which models inter-seismic deformation in New Zealand. They have recently released deformation patches, which model the co-seismic and post-seismic deformation from the Canterbury earthquakes (Crook, 2013). Other WG researchers (Paul Denys and Laura Wallace during her tenure at GNS NZ) have provided insights into localised deformation in New Zealand and geophysical modelling and definition of rigid crustal blocks there.

In Australia, a next-generation geodetic datum, which will be fundamentally dynamic in nature is being developed by the geodesy team at Geoscience Australia, led by WG member John Dawson. Deformation models to support the new datum are being developed by Richard Stanaway and Craig Roberts (Stanaway et al., 2013). This work is being done in close cooperation with the LINZ members of the WG under the aegis of the Co-operative Research Centre for Spatial Information (CRCSI). An Australian Deformation Model which, includes models of uncertainty will be presented at the IAG Assembly in Potsdam in September 2013.

In May 2012, a combined IAG, FIG and ICG workshop "Reference Frames in Practice" was held in Rome prior to the FIG Working week (Figure 1.3.2.2). WG 1.3.2 members Mikael Lilje, John Dawson, Richard Stanaway and Graeme Blick provided substantial input into the

workshop with presentations on deformation models being developed in Australia and New Zealand. This workshop was a great success, and a similar workshop is being run in June 2013 as part of the South-East Asian Surveyors Congress in Manila, The Philippines.



Figure 1.3.2.2. Participants of the IAG, FIG and ICG Reference Frame in Practice (RFIP) Workshop held in Rome, May 2012.

Kevin Kelly at ESRI is developing a new deformation model format for use within GIS. This is a very important contribution to the WG, as the dynamic (kinematic) nature of international and regional reference frames mitigates against their use for most surveying and mapping purposes where precision and repeatability is important over time. A 4D GIS will enable spatial data within a GIS to maintain alignment with kinematic reference frames and positioning technology.

Chris Pearson has been continuing development of the US Horizontal Time-Dependent Positioning software used to transform coordinates within the deforming zone of the Western United States (Figure 1.3.2.3), (Snay and Pearson, 2010; Pearson and Snay, 2011; Pearson et al. 2013). WG member Rob McCaffrey has been developing geophysical modelling tools (e.g. DEFNODE) which underpin the HTDP (Pearson, Snay and McCaffrey, 2012).

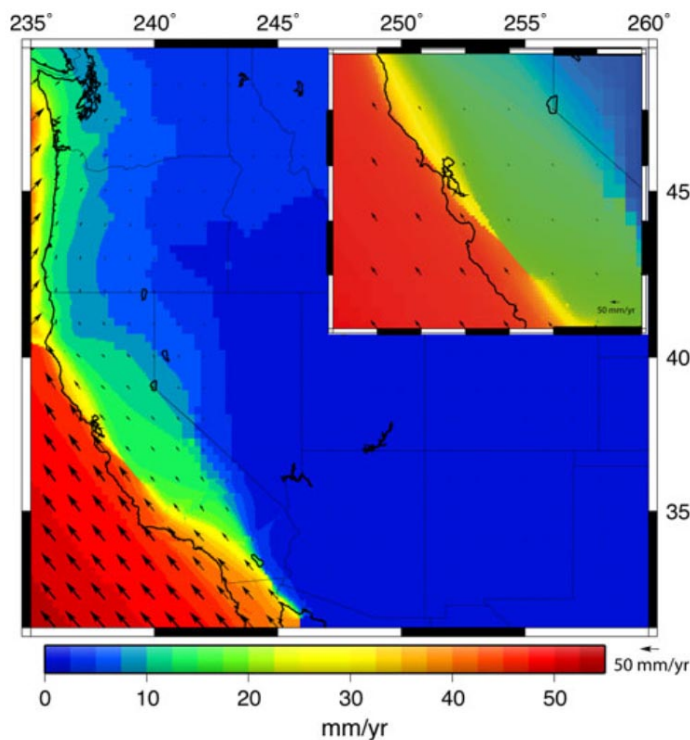


Figure 1.3.2.3: Visualization of the HTDP3.1 velocity field relative to NAD 83(2011). Predicted velocities on 1 degree grid are shown in black. The pixel size in this figure represents the cell spacing in the HTDP velocity grid, coarse in the east where the velocities change very slowly and becoming finer in the tectonically active regions along the west coast

Rui Fernandes is continuing valuable research in Africa, with the development of a velocity field within the Nubian, Somalian, Arabian and Iberian plates. Findings will be presented at FIG and IAG conferences in 2013. Laura Sánchez and Sonia Alves have been involved with development of a high precision deformation model for the South American and Caribbean regions (Figure 1.3.2.4) as part of ongoing development of SIRGAS (Sánchez et al., 2013).

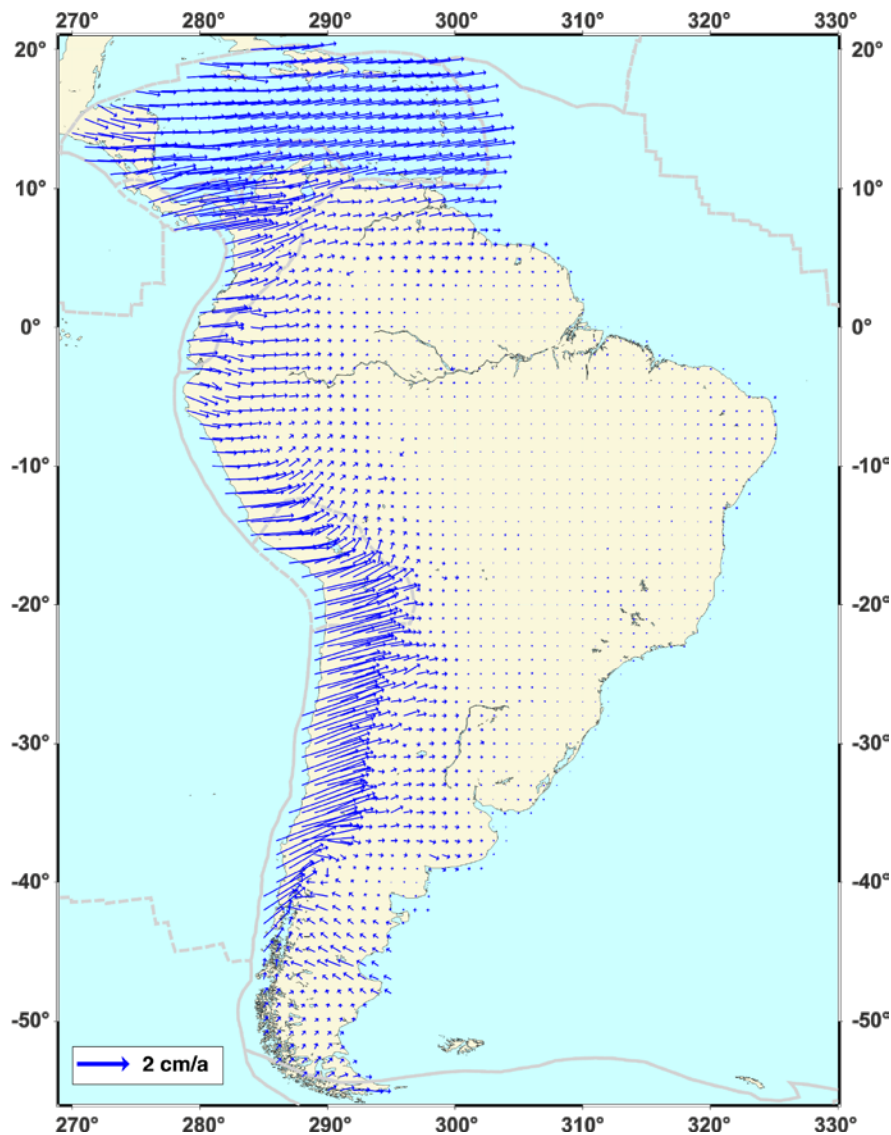


Fig. 1.3.2.4. Horizontal deformation model for South America and the Caribbean (VEMOS2009, Drewes and Heidbach 2012)

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## **Sub-Commission 1.4: Interaction of Celestial and Terrestrial Reference Frames**

*Chair: Johannes Böhm (Austria)*

### **Overview**

Together with the Working Group Chairs Zinovy Malkin (WG1), Sebastien Lambert (WG2), and Chopo Ma (WG3), Johannes Böhm summarized the main challenges for the determination of the terrestrial and celestial references in the proceedings paper for the IVS General Meeting 2012 in Madrid, Spain (Böhm et al., 2012). The authors present and discuss those challenges and perspectives which are tackled within three working groups of Sub-Commission 1.4 on the Interaction of Celestial and Terrestrial Reference Frames, covering improved geophysical and astronomical models, rigorous combination strategies of space geodetic observations, new observation scenarios with radio telescopes to satellites, or the implication of the GAIA mission for the celestial reference frame.

The interaction between the terrestrial and celestial frames has become an important issue in the last years, in particular due to the different estimation strategies of the International Terrestrial Reference Frame (ITRF: combination of different space geodetic techniques) and the International Celestial Reference Frame (ICRF: VLBI-only solution from a single analysis centre). Considering that

*"...the IUGG ... urges that highest consistency between the ICRF, the International Terrestrial Reference Frame (ITRF), and the Earth Orientation Parameters (EOP) as observed and realized by the IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS" (IUGG Resolutions 2011),*

one of the primary goals of this Sub-Commission is to evaluate whether the CRF benefits from (or at least is not degraded by) a combination of VLBI observations with those from other space geodetic techniques. If the latter is proven, the next ICRF should be determined within a combined solution from different techniques. Seitz et al. (2011, 2012) have derived very interesting results, indicating that the combination with other space geodetic techniques has only a very small effect on the source coordinates. Exceptions with larger differences are found for VLBI Calibrator Survey (VCS) sources in right ascension with differences up to 1 mas (see Figure m.1). These particular sources are only observed with the regional VLBA network and are thus likely to benefit from Earth rotation parameters from Global Navigation Satellite Systems (GNSS).

The next ICRF (ICRF-3) is expected for 2018, and it will probably be the last ICRF in the radio for some time, because then GAIA will provide a frame in the optical with significantly more quasars and stars and of similar precision. An important task is the link between the ICRF and sources in the optical domain - a task which is covered by Working Group 3 of this IAG Sub-Commission as well as by the ICRF-3 Working Group of the International Astronomical Union (IAU) chaired by Chris Jacobs. Consequently, a very close co-operation will be held between those two groups, and a very fruitful joint meeting between the communities was held at the European Working Meeting on VLBI for Geodesy and Astrometry (EVGA) in early March 2013 in Espoo, Finland.

## **Past meetings**

### *IAG SC 1.4 Meeting on 25 April 2012 in Vienna during the EGU 2012*

A meeting of IAG Sub-Commission 1.4 was held on 25 April 2012 at the Vienna University of Technology. Since it was scheduled as splinter meeting during the General Assembly of the European Geophysical Union (EGU) in Vienna, in total 18 participants could join. Four presentations were given to stimulate the discussion on future improvements of terrestrial and celestial reference frames, and in particular the consistency between them. For example, Robert Heinkelmann reported about the efforts at DGFI aiming at the consistent determination of the ITRF and ICRS in one combination solution, and Lucia Plank presented simulation results of the observation to satellites with VLBI radio telescopes, i.e., on linking the kinematic and dynamical reference frames.

### *Joint Meeting of the IAU WG on ICRF-3 and the IAG Sub-Commission 1.4 in Espoo, Finland on 7 March 2013*

An important joint meeting was held between the IAU Working Group on the ICRF-3 (chaired by Chris Jacobs) and the IAG Sub-Commission 1.4 and its Working Groups on 7 March 2013. It took place immediately after the EVGA Working Meeting in Espoo, Finland. Both groups are having a similar goal, i.e. the best possible ICRF-3. Additionally, an IUGG resolution is requiring, that the ICRF-3 will be fully consistent with all space geodetic techniques, i.e., not only with VLBI but also with GNSS, SLR, and DORIS. This joint meeting served well the purpose to introduce the two communities to each other. The summary of this meeting will be published in the proceedings of the EVGA meeting.

*Upcoming: An IAG Sub-Commission 1.4 meeting is planned for the IAG Scientific Assembly in Potsdam.*

## **WG 1.4.1: Geophysical and Astronomical Effects and the Consistent Determination of Celestial and Terrestrial Reference Frames**

*Chair: Zinovy Malkin (Russia)*

Working Group 1 is dealing with geophysical and astronomical effects on the consistent determination of celestial and terrestrial reference frames. There have been many papers and presentations on related topics in the past two years, some of which are summarized below. Ongoing topics of research are the modeling of tropospheric gradients or the galactic rotation.

Malkin (2013) outlines several problems related to the realization of the international celestial and terrestrial reference frames at the millimetre level of accuracy, with emphasis on ICRF issues. He considers the current status of the ICRF, the connection between the ICRF and ITRF, and considerations for future ICRF realizations. Several urgent tasks to improve the existing CRF and TRF realizations are were proposed and discussed.

Böhm et al. (2011) compare the influence of two different a priori gradient models on the terrestrial reference frame as determined from VLBI observations. One model has been determined by vertical integration over horizontal gradients of refractivity as derived from data of the Goddard Data Assimilation Office (DAO), whereas the second model (APG) has been determined by ray-tracing through monthly mean pressure level re-analysis data of the European Centre for Medium-Range Weather Forecasts. The authors compare VLBI solutions

from 1990.0 to 2011.0 with fixed DAO and APG gradients to a solution with gradients being estimated, and find better agreement of station coordinates when fixing DAO gradients compared to fixing APG gradients. As a consequence, the authors recommend that gradients are constrained to DAO gradients, in particular in the early years of VLBI observations (up to about 1990), when the number of stations per session is small and the sky distribution is far from uniform. Later than 1990, the gradients can be constrained loosely and the a priori model is of minor importance.

Heinkelmann and Tesmer (2013) assess systematic effects between VLBI terrestrial and celestial reference frame solutions caused by different analysis options. Comparisons are achieved by sequential variation of options relative to a reference solution, which fulfils the requirements of the IVS analysis coordination. Neglecting the total NASA/GSFC Data Assimilation Office (DAO) a priori gradients causes the largest effects: Mean source declinations differ by up to 0.2 mas, station positions are shifted southwards, and heights are systematically larger by up to 3 mm, if no a priori gradients are applied. The effect is explained with the application of gradient constraints. Antenna thermal deformations, atmospheric pressure loading, and the atmosphere pressure used for hydrostatic delay modeling still exhibit significant effects on the TRF, but corresponding CRF differences (about 10  $\mu$ as) are insignificant. The application of the Niell Mapping Functions (NMF) can systematically affect source declinations by up to 30  $\mu$ as, which is in between the estimated axes stability (10  $\mu$ as) and the mean positional accuracy (40  $\mu$ as) specified for the ICRF-2. Further significant systematic effects are seasonal variations of the terrestrial network scale ( $\pm 1$  mm) neglecting antenna thermal deformations, and seasonal variations of station positions, primarily of the vertical component up to 5 mm, neglecting atmospheric loading. The application of NMF instead of the Vienna Mapping Functions 1 results in differences of station heights of up to 6 mm.

Krásná et al. (2013) reaffirm results firstly shown by MacMillan and Ma (1997) with a larger span of data (27 years) including recent, very precise data obtained by the VLBI technique. If tropospheric gradients are neglected, the TRF will experience a scale change of 0.65 ppb compared to a TRF with estimated gradients. Furthermore, clear trends in the north and height components are visible. In the CRF, there is a mean systematic change in the estimated declinations of 0.36 mas with a maximum of about 0.5 mas. On the other hand - concerning the choice of mapping functions (VMF1 or Global Mapping Functions) - only small systematic changes between the reference frames can be observed, e.g. a mean height difference of -0.5 mm over the stations in the terrestrial reference frames.

Liu et al. (2012) show that the effect of the Galactic aberration strongly depends on the distribution of the sources that are used to realize the ICRS. According to different distributions of sources (of the ICRF-1 and ICRF-2 catalogues) the amplitude of the apparent rotation of the ICRS is between 0.2 and 1  $\mu$ as per year. It was shown that this rotation has no component around the axis pointing to the Galactic centre and has zero amplitude in the case of uniform distribution of sources. The effect on the coordinates of the Celestial Intermediate Pole (CIP) is between about 1 to 100  $\mu$ as after one century from J2000.0, while the effects on the Earth rotation angle (ERA) are between 4 and several tens of  $\mu$ as after one century. Thus, the Galactic aberration is responsible for a variation with time of the orientation of the ICRS axes and consequently for systematic errors in the determination of the EOP, which refer to the ICRS. The effect on the ICRS and EOP increases with time and is not negligible after several decades. With high-accuracy astrometry and the increasing length of the available VLBI observation time series, this effect should be considered, particularly in constructing the next realization of the ICRS. Observations of more radio sources, especially in the southern hemi-

sphere, should be developed to more homogeneously distribute defining sources in the ICRF to minimize that effect.

### WG 1.4.2: Co-location on Earth and in Space for the Determination of the Celestial Reference Frame

*Chair: Sebastien Lambert (France)*

Working Group 2 covers the co-location on Earth and in space for the determination of the CRF. This WG also includes the combination of different space geodetic techniques. Over the last years, a lot of simulation work has been carried out towards co-location in space, e.g. at ETH Zürich, Bonn University, or Vienna University of Technology. Upcoming satellite missions like GRASP or MicroGEM will provide the possibility to use ties on the satellite in addition or instead of ties on ground, but also GNSS satellites can be used for observations with VLBI telescopes, as e.g. demonstrated by Wettzell and Onsala.

Seitz et al. (2011) show the first results of a consistent computation of CRF, TRF, and the EOP series linking both frames. The CRF is slightly influenced by the combination in two different ways: by the combination of the EOP and by the combination of the station networks. It is shown that both effects are small. The effect of combining the station networks – mainly driven by the misfits between local ties and results of space geodetic techniques – reaches up to 2 mas, but is much smaller for most of the sources. The mean difference is about 10  $\mu$ as. However, small but clearly systematic effect can be seen. The combination of the EOP also leads to small changes in the source positions. Sources close to the celestial South Pole are affected by a maximum of  $\pm 1$  mas. A further systematic effect ( $-0.5$  mas maximum) is detected for some of the sources with declinations between  $+$  and  $-40^\circ$ . The reasons are not known. The integral impact of the combination on the CRF is small and not significant w.r.t. the axis stability (10  $\mu$ as) and the noise floor (40  $\mu$ as) of ICRF-2.

In continuation of their work, Seitz et al. (2012) deal with the consistent realization of ITRF and ICRF by combining normal equations from VLBI, SLR, and GNSS. The results for the CRF are compared to a classical VLBI-only CRF solution and it turns out that the combination of EOP from the different space geodetic techniques impacts the CRF, in particular the VCS (VLBA Calibrator Survey) sources (see Figure 1.4.1).

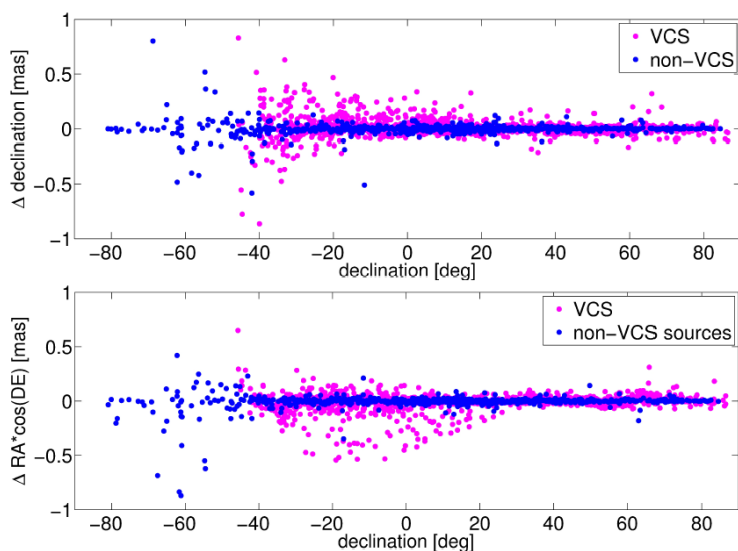


Figure 1.4.1: Differences in source positions between the combined TRF-CRF solution and a VLBI-only solution: declination (upper plot), right ascension (lower plot) (from Seitz et al., 2012).

Plank et al. (2013), in their proceedings paper for the EVGA meeting in Espoo, Finland, discuss and simulate VLBI observations to satellites at different altitudes, like the proposed GRASP mission at 2000 km and a GPS satellite at 20200 km height. Figure 1.4.2 illustrates the benefit of VLBI observations to satellites allowing for space ties in addition to the local ties. These additional constraints are expected to have a positive impact on the consistency between terrestrial and celestial reference frames.

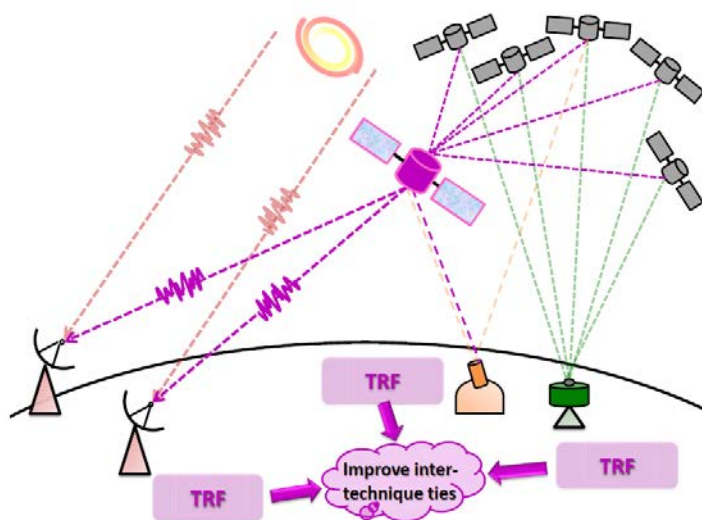


Figure 1.4.2: Concept of co-location in space. A satellite that can be tracked by several space geodetic techniques (e.g. VLBI, SLR, GNSS) realizes a space-tie, directly connecting the frames determined by the different techniques (from Plank et al., 2013).

### WG 1.4.3: Maintenance of Celestial Reference Frames and the link to the new GAIA Frame

*Chair: Chopo Ma (U.S.A.)*

Working Group 3 deals with the maintenance of the ICRF and the link to the new GAIA frame. This WG will be the link to the ICRF-3 WG by the IAU, and it will guarantee that the requirements for both communities are fulfilled: the best possible ICRF-3 as well as the consistency of the ICRF-3 with other space geodetic techniques.

A lot of activities are stimulated towards observing new observation campaigns, in particular for sources in the southern hemisphere. For example, the AUSTRAL network will be applied in the second half of 2013 to observe a series of 10 sessions dedicated to southern sources. Furthermore, a VLBA proposal by David Gordon et al. entitled "Second Epoch VLBA Calibrator Survey Observations for ICRF3" was approved. They were granted 8 days to re-observe up to 2400 single epoch sources. The VLBA broadband RDBE system will be used, which will give much greater sensitivity than the original VLBA Calibrator Survey sessions. Bourda et al. have provided a list of GAIA transfer sources that will be observed regularly by the IVS to improve their radio positions.

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## **Joint Working Group 1.1: Tie Vectors and Local Ties to Support Integration of Techniques**

*Chair: Peirguido Sarti (Italy)*

The Joint Working Group focuses on the provision of accurate tie vectors for ITRF computation. The estimation of tie vectors at co-location sites relies on several different and interconnected phases that contribute and impact the final accuracy.

The JWG has been acting to focus the attention on tie vectors estimation and their importance in the ITRF computation, to bring together and discuss different approaches adopted locally at ITRF co-location sites and to compare the different methods with the purpose of assessing the accuracy of tie vector estimation procedures.

The JWG has been meeting in a timely manner since 2004, usually at the most important international scientific meeting venues. A detailed list of the meetings can be found at the following web address: [http://www.iers.org/nn\\_10900/IERS/EN/Organization/WorkingGroups/SiteSurvey/sitesurvey.html?\\_\\_nnn=true](http://www.iers.org/nn_10900/IERS/EN/Organization/WorkingGroups/SiteSurvey/sitesurvey.html?__nnn=true).

The activities of the JWG are closely linked to the realization of the ITRS and aims at spreading know-how and at defining standards to be adopted as reference in the tie vector estimation process.

So far, different surveying approaches and computation methods are adopted worldwide, mainly on a site-dependent base, which is determined by the surveying crew capabilities. There is a stringent necessity to validate the tie vectors that have been recently estimated as well as re-survey a number of co-location sites whose tie vectors are old (up to 25 years) and whose formal precision are dubious.

The JWG has boosted the discussion and brought together a very large number of scientists and surveyors whose interest are related to the ITRF, GGOS, space geodetic data analysis and local geodetic surveys. Indeed, the number of members of the JWG should reflect the large (33) number of members of the IERS WG and should therefore be updated.

The JWG has the merit to have finally brought together expertise covering the aspects of tie vector surveying and estimation, ITRF combination and space geodetic data analysis and provision of techniques specific solutions used in the combination.

### *Workshop on Site surveys and Co-locations – Paris – May 2013*

The second workshop on site surveys and co-location sites took place in May 2013 in Paris. The web page of the meeting (<http://iersworkshop2013.ign.fr/?page=scope>) nicely and efficiently resumes relevant information such as the scopes of the workshop, its location, the list of participants, the list of presentations and the .pdf files containing the oral contributions. A very important product of the workshop was a list of recommendations that were identified with the contributions of all participants. The document sets actions, deadlines and the person in charge of the specific actions.

Main items and topics were identified and relate to the definition of a clear nomenclature and terminology to be adopted for local tie aspects, to the models to be adopted in the local tie survey data reduction, to the survey priority list for the next ITRF2013 computation, to the

surveying frequency, to the creation of a local survey data archive and the preparation of a draft document containing the site survey guidelines and specifications.

This last aspect has been a long-term objective of the working group whose solution is needed but is far from trivial. A coordinated effort of the whole surveying community is needed and the JWG is the best context to approach the topic and try to solve it with an international coordinated effort.



## **Joint Working Group 1.2: Modelling Environmental Loading Effects for Reference Frame Realizations**

*Chair: Xavier Collilieux (France)*

### **Overview**

The accuracy and precision of current space geodetic techniques are such that displacements due to non-tidal surface mass loading are measurable. Although some models are available, there are still open questions regarding the application of loading corrections for the generation of operational geodetic products. The goal of this working group is to ensure that the optimal usage of loading model is made for Terrestrial Reference Frame (TRF) computation.

The first two years of the working group activity has been dominated by the IERS campaign “for space geodetic solutions corrected for non-tidal atmospheric loading”, an action following the Unified Analysis Workshop 2011. A call for participation has been sent to the analysis technique coordinators of every service in the beginning of 2012. A 6-year loading data set has been generated at The Global Geophysical Fluid Center (GFC) to be used a priori in the data processing of the space geodetic technique observations. Analysis Centres from the four technique services have submitted 12 individual solutions from GNSS, Satellite Laser Ranging (SLR, Very Long Baseline Interferometry (VLBI) and Doppler Orbitography Integrated by satellite (DORIS). These solutions have been analyzed to determine:

- The effect of non-tidal atmospheric loading on the TRF datum and the Earth Orientation Parameters (EOPs)
- The effect of non-tidal atmospheric loading on individual averaged coordinates and velocities
- The level of agreement between a priori corrections and a posteriori corrections

Preliminary results have been presented at the EGU in 2013. They are of primary importance for the generation of future TRFs. This campaign has been successful since it has allowed dialogues between modeling experts and technique ACs. A splinter meeting has been organized on Wednesday 10th of April 2013 at the EGU and another is planned in 2014.

The results of the campaign are still under investigations, so no conclusions are written in this mid-term report (preliminary conclusions are given in Collilieux et al., 2013). Although they inform about the impact of the corrections on the daily/weekly and long-term geodetic products, only one model has been tested. Future works are needed to investigate the level of agreement of all available loading models, which will be the main task of the next two years. It is crucial that users be aware of the strengths and limitations of the available models. We expect that the discussions within this working group will allow such report to be delivered. More information can be found at the working group website at <http://iag.uni.lu/index.php?id=53>.

### **Membership**

- Z. Altamimi (France)
- J. Böhm (Austria)
- J.P. Boy (France)
- L. Métivier (France)
- X. Collilieux (chair, France)

- R. Dach(Switzerland)
- T. Herring (USA)
- Lemoine F. (USA)
- E. Pavlis (USA)
- Jim Ray (USA)
- C. Sciarretta (Italia)
- B. Stetzler (USA)
- P. Tregoning (Australia)
- Tonie van Dam (Luxembourg)
- C. Watson (Australia)
- Xiaoping Wu (USA)

## **Publications**

Collilieux X.; Altamimi, Z.; Métivier, L.; van Dam, T.; Appleby, G.; Boehm, Y.; Dach, R.; Fritsche, M.; Govind, R.; Koenig, R.; Krásná, H.; Kuzmich-Cieslak, M.; Lambert, S.; Lemoine, F. G.; Luceri, C.; MacMillan, D.; Mareyen, M.; Pavlis, E.; Thaller, D., Using non-tidal atmospheric loading model in space geodetic data processing: Preliminary results of the IERS analysis campaign, EGU General Assembly 2013, 7-12 April, Vienna, Austria, EGU2013-4178, [http://recherche.ign.fr/labos/lareg/IAG-JW1.2/nt-atml\\_campaign.html](http://recherche.ign.fr/labos/lareg/IAG-JW1.2/nt-atml_campaign.html)

Call for space geodetic solutions corrected for non-tidal atmospheric loading, GGFC website, [http://geophy.uni.lu/files/call\\_new2.pdf](http://geophy.uni.lu/files/call_new2.pdf)

## Joint Working Group 1.3: Understanding the Relationship of Terrestrial Reference Frames for GIA and Sea-Level Studies

*Chair: Tilo Schöne (Germany)*

### Introduction

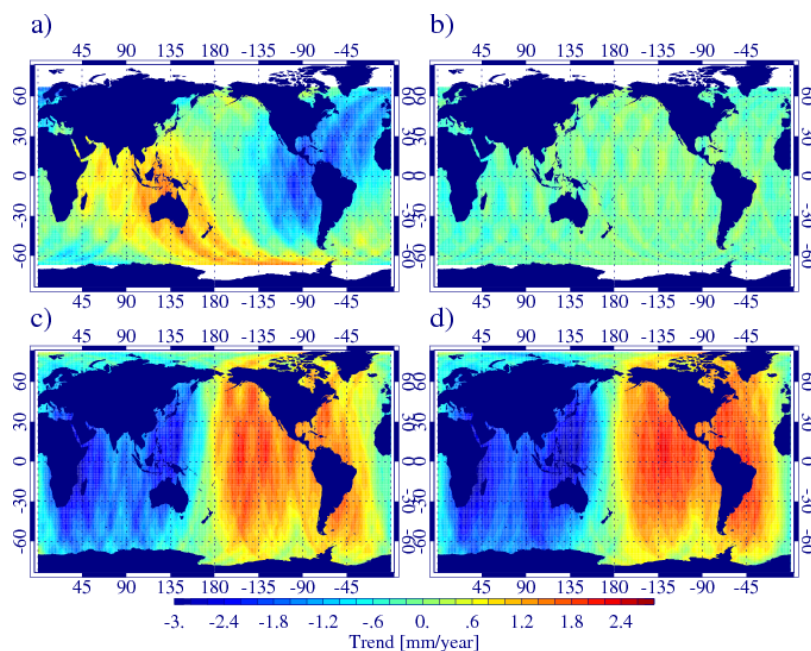
Sea level studies depend in many ways on a global reference frame. Radar altimeters measure sea level heights from space in a TRF, while tide gauges measure sea level at local spots with a local vertical reference. Both data sources can be connected and combined within a common reference frame for example by, connecting GNSS or other space geodetic techniques to tide gauges. On the other hand, only a few tide gauges worldwide have such a connection to the TRF but are useful for many studies. To correct those gauges for at least the long-term ‘geological’ vertical displacement, GIA corrections are commonly applied.

The use of GNSS information in sea level science, the combination and assimilation of GNSS information into Glacial Isostatic Adjustment (GIA) models, the correction of GIA effects on altimetry or tide gauges, or combined studies using information from the different sources requires a common understanding of the individual reference frame realizations.

Today the ITRF realization and their respective updates form the basis for the individual space geodetic techniques. But, in a researcher’s daily work, individual realizations may be more often used. For example, the IGS time series are in a respective IGS frame close to ITRF, or satellite orbits for radar altimetry are using Laser- and DORIS-augmented frames. GIA models employ their own ITRF-independent reference.

### Activities

The work during the reporting period focused on the evaluation of static- and time variable effects in orbit determination and in effects of reference frame changes. Especially the first is of utmost interest, since the effects of time-variable coefficients in the gravity fields are mapping in apparent hemispheric changes in sea level.



Trend of radial orbit differences:  
 Jason-1 **a**: GDR (standard C) minus ESOC (standard D) and **b**: GDR (standard C) minus GSFC  
 Envisat **c**: GDR (standard C) minus ESOC (standard D) and **d**: GDR (standard C) minus GFZ (standard D)

The studies focused on effects in ERS-1, ERS-2, and ENVISAT, with a few comparisons for Topex/Poseidon. The reference frames included has been ITRF2005, ITRF2008, but orbit determination also depend/include SLRF2008 (for laser tracking stations) and DPOD2008 (for DORIS tracking stations). The effects of the inclusion of the later both reference frames have not yet studied in detail.

### **Workplan 2013-2014**

The IGS TIGA Working Group plans to release results by end of 2013. The already ongoing studies for reference frame issues for the combination of GNSS time series and GIA corrections with tide gauge and altimetry time series will be continued by different group members. Also under study will be loading effects in the near- and at-shore GNSS stations at tide gauges and their relation to tide gauge time series.

Also the reference frame studies for radar altimetry will be extended to more recent other missions, like Topex/Poseidon, Jason-1, Jason-2. The studies will be extended to better understand time variable gravity field effects on altimetric orbits and reference frame issues (ITRF2013). This study will be under the ESA CCI initiative.

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## Joint Working Group 1.4: Strategies for Epoch Reference Frames

Chair: *Manuela Seitz (DGFI, Germany)*

### General aspects

The Joint Working Group 1.3 has 13 members from eight countries, whose main interest is either in the field of reference frame computation or in the field of reference frame applications, which require a very high accuracy level of the reference frame. Therefore, the report is divided into two parts related to these two main topics. The work of the group is presented in eight publications and eight presentations. Additionally, a Working Group Website was created (<http://www.dgfi.badw.de/index.php?id=403>), in order to improve the visibility of the activities of the Working Group.

### Computation of epoch reference frames

The computation of Epoch Reference Frames is based on the combination of the different space geodetic techniques VLBI, SLR, GNSS and DORIS. The combination can be done at different levels of the Gauß-Markov adjustment model (Seitz, 2012). We perform the combination at the level of normal equations and at the level of observations in order to identify the individual strengths of these combinations methods. The flowchart for the computation of weekly epoch reference frames at the normal equation level is given by Fig.1.4.1. Weekly normal equations of the satellite techniques are combined first and then the VLBI normal equations are included session by session. The combined parameters are station positions, terrestrial pole coordinates, LOD and nutation rates. The most important steps in the combination, which are also central components of the research activities, are the introduction of local ties information, the weighting of the techniques and the datum realization.

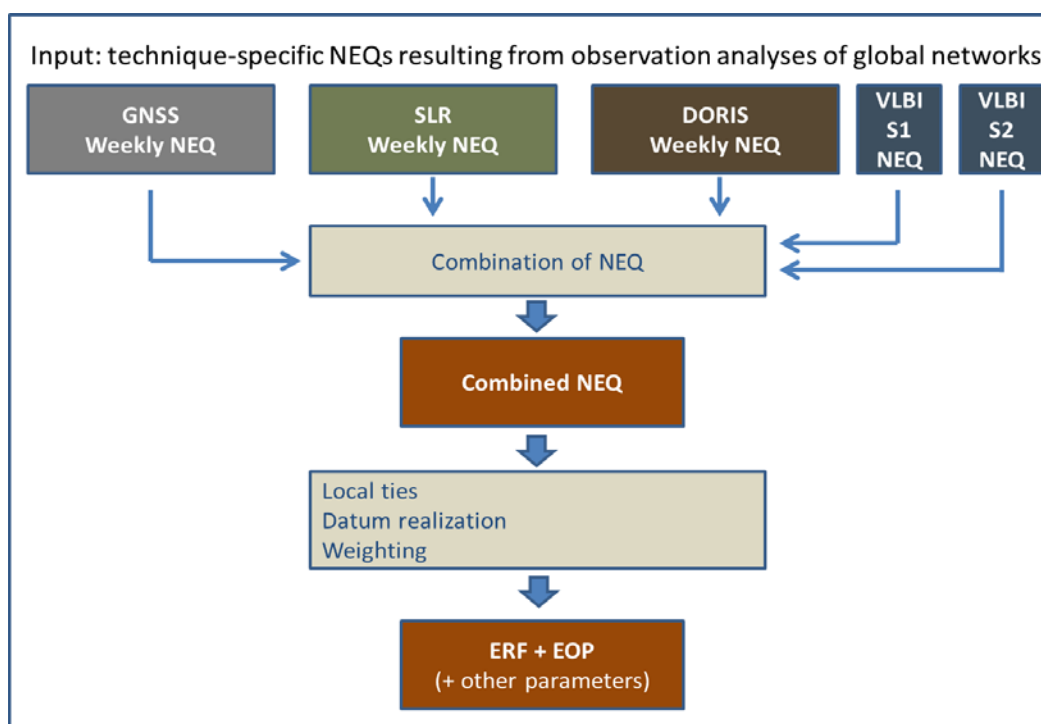


Figure 1.4.1: Strategy for the computation of epoch reference frames developed and applied at DGFI.

The studies related to the combination at the observation level were performed mainly at the University of Berne (AIUB) and are linked to the activities of the IERS Working Group on Combination at the Observation Level (COL).

The results of the research activities show that

- The time series of weekly epoch reference frames approximate the complete station motion (linear and non-linear part) very well,
- The neglecting of non-linear station motions in long-term reference frames affects the consistently estimated EOP-series by annual and semi-annual signals (Bloßfeld et al, submitted to J Geod). EOP of epoch reference frames are not affected, because the station motions are fully considered by the highly resolved station position parameters.
- Epoch reference frames does not provide such a high long-term stability as long-term reference frames do. Further research is needed to improve the long-term stability of the epoch reference frames.
- The weekly combination at the observation level of GNSS and SLR (via satellite co-location) leads to very promising results, which allow (i) the transfer of the SLR-derived centre-of-mass of the Earth to GNSS station network with very high accuracy and (ii) for a validation of the local ties at ground sites.

### **Application of epoch reference frames**

Regional GNSS-based epoch reference frames are meanwhile standard within the International GNSS Service (IGS), e.g., for Europe (EUREF) or Latin America and the Caribbean (SIRGAS) and are important in particular for real-time applications. To realize the geodetic datum of the regional epoch reference frames, they are aligned to the ITRF or long-term IGS solutions. Since these long-term solutions do not consider non-linear station motions - which are fully included in the epoch-wise estimated station positions -, the alignment is in particular affected by the seasonal signals in the station positions, which are mainly caused by atmospheric and hydrological mass load changes but also by very local – sometimes unknown – effects. Therefore, the weekly SIRGAS solutions are now aligned to the weekly IGS solution. This improves the consistency of the time series of weekly SIRGAS solutions significantly and demonstrates the importance of epoch reference frames.

For GNSS-applications, which should be related to a national reference frame, a transformation between the global or regional reference frame, in which the GNSS positions are obtained, and the national frame have to be performed. The reference epochs of the frames often differ by some years. The transformation is in particular problematic for regions affected by seismic events, which usually induce large non-linear station motions. Figure 1.4.2 shows the developed concept of how a transformation between a regional epoch reference frame and a national reference frame (and vice versa) should be performed, including also the transformation of the positions of new stations into the national frame. Besides a 7-parameter similarity (Helmert) transformation, a deformation model is considered (Drewes and Heidbach, 2012), describing the deformations of the network in time.

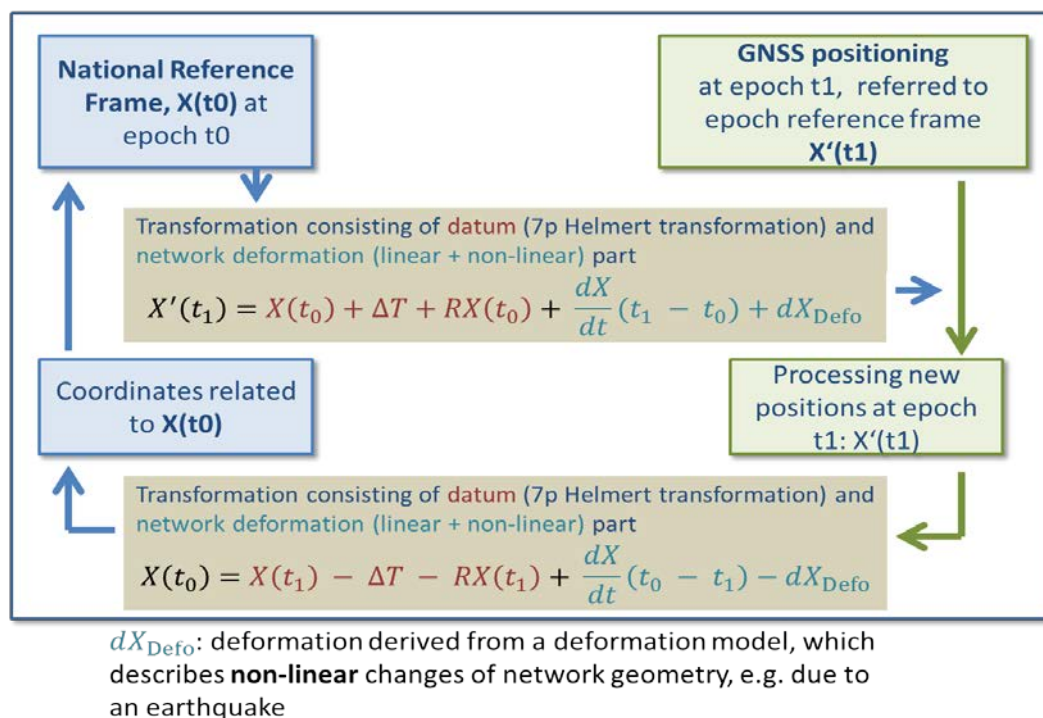


Figure 1.4.2: Transformation between epoch reference frames and national frames for regions affected by deformations. The approach considers also the transformation of positions of new stations into the national frame.

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Bloßfeld, M., Seitz, M., Angermann, D., Different ITRS realizations and consequences for the terrestrial pole coordinates, EGU 2013, Vienna, Austria, 2013-04-09 (Poster)

Bloßfeld, M., Seitz, M., The role of VLBI in the weekly inter-technique combination, 7th IVS General Meeting, Madrid, Spain, 2012-03-04/08

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## Commission 2 – Gravity Field

<http://www.iag-commission2.ch>

*President: Urs Marti (Switzerland)*

*Vice President: Srinivas Bettadpur (USA)*

### Structure

Sub-Commission 2.1:	Gravimetry and Gravity Networks
Sub-Commission 2.2:	Spatial and Temporal Gravity Field and Geoid Modeling
Sub-Commission 2.3:	Dedicated Satellite Gravity Missions
Sub-Commission 2.4:	Regional Geoid Determination
Sub-Commission 2.4a:	Gravity and Geoid in Europe
Sub-Commission 2.4b:	Gravity and Geoid in South America
Sub-Commission 2.4c:	Gravity and Geoid in North and Central America
Sub-Commission 2.4d:	Gravity and Geoid in Africa
Sub-Commission 2.4e:	Gravity and Geoid in the Asia-Pacific
Sub-Commission 2.4f:	Gravity and Geoid in Antarctica
Sub-Commission 2.5:	Satellite Altimetry
Sub-Commission 2.6:	Gravity and Mass Displacements
Joint Project 2.1:	Geodetic Planetology (JP-GP)
Joint Working Group 2.1:	Techniques and Metrology in Absolute Gravimetry
Joint Working Group 2.2:	Absolute Gravimetry and Absolute Gravity Reference System
Joint Working Group 2.3:	Assessment of GOCE Geopotential Models
Joint Working Group 2.4:	Multiple geodetic observations and interpretation over Tibet, Xinjiang and Siberia (TibXS)
Joint Working Group 2.5:	Physics and dynamics of the Earth's interior from gravimetry
Joint Working Group 2.6:	Ice melting & ocean circulation from gravimetry
Joint Working Group 2.7:	Land hydrology from gravimetry
Joint Working Group 2.8:	Modeling and Inversion of Gravity-Solid Earth Coupling

### Overview

This report covers the period of activity of the entities in Commission 2 for the year 2011 to Middle of 2013. Commission 2 consists of six sub-commissions (plus 6 regional sub-commissions), one joint project and several joint working groups and study groups. It is clear that some entities of the Commission were significantly more active than others, but most of them made progress in their stated objectives. Each of the chairs of the entities was asked to summarize their activities. These can be found further down. Here is given only a short summary.

### Conference GGHS2012

The symposium "Gravity, Geoid and Height Systems GGHS2012" was the most important meeting by IAG Commission 2. It was organized with the assistance of the International Gravity Field Service (IGFS) and GGOS Theme 1 "Unified Global Height System". It was arranged by the OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste) which has presently the role of the Central Bureau of the IGFS. The symposium was success-

fully held on the island of San Servolo in the Venetian Lagoon from October 9 to 12 2012 with 140 participants. 30 of them were registered as students and had free access to the conference.

GGHS2012 was the 5th event of the traditional conferences organized by IAG Commission 2 every 4 years after "Gravity, Geoid and Marine Geodesy (Tokyo, Japan, 1996), "Gravity, Geoid and Geodynamics" (Banff, Canada, 2000), "Gravity, Geoid and Space Missions" (Porto, Portugal, 2004) and "Gravity, Geoid and Earth Observation" (Chania, Greece, 2008). The conference covered all activities of IAG Commission 2 except from satellite altimetry which was covered in a special symposium " 20 years of progress in radar altimetry" just 2 weeks before the GGHS2012 - as well held in Venice.

A total of 89 oral presentations and 64 posters were presented in 8 sessions (Gravimetry and Gravity Networks, Global Gravity Field Modeling, Future Gravity Field Missions, Advances in Precise Local and Regional High-Resolution Geoid Modeling, Establishment and Unification of Vertical Reference Systems, Gravity Field and Mass Transport Modeling, Modeling and Inversion of Gravity-Solid Earth Coupling, Gravity Field of Planetary Bodies). Peer-reviewed proceedings of the conference will be published in the IAG Symposia series (volume 140) with Springer. The review process is almost finished.

An important part of the conference was the presentation of the results of the very successful space missions GRACE and GOCE and their application in oceanography, mass transport and solid earth modeling, hydrology and atmospheric sciences. Special attention was given to the loss of ice masses over Greenland and Antarctica and the resulting global sea level rise. Unfortunately, the GRACE and GOCE missions will end in the near future. Therefore, another important topic of the conference was the continuation of gravity space missions. It seems now that a GRACE follow-on mission is advancing well and probably can be launched in 2017 as a result of a collaboration of American and European agencies.

The groups working on the realization of a global height system met during the conference in a splinter meeting of the Joint Working Group "Vertical Datum Standardization" and presented their results of their estimation of the global vertical reference level  $W_0$ . The individual results are now in good agreement in the order of a few centimetres. This implies, that the groups are very close to an agreement on a conventional value for  $W_0$  and the definition of a global height system which can be presented to other interested institutions and be adopted by the scientific communities.

Another open issue of the gravity community is the replacement of the outdated International Gravity Standardization Network IGSN-71 by considering modern absolute measurements and the time series of super-conducting gravimeters. These activities in the corresponding working groups are on a good way and the future of the international comparison campaigns of absolute gravimeters could be assured for the next years.

## **Activities of the Sub-Commissions**

### *SC 2.1 Gravimetry and Gravity Networks*

One activity is the future organization of the International and regional campaigns of absolute gravimeters. They seem to be assured until 2017. The future of these campaigns will be regulated by a strategic paper between the metrological (CCM-GGM of the BIPM) and the geodetic side (IAG commission 2, especially SC 2.1).

One other important issue is the replacement of the out-dated global gravity network IGSN71 and the transfer of the former Global Geodynamics Project (GGP) into a permanent service under the umbrella of the IGFS. These tasks are handled mainly in the JWG 2.2.

A special workshop TGSSM2013 for the practical issues of measuring gravity will be held in St. Petersburg (Russia) in September 2013.

### *SC 2.2 Spatial and Temporal Gravity Field and Geoid Modeling*

This SC deals with the theoretical practical problems in gravity field determination. Many results were presented at various conferences using the latest GRACE, GOCE and combined models in combination with terrestrial and airborne data. The validation of global models in comparison to local solutions and/or GPS/levelling is an activity of many groups and in special of JWG 2.3.

### *SC 2.3 Dedicated Satellite Gravity Missions*

This SC is deeply involved in the derivation of new releases of global gravity field models based on GRACE and GOCE mission data, applying updated background models, processing standards and improved processing strategies. The SC actively contributed to the development and investigation of alternative methods of global gravity field modelling and related problems. It is as well deeply involved in national and international studies in the planning and design of future gravity field missions - especially of a GRACE follow-on mission, which is on a good way.

### *SC 2.4 Regional Geoid Determination*

SC 2.4 coordinates the activities of the 6 regional sub-commissions on gravity and geoid determination and helps in the organization of conferences, workshops and schools. The activities in these regional SCs vary from 'almost no activity' to 'very active'. See descriptions below. In some regions, there are activities on the national level, but absolutely none in international cooperation or data exchange.

### *SC 2.5 Satellite Altimetry*

One main part of this SC over the past two years was the development of new retracers and experiments with several retracers to improve altimeter range measurement accuracies globally and over shallow waters around Taiwan, Australia and the Arctic Ocean. Another result is the publication of an improved Global Marine Gravity Field from Altimetric Geodetic Missions. Future activities include the SCs help in establishing a permanent altimetry service and give to it a better visibility to the public.

### *SC 2.6 Gravity and Mass Displacements*

This new (since 2011) SC profits especially from the long time series and excellent quality of GRACE data. There is an enormous potential for the interpretation of these data in several topics, for which special study groups and working groups have been established. Many interesting and promising results have been presented at several conferences in the fields of sea level rise, ocean circulation, ice melting, land hydrology and gravity/solid earth coupling.

## **Activities of the Joint Project 2.1, Geodetic Planetology**

This is a joint project of commissions 1, 2 and 3 and the ICCT. One of its main goal is the establishment of geodetic planetology as a permanent IAG entity such as an Intercommission Committee on Planetology (ICCP). This task seems to very difficult to reach. The main problem is to motivate scientists to work in this field. There are only very few active groups. Nevertheless, there were some presentations in a special session at the GGHS2012 conference and during the International Symposium on Planetary Sciences (IAPS) (2013, Shanghai, China) with theoretical studies interesting results for the moon and mars.

## **Activities of Study Groups**

There are nine Joint Study Groups where commission 2 is involved as a partner, but none of them reports directly to commission 2. Their reports can be found in the ICCT section (8 groups) or under Commission 3 (1 JSG).

## **Activities of Working Groups**

There are 8 Working Groups reporting to Commission 2. All of them are established as Joint Working groups with Commission 3 and/or the IGFS. Their reports can be found in the corresponding chapters and as a summary in the reports of the leading sub-commissions.

Another JWG "Vertical Datum Standardization" in which Commission 2 is involved, reports to GGOS. Its activities can be found there.

Unfortunately, in one WG (2.5) there was not enough activity and the chair does not see a possibility to be more active in this topic in the near future. It is better to dissolve for now, although there is certainly much potential for activities.

## **Sub-Commission 2.1: Gravimetry and Gravity Networks**

*Chair: Leonid F. Vitushkin (Russia)*

*Vice-chair: Hideo Hanada (Japan)*

Sub-Commission 2.1 with its Joint Working Groups (JWG) with IGFS JWG 2.1 "Techniques and Metrology in absolute gravimetry" (chaired by Vojtech Palinkas) and JWG2.2 "Absolute gravimetry and absolute gravity reference system" (chaired by Herbert Wilmes) was active in the most fields of activity in the frame of its Terms of Reference (ToR). It promoted scientific studies of the methods and instruments for terrestrial, airborne, shipboard measurements, establishment of gravity networks and improvement of strategy in the measurement of gravity networks. The Sub-commission provides the geodesy-geophysics community with the means to access the confidence in gravity measurements at the well-defined level of accuracy through organizing, in cooperation with metrology community, Consultative Committee on Mass and Related Quantities and its Working Group on Gravimetry (CCM WGG), Regional Metrology Organizations (RMO) the international comparisons of absolute gravimeters on continental scale.

The Report of SC2.1 prepared by the members of its Steering Committee and by JWG 2.1 and JWG 2.2 promotes the exchange of information on national activities in various fields of gravimetry.

### *The comparisons of absolute gravimeters*

The first comparison of gravimeters at the International Bureau of Weights and Measures (BIPM, Sèvres, France) took place in 1981 (8 gravimeters took part) and the latest comparison will be organized by CCM and SC2.1 in November 2013 in Walferdange (Luxembourg) with 27 absolute gravimeters.

In 2011 the comparison of European Regional Metrological Organization (RMO) EURAMET was also organized in Walferdange (see Report of JWG 2.1)

The scientific Second North-American Comparison of Absolute Gravimeters (NACAG-2013) is under organization in the Table Mountain Geophysical Observatory (Longmont, Colorado).

The growing request from geodesy community for the determination of metrological characteristics of absolute gravimeters and corresponding growing request for the participation in comparison had put the question about gradual transition to establishing a metrological service for absolute gravimeters on the basis of the primary standards in gravimetry maintained at in NMIs and DIs and about calibrations of absolute gravimeters at the level of National Metrology Institutes (NMI) and Designated Institutes (DI). The creation of such metrological system will require a lot of efforts of both the metrology and the geodetic-geophysical communities because so far the evaluation and presentation of the results of comparison organized by CCM or RMO were different for the absolute gravimeters belonging to NMIs and DIs and for the absolute gravimeters from other institutes and services.

Further investigations of the sources of the uncertainties of the absolute gravimeters based on different principles of operation (laser interferometric absolute ballistic gravimeters of different constructions with macroscopic test body, cold atom gravimeters, etc.), of the reproducibility of their measurements, of the linking between the results of different comparisons and other essential issues still necessary.

The agreement between the CCM and IAG should be reached concerning the ways for implementation of metrological assurance in absolute gravity measurements.

Currently the cooperation between SC2.1, its JWG's and CCM WGG is realized through the mutual membership of their members and joined meetings. The establishment of the connections between the CCM and IAG on the basis of the official documents will ensure the metrological support of gravity measurements in the frame of important geodesy projects like the Global Geodetic Observation System (GGOS), the former Global Geodynamic Project (GGP) and others.

*Support to development of the project of the global International System of Fundamental Absolute Gravity Stations*

SC2.1 supports the development of a new international gravity reference system (currently with a preliminary name International System of Fundamental Absolute Gravity Stations - ISFAGS) which can be realized through organization in cooperation with relevant metrological bodies of comparisons of absolute gravimeters at the sites of future ISFAGS situated on all the continents and superposed with the system of the sites of GGP.

*Support of the R&D of gravity measurement techniques*

SC 2.1 supports the projects of the research and development of absolute gravimeters and gravity gradiometers. It encourages and promotes special absolute/relative gravity campaigns, techniques and procedures for the adjustment of the results of gravity surveys on a regional scale (see, for example, the reports of Vice-President of SC2.1 Hideo Hanada and of the member of SC2.1 Steering Committee Yoichi Fukuda).

The NMI "D.I. Mendeleev Research Institute for Metrology" (Russian acronym VNIIM) reported to SC2.1 on the development of a new absolute ballistic gravimeter VNIIM-ABG-1.

*Workshops, conferences, symposiums*

The SC2.1 and its JWG's organize and participate in the meetings, workshops, symposiums and conferences.

In February 2012 JWG 2.1 and JWG 2.2 in cooperation with CCM WGG organized in Vienna the Discussion Meeting on Absolute Gravimetry dedicated to the analysis of some systematic effects in absolute gravimeters and results of international comparisons of absolute gravimeters (see details the report of JWG 2.1).

SC2.1 organized the Third IAG Commission 2 Symposium "Terrestrial Gravimetry. Static and Mobile Measurements - TGSMM-2013" in St Petersburg, Russian Federation (<http://www.elektropribor.spb.ru/tgsmm2013/eindex>). This symposium is organized for the third time with three-years interval and dedicated mainly to the techniques and methods of terrestrial gravity measurements. The TGSMM symposium helps to diminish the load on IAG Assemblies with the details of the measurement techniques in gravimetry and represents a forum for reporting and discussion in this field.

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## Reports of members of the Steering Committee

### *Gravimetry in Japan (Reported by Hideo Hanada)*

#### *Absolute gravimetry*

Tsubokawa et al developed a prototype of small sized absolute gravimeter using silent drop method which can reduce the rotation of a falling body and vibration induced from dropping mechanism. The accuracy is estimated to be about  $8 \times 10^{-9} \text{m/s}^2$  ( $0.8 \mu\text{Gal}$ ) as a standard error from 601 drops. Kazama et al. compared the frequency of atomic clocks used in absolute gravimeters, and found that the frequency of the Rubidium clock in the A10 gravimeter (No. 1) shifts by about  $+0.15 \text{ Hz}$  from  $10 \text{ MHz}$ . They pointed out the importance of correction of frequency difference. Sakai and Araya of the Earthquake Research Institute, University of Tokyo (ERI) are trying to miniaturize the absolute gravimeter of rise and fall method in order to apply it to observation in volcanic area. At present, combination of one absolute gravity station as a reference and many gravity stations surveyed by relative gravimeters are usually used in volcanic area and it takes longer time and is troublesome. The new absolute gravimeter which lifts a corner cube about  $10 \text{ cm}$  up and has the target accuracy of in the order of  $1 \times 10^{-7} \text{ m/s}^2$  ( $10 \mu\text{Gal}$ ), will overcome these difficulties.

#### *Relative gravimetry*

Murata of the National Institute of Advanced Industrial Science and Technology (AIST) checked the drift rate of a Scintrex CD Gravimeter (#270) in the period not used for gravity surveys, and found annual variation of the drift rate. Tokue et al. of Tokyo Institute of Technology (TITEC) proposed a 2D and 3D numerical model of a two-axes gimbal system for supporting of relative gravimeters, and made a prototype of the gimbal. The gimbal system can maintain the gravity meter horizontally and can attenuate a vibration caused by the body.

#### *Other kinds of gravimetry*

Fujimoto et al. of Tohoku University began to build a brand-new hybrid gravimetry system in 2010, which consists of a gravimeter and a gradiometer both for underwater gravimetry. The former aims at quantitative mapping of density anomalies below the seafloor, and the latter can be more sensitive in detection of density variations. The hybrid system can estimate the subterranean structure more accurately than a gravimeter alone. The gradiometer consists of a pair of high precision accelerometers that have been developed for an absolute gravimeter. Both of the sensors will be kept vertical with each gyro. The new underwater gravimeter of the hybrid system, on the other hand, was designed considering the results of the examination of the old one in the previous year. While the concept of design remains unchanged, a gravity sensor is kept vertical with forced gimbals by use of a gyro, the gravimeter has adopted a

newly developed dynamic gravity sensor, a high precision gyro, and a highly rigid mechanism for the gimbals in order to improve the precision.

### *Gravity networks*

Geographic Survey Institute (GSI) is constructing new gravity standardization net, "Japan Gravity Standardization Net 2010 (JGSN2010)", to improve former one and contribute to research for the earth's internal structure. Constructing it requires to conform JGSN2010 to a gravity reference system. In this presentation, we will report the proposal of Japan Gravity Reference System and the plan of future construction of JGSN2010. It consists of 29 stations measured by absolute gravimeters and 172 stations measured by relative gravimeters. Standard error of absolute stations will be less than  $1 \times 10^{-8} \text{ m/s}^2$  (1  $\mu\text{Gal}$ ) and that of relative stations will be less than  $1 \times 10^{-7} \text{ m/s}^2$  (10  $\mu\text{Gal}$ ). The website of JGSN2010 (in Japanese) is <http://www.gsi.go.jp/common/000071404.pdf#search='JGSN2010'>. Doi et al. of National Institute of Polar Research (NIPR) have started a project to implement absolute gravity measurements with GPS measurements at two areas, i.e. Syowa Station and Langhovde in East Antarctica in the framework of the 53rd Japanese Antarctic Research Expedition (JARE53). The objectives of the measurements are precise determination of gravity field of Antarctic region and estimation of crustal movements associated with Glacial Isostatic Adjustment (GIA). The absolute gravity measurements have already been made by A10 tentatively with standard deviation of 2.4  $\mu\text{Gal}$ .

### *Gravity gradiometer*

Araya et al. of Earthquake Research Institute of University of Tokyo (ERI) are developing a gravity gradiometer for hybrid gravimetry system including a gravimeter and a gravity gradiometer. The gravity gradiometer comprises two vertically-separated accelerometers with astatic reference pendulums, and the gravity gradient can be obtained from the differential signal between them. Rotation of the instrument would be a major noise source and is controlled to keep it vertical installed on a gimbal. We operated the developed gradiometer at a quiet site on land and estimated its self-noise to be  $6 \text{ E}$  ( $6 \times 10^{-9} \text{ s}^{-2}$ ) in the range from 2 to 50 mHz where gravity gradient signal is expected to be dominant when an autonomous underwater vehicle passes above a typical ore deposit. Shiomi et al. of Aso Volcanological Laboratory, Kyoto University are developing another kind of gravity gradiometer employing the free-fall interferometer similar to that developed for tests of the Weak Equivalence Principle. [1] Two test bodies are put in free fall and their differential displacements during the free fall are monitored by a laser interferometer. Unlike the tests of the Equivalence Principle, the centres of mass of the test bodies are separated along the vertical direction before free falls. This separation allows us to obtain the vertical difference in the gravitational fields. Because of the differential measurements, the obtained gravity gradients are, in principle, insensitive to the motion of the vehicles on which the measurements are carried out. The target sensitivity is a few microgals which is about two orders of magnitude better than the sensitivity of mechanical gravimeters which are typically used on aircraft and ships. This gravity gradiometer would allow us to carry out on-board measurements in inaccessible areas, with an unprecedented high sensitivity.

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### ***East Asia and Western Pacific Gravity Networks (Reported by Yoichi Fukuda)***

Geospatial Information Authority of Japan (GSI) has organized local comparisons of absolute gravimeters in Japan annually since 2002. The comparisons have been taken place at a quiet site near Mt. Tsukuba. Each time about 4-5 FG5s from GSI, universities and other institutions including National Metrology Institute of Japan (NMIJ), which has regularly joined ICAGs, participated in the comparisons. The comparison results generally show good agreements and they ensure the reliability of the gravity values measured by the FG5s which participated in the comparisons.

The Japan Gravity Standardization Net 1975 (JGSN75) which was established in 1976 has been used as the reference of the Japanese gravity network until now. GSI has conducted a huge number of gravity measurements so far, and the accuracies of the data have been improved drastically. Using the newly obtained data including absolute gravity data, GSI is working to revise JGSN75 whose accuracy is 0.1mgal and establish a new gravity network with the accuracy of 0.01mgal. GSI has already finished to calculate the new gravity values at the reference gravity points (34 points) and the 1st order gravity points (80 points), however still needs time to complete the net adjustments of the 2nd order gravity points (about 14,000 points).

GSI has conducted the gravity measurements at the reference and the 1st order gravity points repeatedly and detected the gravity changes before and after the 2011 Tohoku-Oki earthquake. The obtained gravity changes were several tens micro gals and showed the tendency of gravity increases along the coastal areas and decreases at inland areas.

GSI and Earthquake Research Institute of the University of Tokyo have cooperatively conducted repeated absolute gravity measurements at Omaezaki FGS since 2000. The station is located in the area of the anticipated great Tokai earthquake, where the clear subsidence due to the plate motion is observed. Using the obtained gravity data so far, the estimated rate of the gravity increase is 0.0011mGal/yr.

### ***Gravimetry in North America (Reported by Mark Eckl)***

#### *North American Comparison of Absolute Gravimetry (NACAG 2013)*

See: <http://www.ngs.noaa.gov/GRAV-D/Comparison/index.shtml>

- The results of the first North-American Comparison of Absolute Gravimeters are published [1].
- Scheduled for the 1st and 2nd weeks of October 2013 at the NOAA Table Mountain Geophysical Observatory (TMGO), Longmont, Colorado.
- As with NACAG 2010 we expect representatives from NGA/NIST/NOAA/USGS (U.S.), GSD/NRCAN (Canada), NSF (operated by Micro-g), and gravimeters from Brazil and Germany- - A one day forum is scheduled to be held Monday, Oct. 14 during a break in the comparison.

#### *AGRAV Database*

See: (<http://agrav.bkg.bund.de/agrav-meta/>)

- AG operators have been tasked with loading any new U.S. absolute gravity observations into the AGRAV database of BKG-BGI.
- Past observations will be loaded as time allows.

### *Superconducting Gravity*

- SG CT 024 has been returned to its observing pier at TMGO after a thorough inspection, repair, and upgrades by GWR Instruments
- SG 024 is installed and operating at TMGO on a backup compressor (the main compressor is in for repair).
- Sometime during the summer of 2013 SG CT 024 will be once again contributing to the Global Geodynamics Project (GGP) database ([www.eas.slu.edu/GGP/ggphome](http://www.eas.slu.edu/GGP/ggphome)).

### *Terrestrial Gravity Standards and Specifications*

- As the lead for the geodetic theme for the FGDC NGS is working towards standards and specifications for gravity data submitted to the NGS Integrated Database (NGSIDB)
- NACAG 2013 will be an opportunity for the U.S. Federal agencies and Canadian representative to discuss common terrestrial gravity data needs

### *New Vertical Datum*

- An expected adoption year of the new U.S. vertical datum is 2023
- The reference surface of this new datum will be a geopotential surface (geoid)
- The U.S. and Canada have agreed on a  $W_0$  for the reference surface

### *Gravity for the Redefinition of the American Vertical Datum (GRAV-D)*

See: <http://www.ngs.noaa.gov/GRAV-D/>

- We are currently in the possession of three of Micro-g LaCoste airborne gravity meters.
- Government/Contracted flights have covered nearly 25% of the U.S.
- Alaska, Great Lakes, and large sections of CONUS coast line has been surveyed.
- Currently working on the North-East coast line to support recovery efforts from Hurricane Sandy

### *Geoid Slope Validation Surveys (GSVS12 & GSVS14)*

See: <http://www.ngs.noaa.gov/GEOID/GSVS11/>

- The GSVS surveys are designed to validate the short wave lengths of various geoid models.
- The surveys consist of airborne gravity, LIDAR, differential leveling, static GPS, deflection of the vertical (w/DIADEM<sup>5</sup>), gravity gradients, relative gravity (L&R meters), and absolute gravity (FG-5 & A10).
- 200+ kilometres with marks set at one mile intervals (GSVS11 = Texas, GSVS14 = Iowa).
- The primary study was to look at the differences comparing geoid slopes determined by 1) various geoid models, 2) GPS/Leveling segment differences and, 3) the DIADEM DOV.
- GSVS11 was little to no separation between the ground surface and geoid while the GSVS14 will study the same issues with a large separation between surfaces.
- Papers and presentations have been given at various gatherings and published regarding GSVS11.
- GSVS14 mark setting is now in progress.

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<sup>5</sup> DIADEM = The Digital Astronomical Deflection Measuring System <http://www.ggl.baug.ethz.ch/people/buerki>

## *Abbreviations*

CONUS = Continental U.S. (Lower 48 states)  
GSD = Geodetic Survey Division of Canada  
NGA = formally NIMA formally DMA = National Geospatial Intelligence Agency  
NGS = National Geodetic Survey  
NIST = National Institute of Standards and Technology  
NRCan = National Resources Canada  
NSF = National Science Foundation  
USGS = U.S. Geological Survey

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## *Shipboard Gravimetry* (Reported by Dag Solheim)

### *Golden opportunity (not to be missed)*

The last years several dedicated national marine mapping projects have been initiated. Ideally marine gravity measurements should be an integrated part of these projects, whenever applicable, in order to maximise the return of the considerable investments involved in these projects. An example of such an activity is the Norwegian MAREANO-project (<http://www.mareano.no/en>). Gravity is unfortunately not an integrated part of this project, but gravimeters may be installed on the ships for free. Another example are Danish measurements along the coast of Greenland.

Considering the importance of such measurements in determining a high precision geoid both on land and sea, these projects represent an opportunity not to be missed if geodesy is to provide information on the ocean circulation on smaller scales than typically 100km provided by the ESA Satellite GOCE. Satellite altimetry in combination with an accurate and detailed geoid will eventually become an important and valuable new source of information for oceanography and climate research. To achieve this, improved knowledge about the geoid is necessary, something that can be accomplished by having access to detailed high quality marine gravity data sets.

Marine gravity data sets are also of huge value to geologists, geophysicists, oil companies in search of new oil and gas fields as well as for connecting height systems on a global scale. IAG should encourage gravity measurements to be a part such projects and if necessary provide guidelines and recommendations.

### *Processing of data.*

There seems to be two slightly different schools on how to process marine gravity data. A fast and efficient method processing the data as a continuous stream of data and afterwards selecting the "good part" of the data based on criteria like the Eötvös correction, velocity and heading. Another approach is to divide the stream of data into straight line segments and process each segment separately.

The first method is generally very efficient but is highly dependent on the algorithm used to determine reliable data. The second method is normally much more laborious but the processing of each line segment may be fine-tuned in a way not possible by the first method. This can be very advantageous when alternating between sailing with and against the waves/wind in which case the need for filtering may vary a lot. The second method is also often accompanied by graphical visualization aids making it easier to identify erroneous data. Both methods may be further developed, increased quality for the first method and improved efficiency for the second.

### *Marine gravity survey example*

The second method was used when processing the data from a joint Icelandic Norwegian survey between Iceland and the island Jan Mayen in the North Atlantic. As can be seen from the cross over statistics in table 1, excellent results were obtained. With  $\sigma_T$ , the standard deviation of each track and assuming that all tracks have the same standard deviation, then  $\sigma_T$  is related to the standard deviation of the cross overs,  $\sigma_X$ , by  $\sigma_T = \sigma_X/\sqrt{2}$ .

Table 1. Cross over statistics of the free air anomalies (units mGal)

	#	Mean	Minimum	Maximum	RMS	$\sigma_X$	$\sigma_T$
Before adjustment	186	0.21	-1.49	1.29	0.55	0.51	0.36
After adjustment	186	0.00	-0.58	0.78	0.20	0.20	0.14

The post cross over statistics may be slightly misleading and too optimistic. A more realistic measure of the accuracy may be obtained by comparing the 2D filtered version of the data set with unfiltered one. The statistics of these comparisons are shown in table 2.

Table 2. Inter comparison of filtered and unfiltered data set (units mGal)

#	Mean	Minimum	Maximum	RMS	$\sigma_X$
18390	0.00	-5.30	2.07	0.33	0.33

Even though cross over computations are very easy to perform, they are, for some strange reason, not always done when using the first method. Small cross over differences is a required condition for a high accuracy data set. Large cross overs are an indication of significant errors in the data set. Small cross overs do however not necessarily imply high quality data. Further investigations are needed to decide upon that.

### *Importance for the geoid on land*

As mentioned above marine gravity data are of great importance for the geoid on land. This has been clearly demonstrated in the Sognefjorden area in Norway. Figure 1 shows the difference between the gravity field with and without the marine gravity data in the fjord. The effect on the geoid is presented in Figure 2.

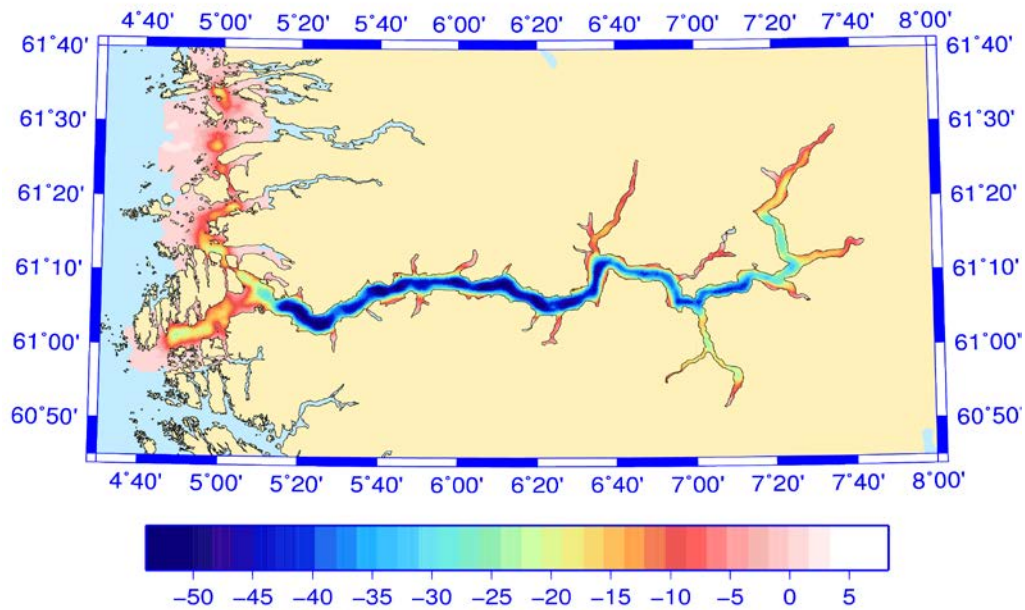


Figure 1. Gravity signal from the Sognefjorden (units mGal)

Without marine gravity data and when not correcting for the bathymetry, the computed gravity value on the fjord, based on data on land only, is too high, as expected since the density of sea water is less than that of rocks. When the gravity field decreases the geoid also decreases in accordance with what is shown in figures 1 and 2.

If a detailed high precision geoid is to be determined in areas with deep fjords, either access to marine gravity data is needed or a proper handling of the bathymetry (missing mass) is necessary. Ideally access to both a detailed bathymetric model and marine gravity data would be preferable.

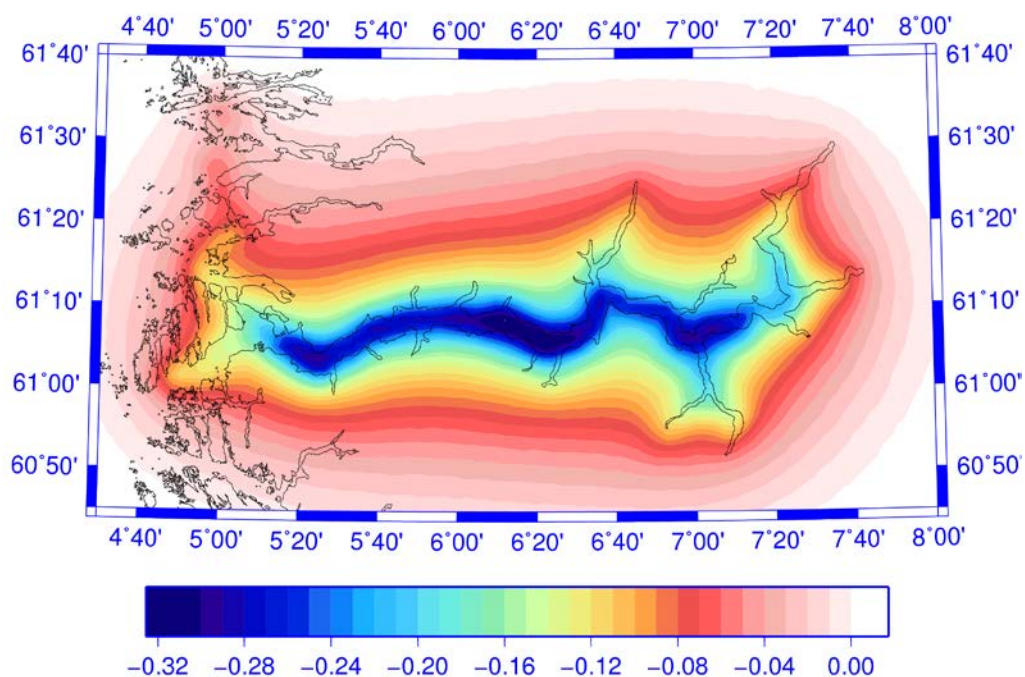


Figure 2. Effect on the geoid when including the marine gravity data shown in Figure 1 (units mGal)

## **Sub-Commission 2.2: Spatial and Temporal Gravity Field and Geoid Modelling**

*Chair: Yan Ming Wang (USA)*

### **Introduction**

This document presents a status report of the work undertaken by the sub-commission (SC) 2.2 since 2011 after the IUGG General Assembly in Melbourne, Australia.

### **Primary Objectives of Sub-Commission 2.2**

The primary objective of this SC is to promote and support scientific research on the determination of the Earth's gravity field which is essential for many scientific and operational applications. Some research topics are endorsed by this SC are as the following:

- Studies of the effect of topographic density variations on the Earth's gravity field, including the geoid.
- Rigorous yet efficient calculation of the topographic effects, and refinement of the topographic and gravity reductions.
- Studies on harmonic upward and downward continuations.
- Non-linear effects of the geodetic boundary value problems on geoid determination.
- Optimal combination of global gravity models with local gravity data.
- Exploration of numerical methods in solving the geodetic boundary value problem (domain decomposition, finite elements, and others).
- Studies on data requirements, data quality, distribution and sampling rate, for a cm-accurate geoid.
- Studies on the interdisciplinary approach for marine geoid determination, e.g., research on realization of a global geoid consistent with the global mean sea surface observed by satellite altimetry.
- Studies on airborne, ship-borne gravimetry and the Antarctica gravity field.
- Studies on  $W_0$  determination, and on global and regional vertical datum realization.
- Studies on ocean, solid-Earth and polar tides.
- Studies on time variation of the gravity field due to postglacial rebound and land subsidence.
- Studies on geocentre movement and time variation of  $J_n$  and its impact on the geoid.
- Studies on sea level change and the vertical datum realization

### **Activities of the SC**

The SC continues the long journey of gravity field determination. From the current satellite gravity missions GRACE and GOCE, the static and time varying gravity field have been determined to a very high accuracy and high spatial resolution. A few airborne gravity projects have been collecting gravity data near Earth's surface which can be viewed as supplementary to satellite gravity missions. Research on geoid determination, national and global vertical datum establishment and improvement has drawn considerable devotion. The

SC has proposed and participated in scientific meetings, summer schools, and seminars. Research results have been presented at various meetings and conferences such as the AOGS 2012, Singapore; at the International Symposium on Gravity, Geoid and Height Systems 2012, Venice; and the AGU, CGU and EGU, as well as in scientific journals and proceedings.

## Future Activities

The SC will work closely with the officers of commission 2 to promote the gravity field determination through organizing meetings, conferences, seminars and summer schools. It encourages the establishment of special study groups on important contemporary research areas, e.g., the contribution of airborne gravimetry to the gravity field determination, and studies in theory and computation methods in data combination.

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## **Sub-Commission 2.3: Dedicated Satellite Gravity Missions**

*Chair: Roland Pail (Germany)*

*Webpage: <http://www.iapg.bv.tum.de/IAG-SC23/>*

The main tasks of the Sub-Commission 2.3 are defined as follows:

- generation of static and temporal global gravity field models based on observations by the satellite gravity missions CHAMP, GRACE, and GOCE, as well as optimum combination with complementary data types (SLR, terrestrial and air-borne data, satellite altimetry, etc.).
- investigation of alternative methods and new approaches for global gravity field modelling, with special emphasis on functional and stochastic models and optimum data combination.
- identification, investigation and definition of enabling technologies for future gravity field missions: observation types, technology, formation flights, etc.
- communication/interfacing with gravity field model user communities (climatology, oceanography/altimetry, glaciology, solid Earth physics, geodesy, ...).
- communication/interfacing with other IAG organizations, especially the GGOS Working Group for Satellite Missions and the GGOS Bureau for Standards and Conventions

### **Static and temporal global gravity field models**

#### *Activities and results*

Sub-commission members are deeply involved in the derivation of new releases of global gravity field models based on GRACE and GOCE mission data, applying updated background models, processing standards and improved processing strategies, e.g.: EIGEN-6S ([3]), AIUB-GRACE03S [7]. In addition to improved static gravity field models, also monthly, 10-days, weekly and even daily GRACE solutions (GFZ, CSR, JPL, CNES-GRGS, Univ. Bonn) have been derived. The GRACE Science Data System has reprocessed the complete GRACE mission data with improved instrument data, background models and processing standards, resulting in the release 05 of monthly and weekly models (e.g. GFZ Release 5; [2]). Compared to RL04, the current RL05 time-series shows improvements of about a factor of 2 in terms of noise reduction (i.e. less pronounced typical GRACE striping artefacts) and spatial resolution (cf. Fig. 1). Special emphasis has been given to the de-aliasing from short-term tidal and non-tidal gravity signal contributions, in order to reduce the unrealistic meridional striping patterns (e.g., [2], [14]).

Several members of the SC 2.3 are also active participants in the ESA project GOCE High-Level Processing Facility (HPF), which is responsible for the generation of GOCE final orbit and gravity field products. This task is performed by a consortium of 10 university and research facilities in Europe. In the frame of this project, innovative strategies for the solution of several specific problems of high-level gravity field modelling, precise orbit determination and the analysis and calibration of space-borne accelerometer, gradiometer, and star-tracker observations have been investigated. An alternative algorithm for the angular rate reconstruction in the frame of the gravity gradient processing has been developed ([12]) implemented in the official ESA Level 1b processor ([13]), and the complete mission data has been reprocessed, leading to a substantial improvement of the gravity field solutions ([9]). In the report period the Releases 3 and 4 of GOCE Gravity field models have been computed and

released. Three different strategies are applied for gravity field processing ([8]): the direct approach (DIR), the time-wise approach (TIM), and the space-wise approach (SPW). While the DIR models ([1]) are satellite-only combination models, the TIM models ([10]) are based solely on GOCE data. The SPW approach has been redefined to provide gravity gradient grids mainly for geophysical users ([11]). These gravity field models have been externally validated applying different validation strategies ([5]). As an example, Fig. 2 shows the rms of geoid height differences between release 3 and 4 gravity field models and 675 GPS/levelling observations in Germany.

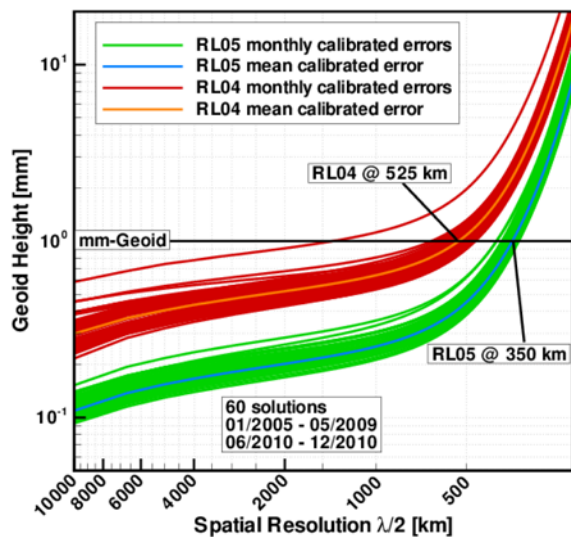


Figure 1.1: Degree variances of calibrated GRACE errors

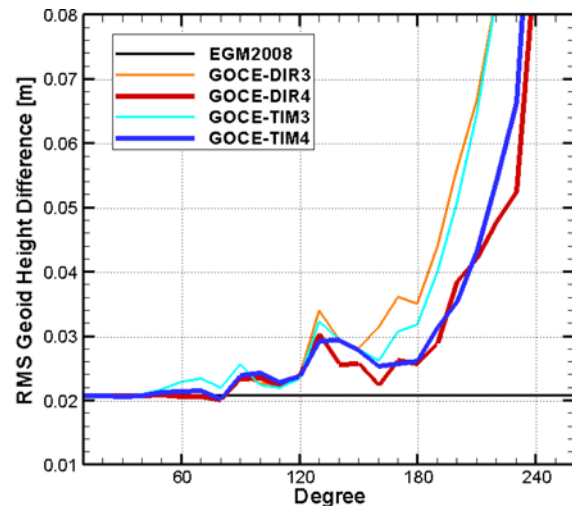


Figure 1.2: Rms of geoid height differences in Germany

In addition to these GOCE models, also combinations with complementary satellite data from GRACE, CHAMP and SLR such as GOCO03S ([6]), and additionally terrestrial and satellite altimetry data such as EIGEN-6C2 ([4]) have been released with intense participation of members of the SC 2.3.

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## **Alternative methods and new approaches for global gravity field modelling**

### *Activities and results*

Sub-commission members have actively contributed to the development and investigation of alternative methods of global gravity field modelling and related problems, such as the optimum combination of different gravity data types, and stochastic modelling issues. As an example, an alternative approach for the combination of high-resolution and satellite-only global gravity models has been proposed ([15]). A complete overview compilation will be presented and discussed in the final report.

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## **Future gravity field missions**

### *Activities and results*

Members of SC 2.3 were deeply involved in national and international studies in the planning and design of future gravity field missions. On ESA level, during the reporting period two studies on the “Assessment of a next Generation Mission for Monitoring the Variations of Earth Gravity” were conducted in parallel by joint industrial and scientific consortia and meanwhile have been finalized ([16] and [19]). Goal of these studies were the definition of mission requirements resulting from science requirements, the definition of measurement objectives and the required performance, the identification of engineering requirements for key technology, a complete mission analysis and finally an end-to-end simulation by means of numerical methods.

Further studies and mission proposals on national and international level have been worked out during the reporting period. Within the framework of the German Geotechnologien Programme further studies on future gravity field missions with a medium to long perspective have been carried out.

Members of this SC play a central role in the implementation of the next gravity field mission, i.e. the US-German project GRACE Follow-on (GRACE-FO), to be launched in 2017 ([17]). The primary objective of GRACE-FO is to continue the current GRACE gravity data series with a gap as short as possible. Therefore it is essentially a re-build of GRACE using the same microwave inter-satellite ranging system. In addition, as a secondary objective, it will carry an experimental Laser Ranging Interferometer (LRI) intended as technology demonstrator for future missions ([20]). The LRI will measure with about 20 times less measurement noise and provide in addition precise data about the orientation of each spacecraft with respect to the line of sight to the other spacecraft. That additional data will allow mutual comparisons and diagnostics between the microwave and laser systems. Preparations for the required new data analysis algorithms are already under way. The LRI is a joint development between NASA/JPL and a German team under the technical leadership of the AEI Hannover and general management by GFZ.

The 12 COSMIC-2 satellites will be equipped with a SLR retro-reflector for precise orbit determination and time-varying gravity study. The Phase I and II of COSMIC-2 satellites will be launched in 2016 and 2018, respectively. A joint Taiwan-UCAR team will work on the COSMIC-2 SLR data processing and applications.

Several scientific studies on specific challenges of future gravity field missions have been investigated, such as improved methods of de-aliasing by including covariance information of the background models ([20]) or the optimum orbit choice for aliasing reduction ([17]).

On an organizational and programmatic level, in a joint initiative of SC 2.3 and the GGOS Satellite Mission Working Group a letter by the IUGG President Harsh Gupta to ESA and NASA has been triggered, which expresses the strong need of the science community for a future gravity field mission, in accordance with the IUGG 2011 Resolution 2: „Gravity and magnetic field missions“. Additionally, as a joint initiative of IAG SC 2.3 and SC 2.6, GGOS SMWG and the IUGG, and supported by the space agencies, a workshop on the “Consolidation of Science Requirements” for a future double-pair mission is in preparation, which shall take place in the second half of 2014.

Several German members of the SC 2.3 are involved in a German preparatory study “NGGM-Germany” funded by the German Aerospace Center (DLR) in preparation of the upcoming call for ESA Earth Explorer 9.

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## **Communication / interfacing with user communities**

### *Activities and results*

The workshop discussed above, joint organized with the IUGG and its associations, will represent an important platform to involve all relevant user groups of gravity field products in the planning of satellite gravimetry missions and the definition of their requirements.

Online service access points for geoscientific data products, such as the Information System and Data Center (ISDC) portal maintained by the GFZ ([23]) show a steadily growing number of users from various user communities (climatology, oceanography, glaciology, geodesy, solid Earth physics, etc.).

The International Center for Global Earth Models (ICGEM; [22]) has been furthermore well established as one of the six centres of the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). ICGEM is also maintained by GFZ and comprises a widely used archive of all existing global gravity field models and an increasingly used service for calculation and visualization of gravity field functionals.

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- [22] <http://icgem.gfz-potsdam.de>
- [23] <http://isdc.gfz-potsdam.de>

## **Communication / interfacing with other IAG organizations**

### *Activities and results*

Close cooperation between the SC 2.3 and SC 2.6 exists with the joint preparation of a future gravity workshop on “Science Requirement Consolidation”. With this and other joint initiatives, close interactions exist also with the GGOS SMWG. Another strong interface has been built with GGOS Bureau for Standards and Conventions, where members of the SC2.3 play an active role, especially concerning the definition of consistent gravity standards ([24]).

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## Sub-Commission 2.4: Regional Geoid Determination

*Chair: Hussein Abd-Elmotaal (Egypt)*

*Webpage: <http://www.minia.edu.eg/Geodesy/Comm2.4/>*

The main purpose of Sub-Commission 2.4 is to initiate and coordinate the activities of the regional gravity and geoid sub-commissions. These have been re-structured from the former regional geoid projects into SCs in 2011 in order to give them a more long-term character. Currently there are 6 of them:

- SC 2.4a: Gravity and Geoid in Europe (chair H. Denker)
- SC 2.4b: Gravity and Geoid in South America (chair M.C. Pacino)
- SC 2.4c: Gravity and Geoid in North and Central America (chair D. Avalos)
- SC 2.4d: Gravity and Geoid in Africa (chair H. Abd-Elmotaal)
- SC 2.4e: Gravity and Geoid in the Asia-Pacific (chair W. Featherstone)
- SC 2.4f: Gravity and Geoid in Antarctica (chair M. Scheinert)

The chair persons of these regional SCs form the steering committee of SC2.4.

These regional SC nominally cover the whole world with the exception of a larger region in the middle east (see figure 1). But it is clear that not all countries which are listed as a member of a regional SC, are actively participating in international projects or data exchange agreements. This is especially true for some countries in Central America, the Caribbean, Africa and Asia.

In comparison to the former regional geoid projects the covered areas have been extended in 2 cases:

- a) Central America and the Caribbean are associated with the North American SC. But there is a very close collaboration as well with the South American SC in some countries.
- b) The former regional geoid project of South Asia and Australia has been extended to all 48 member countries of PCGIAP (Permanent Committee for GIS Infrastructure for Asia and the Pacific). In the case of gravity field determination, the collaboration of these countries is not very strong.

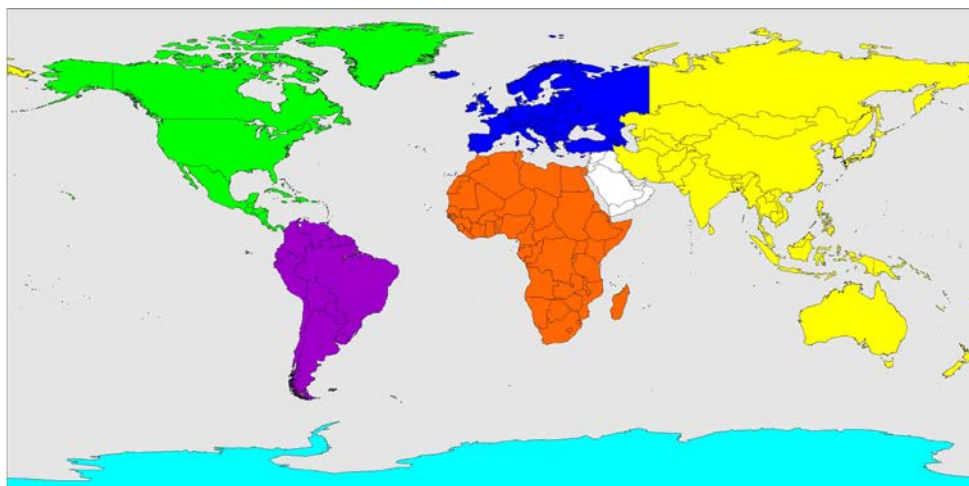


Figure 1: Coverage of the regional sub-commissions

## **Short summary of the activities of the regional SCs**

SC 2.4a (Europe) is planning to release a new computation of the European geoid/quasigeoid in 2015. Due to the already very good quality of the gravity data set, improvements by including GOCE data, are expected only in some limited areas. New terrestrial gravity data will be available for some countries (Germany, Bulgaria).

SC 2.4b (South America) is improving the gravity data coverage and the corresponding database in several countries by activities of many groups.

SC 2.4c (North and Central America) extended their activities into several countries of Central America and the Caribbean and good contacts have been established. Good contacts exist as well with the South American SC and several North American universities. The main goal is in definition of a common North American height datum and in some countries the education for setting up national gravity networks and the calculation of national/regional geoid models.

SC 2.4d (Africa) is trying to improve the collaboration between the countries and to collect the available terrestrial gravity data from different sources. Many tests are made with the newly available satellite data and with global and national DHMs. An IUGG project "Detailed Geoid Model for Africa" was initiated and accepted and is still going on.

SC 2.4e (Asia Pacific) was not very active until now. There were some contacts through the PCGIAP, which still have to be improved. It is very difficult to make contacts and, moreover, get data in this region. In this region, most activities still remain on the national level, where good results were presented in several countries.

SC 2.4f (Antarctica) is active in trying to densify the gravity data coverage mainly by airborne but also by terrestrial campaigns. Other activities include getting access to already existing data. The publication of a gridded gravity data set and a geoid model is planned for the near future.

SC 2.4 was and will be very active in organising courses and related sessions at international conferences such as the GGHS2012 conference in Venice (2012) and the IAG Scientific Assembly in Potsdam 2013.

A Meeting of the steering committee of SC 2.4 will take place at the commission 2 meeting during IAG2013 in Potsdam.

## **Sub-Commission 2.4a: Gravity and Geoid in Europe**

*Chair: Heiner Denker (Germany)*

### **Activities and future plans**

The topic of regional geoid determination was handled from 2003 – 2011 within Commission 2 Projects, and since 2011 the responsibility for this task is with Sub-Commission 2.4, which is further sub-divided according to different regions of the world, such as Sub-Commission SC 2.4a “Gravity and Geoid in Europe”. The primary objective of SC 2.4a is the development of improved regional gravity field models (especially geoid/quasigeoid) for Europe which can be used for applications in geodesy, oceanography, geophysics and engineering, e.g., height determination with GNSS techniques, vertical datum definition and unification, dynamic ocean topography estimation, geophysical modelling, and navigation. SC 2.4a cooperates with national delegates from nearly all European countries, whereby existing contacts have been continued and extended.

The last complete re-computation of the European geoid/quasigeoid is EGG2008 (European Gravimetric Geoid 2008); the used theory and possible refinements as well as the detailed computation procedure are described in a monograph published by Denker (2013). Besides this, the work concentrated on the use of the GOCE global geopotential models, which were first evaluated by the existing terrestrial gravity field data sets, showing that the GOCE models improved from release to release with the inclusion of longer observation time series. The agreement between the release 3 GOCE models and terrestrial data up to degree and order 200 is about 5.5 cm for height anomalies, 1.7 mGal for gravity anomalies, and 0.55" for vertical deflections, respectively, being fully compatible with the relevant error estimates. So far, the combination solutions based on GOCE and terrestrial data mostly perform similar to corresponding calculations relying on EGM2008, which is due to the high quality of the European data sets utilized in the EGM2008 development; however, in selected areas with known weaknesses in the terrestrial gravity data (e.g., Bulgaria, Romania), the inclusion of the GOCE models instead of EGM2008 leads to some improvements in terms of GPS/leveling fits. Most of the GOCE investigations were carried out in the framework of the REAL GOCE project funded by the German Ministry of Education and Research (BMBF) and the German Research Foundation (DFG); for further details see Ihde et al. (2010) as well as Voigt and Denker (2011 and 2013).

Besides the global models, also selected terrestrial gravity data sets were upgraded and extended, e.g., in Germany and Bulgaria. For Bulgaria, work is not yet completed, but it appears that the existing mean gravity values can be replaced by much better point gravity values. A few other countries have also been approached regarding an update of the relevant gravity data.

Furthermore, the Leibniz Universität Hannover is involved in another interesting project, which is related to the new optical clocks with a projected performance at the level of 10-18; according to the laws of general relativity, such clocks are sensitive to the gravity potential equivalent to 1 cm in height. Hence, the optical clocks may offer in the near future completely new options to independently observe and verify geopotential differences over large distances; for further details on the entire project (International Timescales with Optical Clocks, ITOC) see Margolis et al. (2013a,b).

A SC 2.4a meeting is planned for the IAG Scientific Assembly 2013 in Potsdam, and a complete re-computation of the European geoid is foreseen until 2015, which should then utilize the latest terrestrial data sets as well as a corresponding global geopotential model based on GOCE and other satellite gravity field mission data.

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## Sub-Commission 2.4b: Gravity and Geoid in South America

*Chairs: Maria Cristina Pacino (Argentina), Denizar Blitzkow (Brazil)*

### Introduction

This report intends to cover most of the activities in South America related to gravity field determination. It is not complete certainly due to the many activities going on by different organizations, universities and research institutes.

A big effort was carried out by many different organizations in the last few years to improve the gravity data coverage all over South America. As a result approximately 953,316 stations gravity data is available for geoid determination. Figure 1 shows the new and old gravity data. The new gravity observations have been carried out with LaCoste&Romberg and/or CG5 gravity meters. GPS double frequency receivers have been used to derive the geodetic coordinates of the stations. The orthometric height for the recent surveys was derived from geodetic height using EGM2008 restricted to degree and order 150.

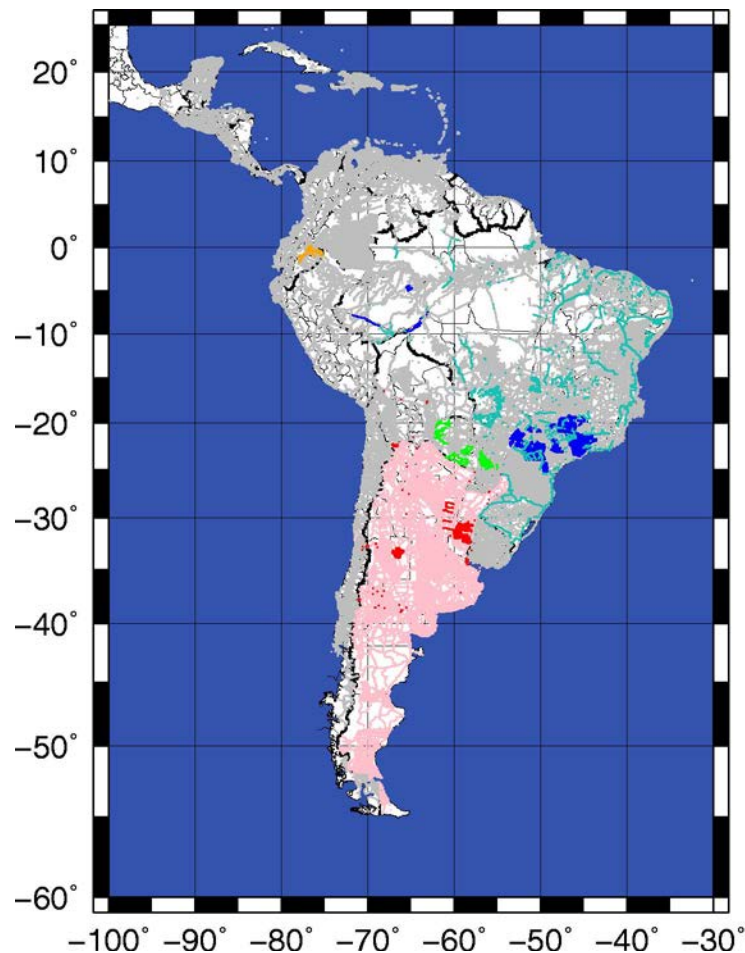


Figure 1 – South America gravity data

## Argentina

The last two years, 504 new gravity stations have been measured in Argentina (Figure 2).

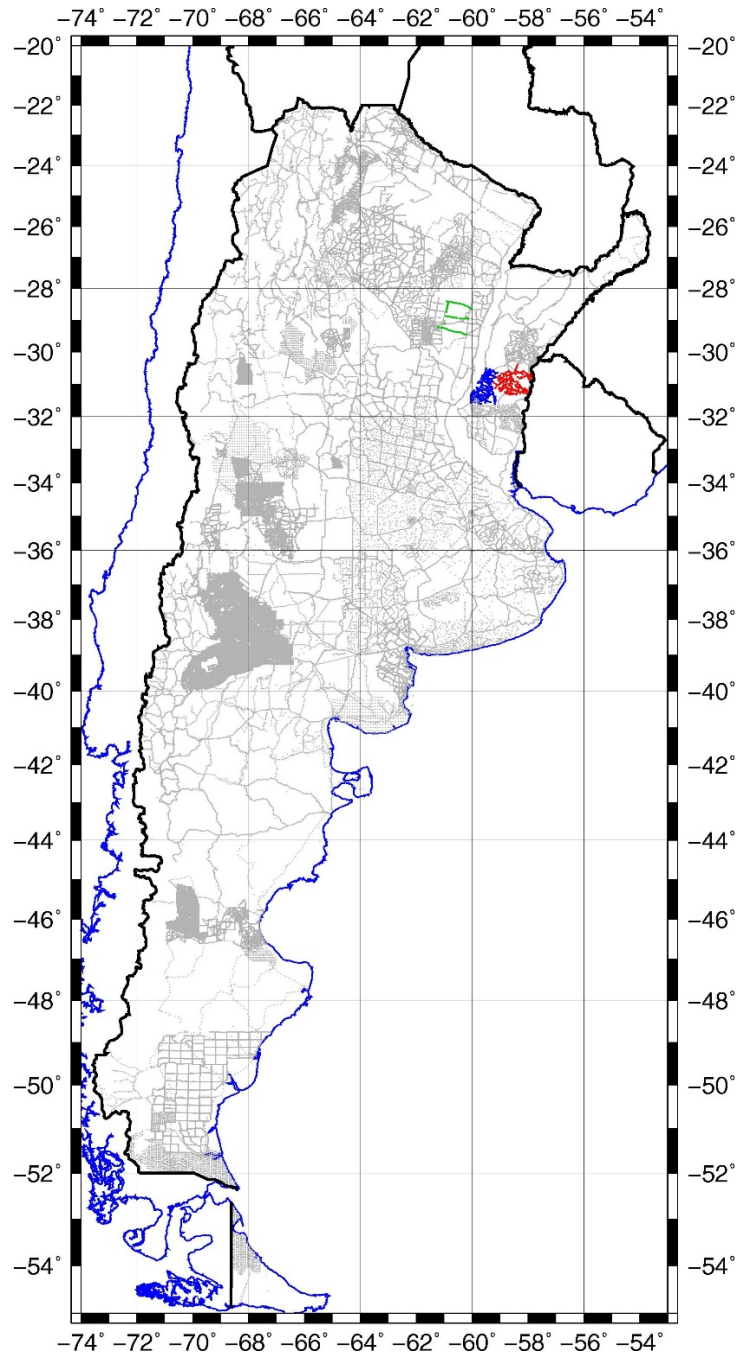


Figure 2 – Gravity data in Argentina

## Brazil

In the last two years, IBGE (CGED), Polytechnic School of the University of São Paulo, Laboratory of Surveying and Geodesy (EPUSP-LTG), SAGS project (GETECH/NGA) and the Thematic Project (FAPESP, Brazilian research foundation) a total of 11,941 new gravity stations have been measured (Figure 3).

Just Thematic Project surveyed a total of 8,521 points in recent surveys (details in Figure 4).

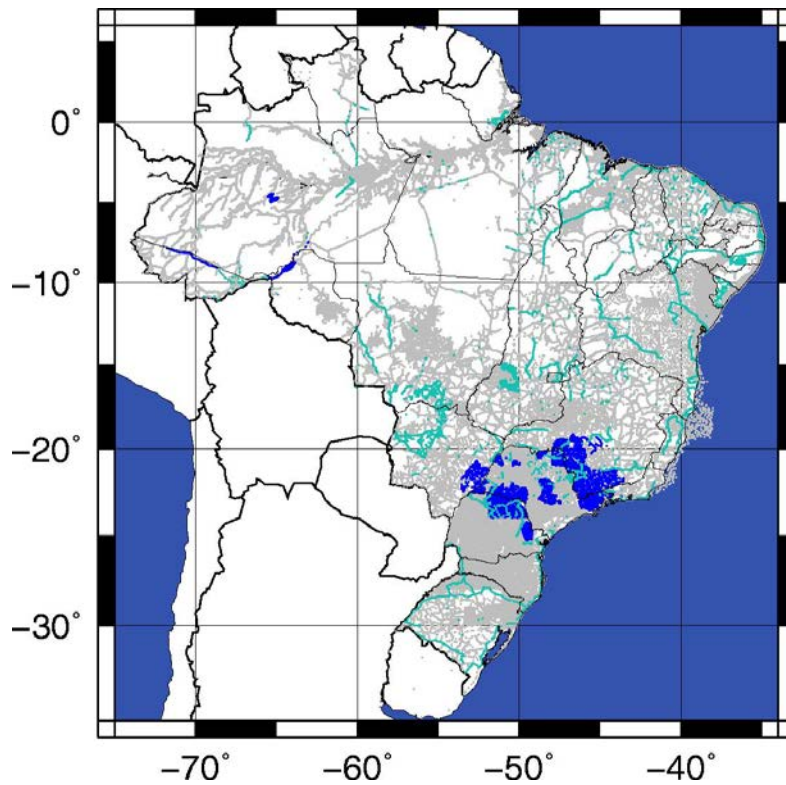


Figure 3 – Brazil new gravity data

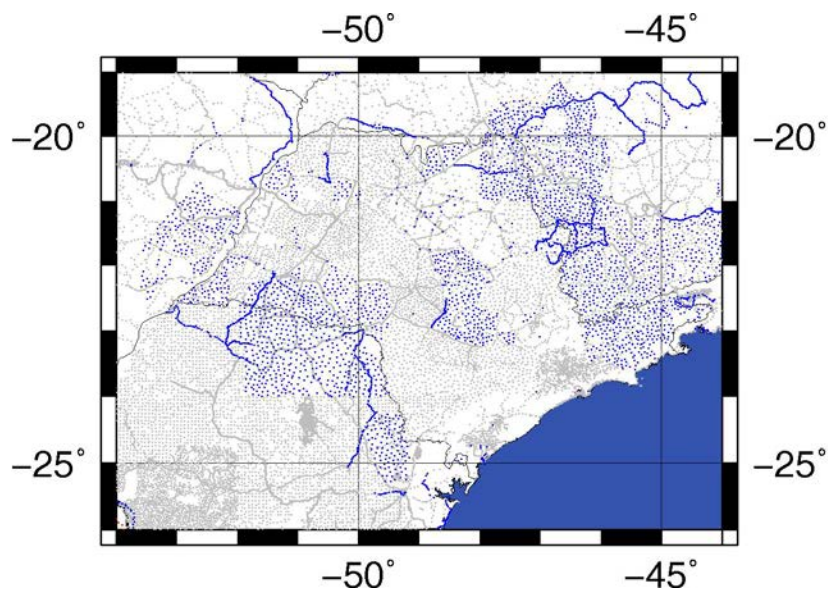


Figure 4 – Thematic project

## Ecuador

From 2009 up to 2012, gravimetric surveys in Ecuador obtained 235 new points (SAGS2011-2012) and another 308 points by IGM. SAGS gravity data were surveyed by IGM, IBGE and EPUSP in NAPO and AGUARICO rivers and in some trials.

A sophisticated logistics were established to support the surveys along the wild rivers. The gravity values of the densification surveys were connected to the existing FGN (Fundamental Gravity Network) in the country.

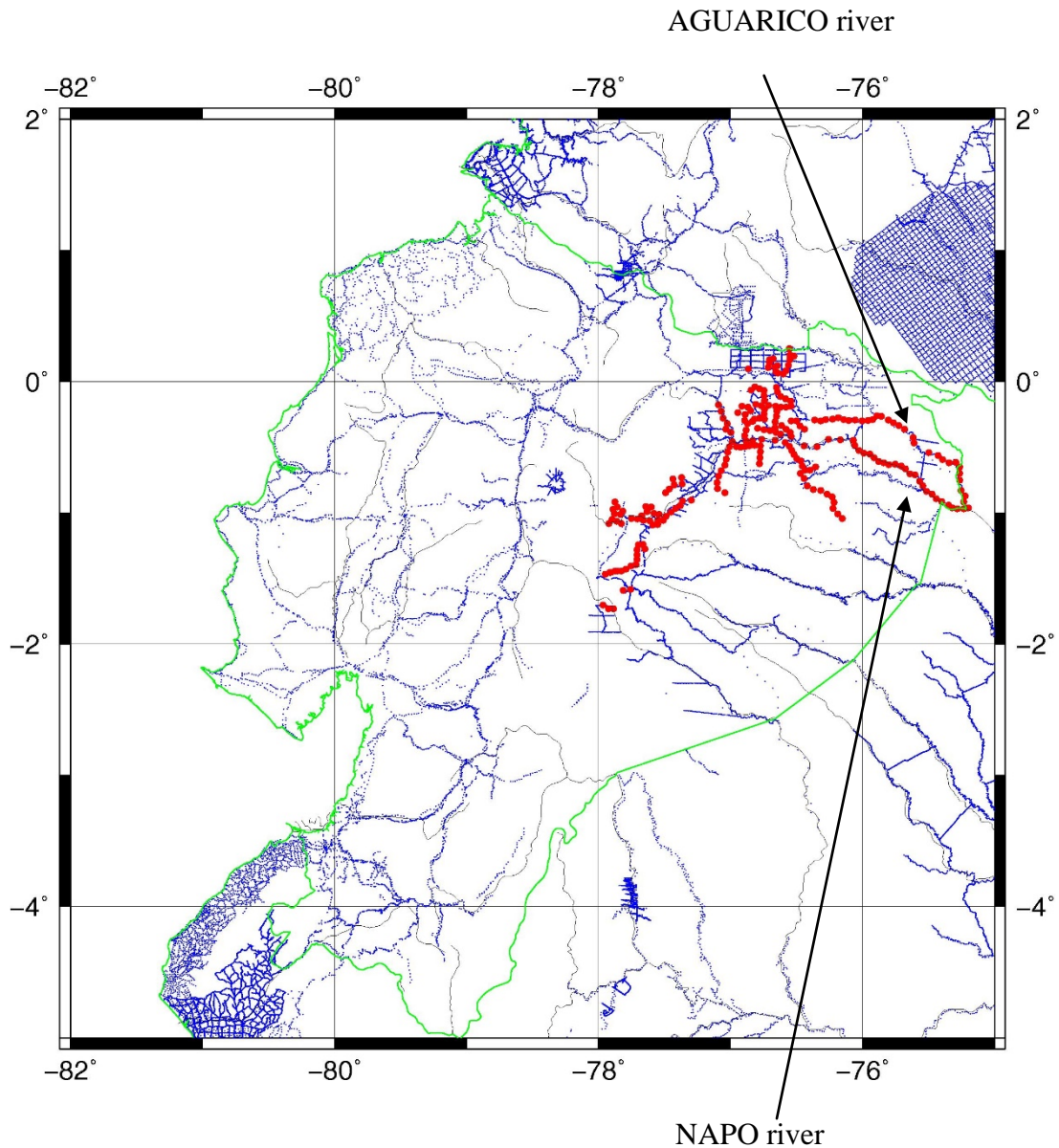


Figure 5 – Ecuador surveys



## Paraguay

New gravity data in Paraguay surveyed 771 points located in the Chaco region (northwest part of the country), Concepcion and San Pedro provinces. Chaco is a remote region with difficult logistics.

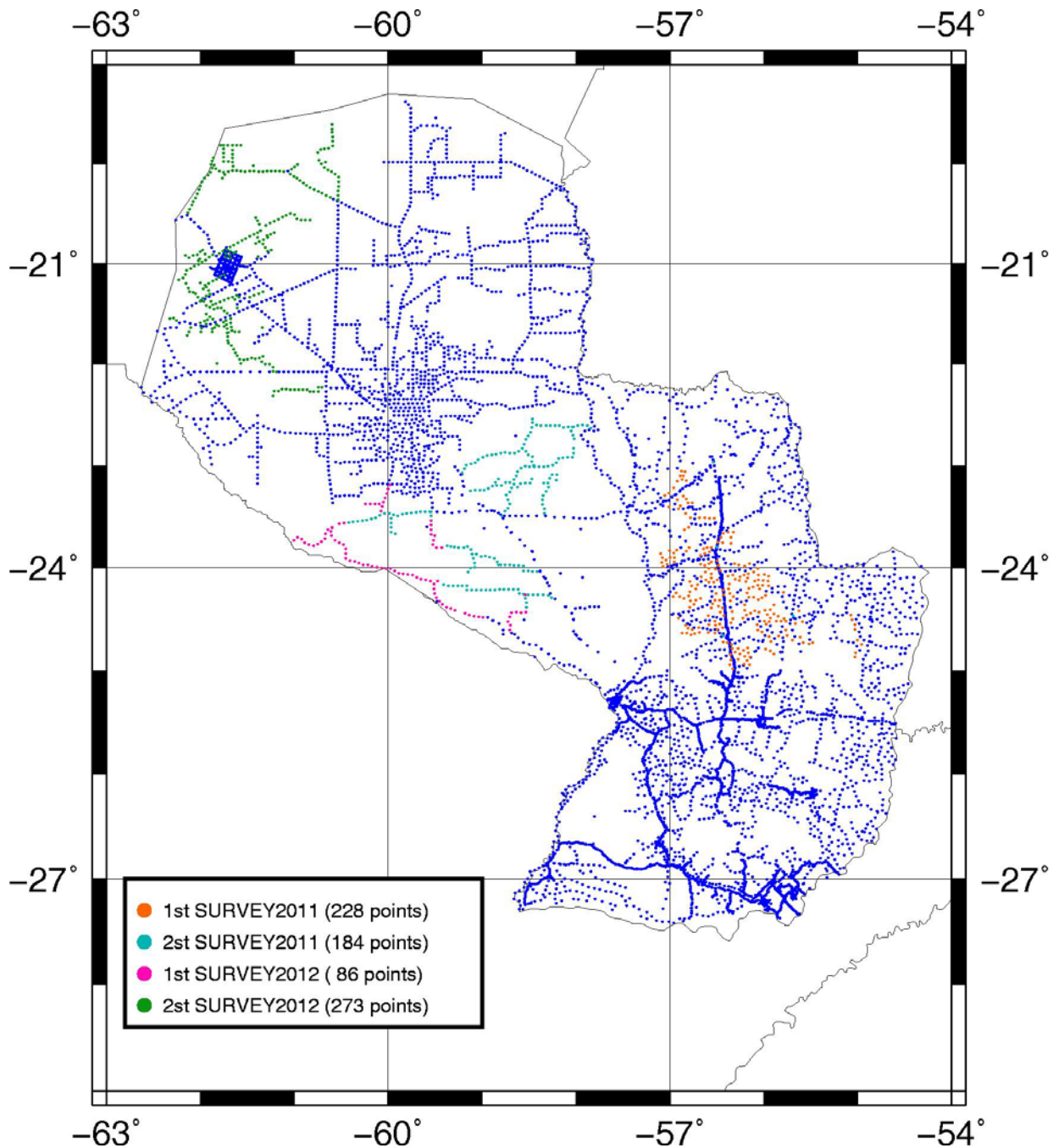


Figure 6 – Gravity data in Paraguay

## Earth tide model

A new project in Brazil under the coordination of the LTG is designed to establish an Earth tide model. This Project will be supported by GEORADAR Levantamentos Geofísicos S.A. and IGC (Instituto Geográfico e Cartográfico) .

Two MicroG LaCoste (gPhone) and one A-10 (absolute) gravimeters are available. The first phase of the project is intended to determine a preliminary model for the Earth tide in São Paulo state. The project aims to establish 5 stations well distributed in Brazil, one of long term in Manaus, Amazon, and 4 others in a sequence of one year operation in different places (Figure 7).

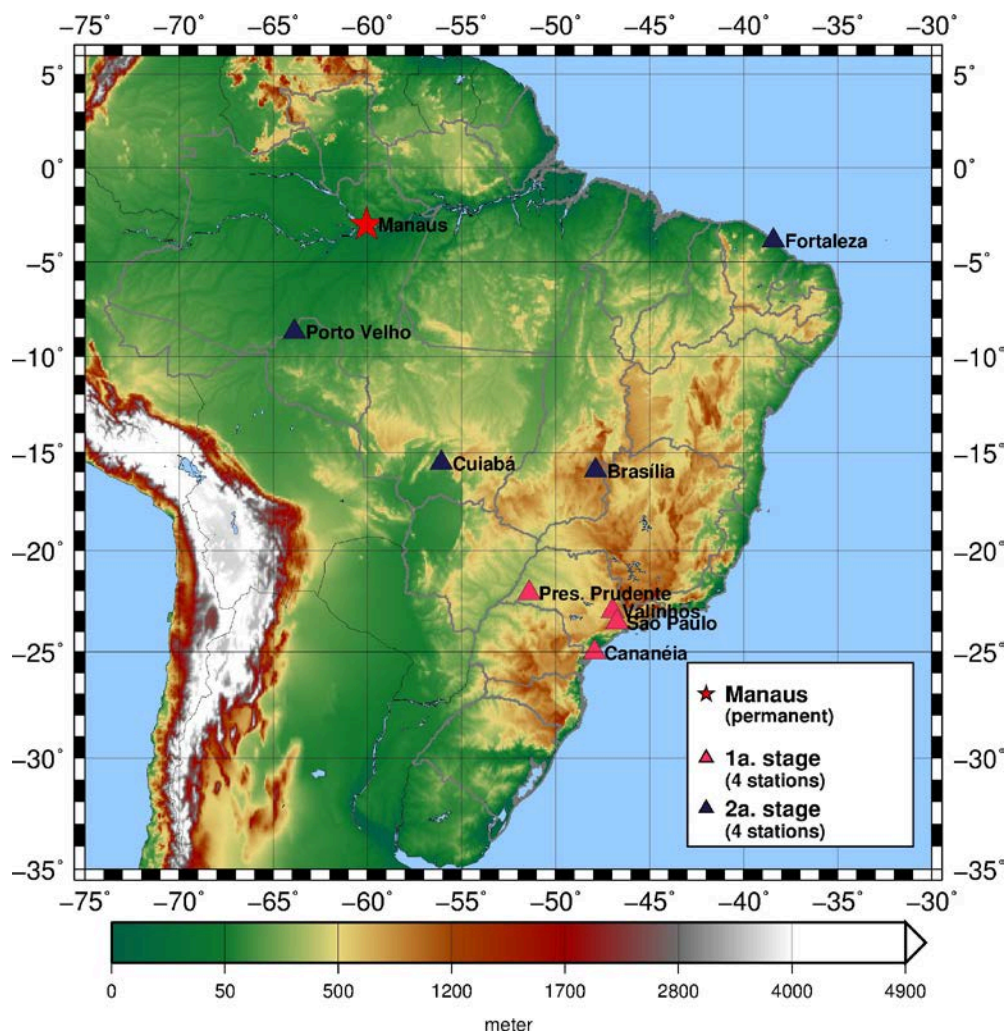


Figure 7 – g-Phone survey.

A fundamental gravity network will be established in Brazil with A-10 absolute gravimeter as a reference for densification measurements. It will be used also for controlling the drift of the gPhone when necessary. In a first phase, stations will be established in São Paulo state (Figure 8) and in the second in Amazon region across the main rivers in cooperation with CPRM (Figure 9).

An agreement is under arrangement in order to undertake measurements in Argentina as cooperation between EPUSP and the University of Rosario.

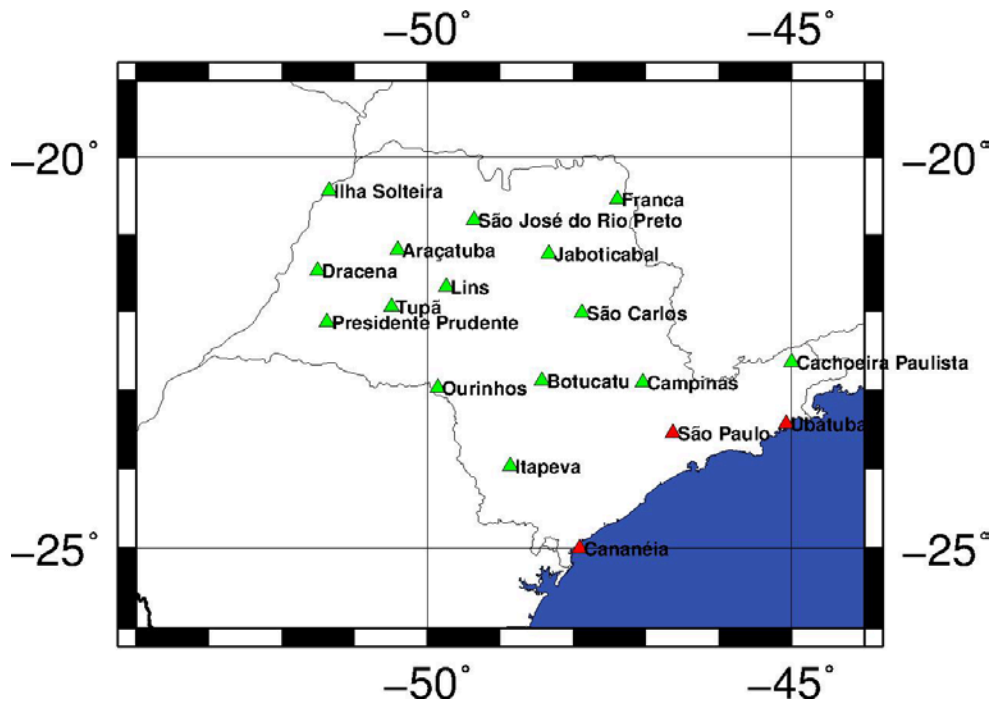


Figure 8 – A-10 Absolute Network in São Paulo state.

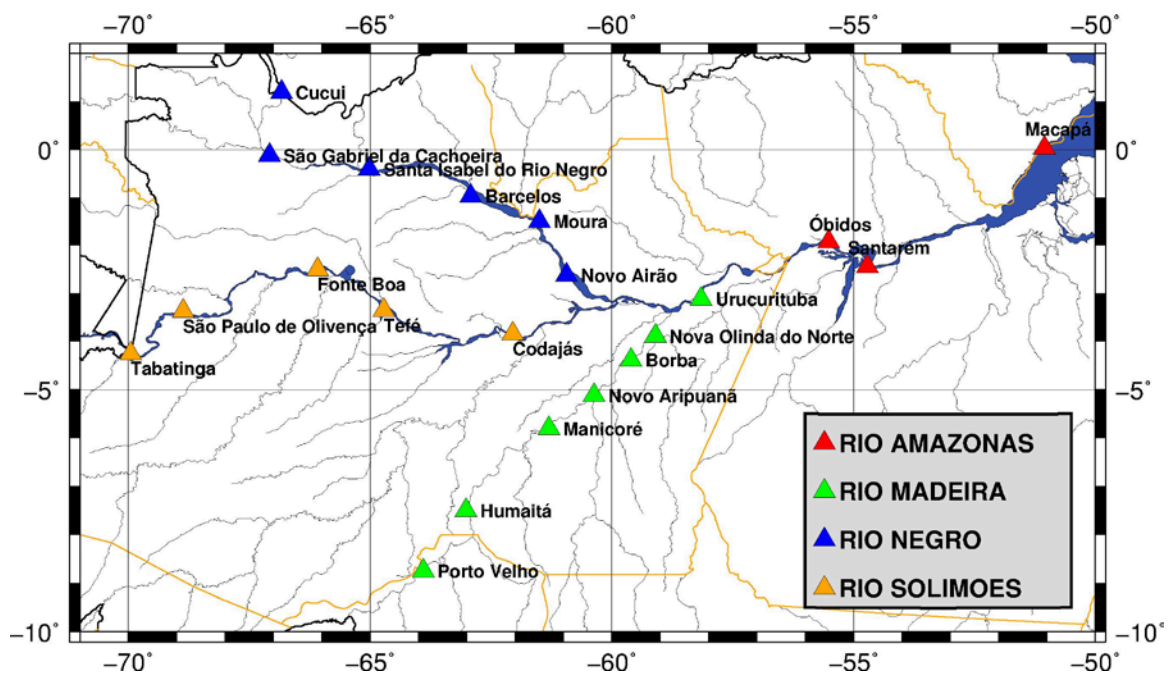


Figure 9 – A-10 Absolute Gravity meter in Amazonia region.

## **Sub-Commission 2.4c: Gravity and Geoid in North and Central America**

*Chair: David Avalos (Mexico)*

### **Steering Committee**

David Avalos (Chair, INEGI, Mexico)  
Rene Forsberg (DTU, Denmark)  
Marc Véronneau (NRCan, Canada)  
Dan Roman (NOAA, U.S.A.)  
Laramie Potts (NJIT, U.S.A.)  
Vinicio Robles (IGN, Guatemala)  
Carlos E. Figueroa (IGN-CNR, El Salvador)  
Anthony Watts (L&SD, Cayman Islands)  
Oscar Meza (IP, Honduras)  
Alvaro Alvarez (IGN, Costa Rica)

### **Activities**

Collaboration continues expanding from the achievements reported on 2011 by the commission 2 project 2.2 on the North American geoid. Within the period 2011-2013, governmental geodetic sections and some universities expressed in different forums an interest in gravity field and geoid determination with two fundamental coincidences: further promote an open access to databases on terrestrial gravity, and the unification of vertical reference frames over the realization of a standard geopotential surface.

Regarding the impulse to inter-institutional relations, Canada and the U.S.A. were most actively represented by the NRCAN/GSD, the University of Calgary, University of Toronto and the NOAA/NGS. A coordinated work among them delivered a study on the geopotential value representative of the North American mean sea level as well as a formal agreement between GSD and NGS to make national geoid modeling correspond to the value  $W_0=62,636,856.0 \text{ m}^2 \text{ s}^{-2}$ , which was recommended as a standard by the study. PSMSL and ESA participated in this effort as partners from abroad.

From Central America and Caribbean countries, Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama and the Dominican Republic consolidated a communication network with the aim to exchange expertise on gravity field and geoid determination. The corresponding partner institutions in this group are: Instituto Nacional de Estadística y Geografía (Mexico), Instituto Geográfico Nacional (Guatemala), Centro Nacional de Registros (El Salvador), Instituto de la Propiedad (Honduras), Instituto Nacional de Estudios del Territorio (Nicaragua), Instituto Geográfico Nacional (Costa Rica), Instituto Geográfico Nacional Tommy Guardia (Panama) and Instituto Cartográfico Militar (Dominican Republic). The Pan-American Institute of Geography and History, together with Mexico's representation, had the role of initial supporters on 2011. The results from this collaboration can be summarized in: a) sharing information about existing national geodetic control to integrate a document of public domain, b) exchange of capabilities in handling terrestrial gravity data, c) exchange of theoretical concepts for modern geoid modeling, d) establishment of a minimum structure for national gravity databases. The NGS and the Canadian University of New Brunswick have participated in this effort as consultants from abroad.

Regarding the current national geoid models in the region and their discrepancy, Canada and the U.S.A. achieved a mean difference of 0 cm with standard deviation of 4 cm, while Mexico's model differs by 18 cm in the mean and 18 in standard deviation. So far, none of the published models comply with the  $W_0$  value mentioned above; however, Canada plans to deliver the first geoid model on such a geopotential value as an official vertical datum before the end of year 2013. Since May 2012, representatives from national geodetic agencies of Canada, USA and Mexico concurred in the convenience to adopt a scheme of producing geoid models with an explicit reference epoch and an associated model of geoidal height velocity. This in order to guarantee that the nearly 1 cm accuracy achieved can be preserved in time.

## Meetings

International scientific forums have served as meeting points for the people interested in gravity field and geoid within North and Central America. These opportunities derived on impulse to plans for future collaboration in topics like a) the determination of gravity field from permafrost over Greenland and Canada, b) the unification of gravity databases in North and Central America, c) the promotion of open access to all national gravity holdings in the region, d) the promotion of a standard  $W_0$  value for regional reference, and e) the analysis of pros and cons about merging the Sub-Commissions for North, Central and South America. This is a list of conferences where the main discussion has taken place:

- IUGG in Melbourne, Australia (2011),
- INEGI's workshop in Aguascalientes, Mexico (2011),
- AGU in San Francisco, USA (2011),
- INEGI's teleconference, Mexico (April 2012),
- CGU in Banff, Canada (2012),
- IAG Commission 2 (GGHS2012) in Venice, Italy (2012),
- INEGI's teleconference, Mexico (November 2012),
- AGU in San Francisco, USA (2012),
- AGU Meeting of the Americas in Cancun, Mexico (2013),
- CGU in Saskatoon, Canada (2013).

The CGU meetings in 2012 and 2013 included the annual Canadian geoid workshop. In 2012, the participation came from Canada, USA, Mexico and European countries which attended the meeting to focus on results from GOCE for the Unification of the Height Systems. In 2013, the workshop focussed on the collection, processing and analysis of the GRAV-D data. The participants included only USA and Canada.

Following events during the next two years will likely continue to serve as the main opportunity to progress towards a better modeling of the entire region.

## Main advances in gravity data collection.

Presently two major programs of field gravity data collection exist in the region: the NOAA/NGS' GRAV-D project and the INEGI's gravity network. The former continues delivering final results of gravity values from airborne gravimetry over areas with little coverage within the conterminous USA. With this effort, the gravity field determination improved significantly over large extensions in Alaska, Eastern and Southern US. Next, areas like

Mexico-US border are targeted. In Mexico, the survey of terrestrial gravimetry expands by about 5000 new observations, making a uniform coverage over 9 degree cells every year. The NOAA/NGS managed to set an open access to a large collection of marine gravimetry from different epochs.

Regarding the determination of a reference gravity field to link the work of target areas on a consistent surface, most parties in the region make a strong use of the GOCE models. These gravity field representations in spherical harmonics up to degree and order 180 are seen as basic tools to implement a regional datum unification.

### **Contributions from research.**

Several universities continue to deliver useful results to understand the dynamic behaviour of the gravity field in North and Central America. Researchers from the University of Texas at Dallas, University of Calgary, York University, University of New Brunswick, and from national geodetic agencies like the NRCAN/GSD and NOAA/NGS released most of the methodological improvement to model the gravity field, the geoid and their time variations.

The GEOIDE network of centres of excellence's project named "A geoid-based vertical reference frame for height modernization in North America", produced a large series of results like new parameters and models linked to inter-institutional agreements. Within the numerous conclusions obtained, this is a representative sample: a) a  $W_0$  value expressed as a recommendation to fit the mean sea level in North America, followed by a formal agreement between NGS and GSD to use it for national geoid modeling; b) threshold values to use the GOCE and GRACE models as reference to specific spectral resolution; c) magnitudes of the bias among official vertical datums; d) estimates of the effect in the geoid from long term variations in post glacial rebound, hydrology and ice load.

### **Collaboration with other Sub-Commissions**

In communication, mainly by e-mail, this Sub-Commission has promoted the understanding with the chair and co-chair of Sub-Commission 2.4b Geoid and Gravity in South America. For now, the topics for discussion are focused in two points: a) the impulse to increase contacts and partners to increase the capability of Central American countries to start their own gravity surveys, and b) the terms to obtain permission from individual institutions to give open access to gravity databases in benefit of both regions. An activity to promote the contact between particular Central American agencies and North American institutions of known experience in collaborative surveying (i.e. NGS and NGA) is currently on its way to help assembling project proposals for target zones. During the following year it is expected to facilitate the direct communication between those Central Americans or Caribbeans that express a concrete interest (including Mexico) and those institutions with a possibility to act as partners.

## **Sub-Commission 2.4d: Gravity and Geoid in Africa**

*Chair: Hussein Abd-Elmotaal (Egypt)*

Webpage: <http://www.minia.edu.eg/Geodesy/AFRgeo/>

### **Activities and future plans**

A 2-year project " Detailed Geoid Model for Africa " in collaboration between IAG and IASPEI was accepted by IUGG. In this project, IUGG helps in the acquisition of gravity data for Africa needed for computing the geoid as well as in attending the geodetic international conferences to disseminate the project results. This will allow the determination of a precise geoid for Africa as well as it will foster cooperation between African geodesists and will help in providing high-level training in geoid computation to African geodesists. A separate detailed report of this project will go directly to IUGG.

There were several attempts to collect gravimetric point data for the African continent. Contacts were established with the BGI, NGA and GETECH. Until now, this was not very successful.

Abdalla et al. (2012) have tested the most recent GRACE/GOCE global geopotential models using GPS/levelling data (in Khartoum State) and gravity data of Sudan.

Abd-Elmotaal (2012) performed gravity interpolation within large gaps, which is the case of the gravity network in Africa, in order to obtain the best suited interpolation process for such cases.

Abd-Elmotaal and Ashry (2013) have established a 3" x 3" DHM for Egypt using SRTM 3" and other local and regional resources.

Abd-Elmotaal et al. (2013) have established a very detailed 1" x 1" DHM for Egypt using ASTER-GDEM 1", SRTM 3" and other local and regional resources.

Abd-Elmotaal and Kuehtreiber (2013) have investigated the effect of DHM resolution in computing the topographic-isostatic harmonic coefficients within the window technique in order to get the optimum resolution of computing the window topographic-isostatic coefficients.

Abd-Elmotaal and Makhloof (2013) have made a study regarding the gross-errors detection in the ship-borne data set for oceans surrounding Africa, which will be presented at the Geodetic Week & INTERGEO 2013, Essen, Germany, October 8-10, 2013.

Comparison of recent geopotential models for the recovery of the gravity field in Africa has been performed by Abd-Elmotaal and Makhloof (2013) and will be presented at the Geodetic Week & INTERGEO 2013, Essen, Germany, October 8-10, 2013.

Land gravity data has been collected, and a gross-error detection algorithm is being under process.

An African 3" x 3" DHM using SRTM 3" and SRTM30+ is under process.

A Tailored Reference Geopotential Model for Africa is being computed with the cooperation of Heck and his co-workers and will be presented at IAG2013 in Potsdam.

Establishment of the Gravity Database for the African Geoid, which is the core of the regional sub-commission for Africa and the most important and time consuming task, is taken place with the cooperation of Heck and his co-workers and Kuehtreiber and his co-workers. It is planned to present the output of this research at the EGU2014 in Vienna 2014.

The geoid computation for the African geoid model will then take place and will be presented at the IUGG XXVI General Assembly 2015.

A splinter meeting for the steering committee of the 2.4d regional sub-commission will take place during IAG2013 in Potsdam

Ben Ahmed Daho works on the investigation the possibility of improving the accuracy of the latest geoid model for Algeria using the new and revolutionary Global Gravitational Model EGM2008 and the satellite altimetry-derived marine gravity anomalies. For this purpose, a new gravimetric geoid model for Algeria has been computed using the land gravity data supplied by the BGI, EGM2008 to degree 2190 as the reference field, Digital Elevation Model derived from SRTM for topographic correction, and DNSC2008GRA altimetry-derived gravity anomalies offshore. According to our numerical results, the new geoid shows an improvement in precision and reliability, fitting the geoidal heights of these GPS/levelling points with more accuracy than the previous geoids. Its standard deviations fit with GPS/levelling data are 12.7cm and 2.5cm before and after fitting using the seven-parameter similarity transformation model.

Moreover, the analysis of the results shows that the signals in benchmarks are dominated by errors in the geoid due to the bad gravimetry, while the noise level indicates of the presence of errors in our vertical datum. The available and accuracy of the land gravity data remains insufficient to agree with GPS/Levelling at the sub-centimetre level. This new geoid model will be used to support Levelling by GPS at least for the low order levelling network densification.

Improvement the accuracy of the latest geoid model (Benahmed et al., 2009), especially in mountainous areas by considering the effect of lateral density variations. Numerical results show that the differences in the geoid height due to actual density model can reach up to 13 cm, which is not negligible in a precise geoid determination with centimetre accuracy. Our results suggest that the effect of topographical density lateral variations is significant enough and ought to be taken into account especially in mountainous regions in the determination of a precise geoid model for Algeria. However, basically because of the lack of GPS/levelling data in mountainous areas and the most of our GPS/levelling points used in this investigation are located in moderate heights areas, we could not see much improvement by evaluation of the corrected gravimetric geoid model versus GPS/levelling.

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Benahmed Daho S.A., Goughali M. (2013): A refined geoid model for Algeria using EGM2008 and the satellite altimetry-derived marine gravity anomalies in Algeria. Communication accepted for presentation in upcoming IAG General Assembly – Potsdam - Germany (Gravity Field Determination and Applications / Regional gravity and geoid studies)

## **Sub-Commission 2.4e: Gravity and Geoid in the Asia-Pacific**

*Chair: Will Featherstone (Australia)*

### **Summary of Problems**

This group has not been as active as it should have. As was the case for its predecessor SCs, it is difficult to make contacts and, moreover, to get data exchange. Depending on one's definition of Asia-Pacific, this SC could cover as many as 48 countries. These are diverse in terms of languages, politics, governments and wealth, which presents a significant challenge for the exchange of gravity and geoid data and expertise.

### **Future Activities (2013-2015)**

- Determine list of countries and establish contacts.
- Audit data sources and determine their availability.
- Establish protocols for data sharing and/or exchange.
- Follow up on potential contacts through the Geodesy Working Group of the Permanent Committee for GIS Infrastructure in Asia and the Pacific (PCGIAP). This group comprises the main authorities that deal with geoids and height datums in the region and beyond.
- The chair is also member of a group recently convened by J. Kwon (South Korea) on height systems and vertical datums in the Asia-Pacific region (APRHSU: Asia-Pacific Regional Height System Unification), so that may generate more contacts.
- Establish other contacts in the Asia-Pacific region through FIG Commission 5, which has a strong interest in these matters from the viewpoint of operational geodesy.

Explore ways in which we may

- (a) share available gravity data (e.g. via International Gravity Bureau)
- (b) share available DEMs along common borders (National Geodetic Authorities)
- (c) combine resources for terrestrial gravity surveys along common borders
- (d) combine resources for airborne gravity surveys in the region.

Explore ways in which countries of the region may cooperate by

- (a) sharing geometric (GNSS/levelling and vertical deflections) geoid control data
- (b) combining efforts in global GNSS campaigns
- (c) undertaking joint campaign for the connection of regional vertical datums.

Encourage and sponsor, for the region,

- (a) meetings and workshops, e.g., with the International Geoid Service, to foster understanding of gravimetric quasi/geoids, and in their application to efficient height determination with GNSS.
- (b) technical sessions in scientific and professional conferences
- (c) research into matters of common concern/interest.

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## **Sub-Commission 2.4f: Gravity and Geoid in Antarctica**

*Chair: Mirko Scheinert (Germany)*

### **Short Review**

This group was adopted at the IAG General Assembly in Sapporo 2003. In 2011 it was transferred from a Commission Project to the Sub-Commission 2.4f. The Sub-Commission is dedicated to the determination of the gravity field in Antarctica. In terms of observations mainly airborne, but also terrestrial campaigns have been and are being carried out to complement and to densify satellite data. Because of the region and its special conditions the collaboration extends beyond the field of geodesy – the cooperation is truly interdisciplinary, especially incorporating experts from the fields of geophysics and glaciology. This is also reflected in the group membership (cf. below).

During the last period of (2011-2013) further progress has been made to include new data and to open access to already existing data. It is anticipated to finally deliver a suitable grid of terrestrial gravity data and of regional geoid solution(s). A respective publication is in progress. Presentations dedicated to this topic have been given at the IUGG General Assembly in Melbourne, 2011, at the XI International Symposium on Antarctic Earth Sciences (ISAES) in Edinburgh, 2011, or at the XXXII SCAR Meeting and Open Science Conference, Portland, 2012.

The coverage of gravity data in Antarctica has been continuously improved by new surveys. In this respect, the International Polar Year 2007/2008 (IPY, March 2007 – February 2009) played an important role. Of these IPY projects, for instance, gravity data from the project 67 “Origin, evolution and setting of the Gamburtsev sub-glacial highlands (AGAP)” could be incorporated.

Further data were released by the NASA project ICEBRIDGE (which mainly aims to close gaps between ICESAT and ICESAT-2 satellite missions), and by further national or multi-national projects.

A close linkage is maintained to the Scientific Committee on Antarctic Research (SCAR), where the geodesy group (SCAR Standing Scientific Group on Geosciences (SSG-GS), Expert Group on Geospatial Information and Geodesy (GIANT Geodetic Infrastructure in Antarctica)) adopted a new program at the SCAR Meeting in Portland, Oregon, 2012. M. Scheinert co-chairs GIANT as well as chairs the GIANT project “Gravity Field”.

Information has been maintained through circular letters and a webpage under <http://tpg.geo.tu-dresden.de/antgp>.

### **Future plans and activities**

Future activities are well defined following the “Terms of Reference”. Since any Antarctic activity call for a long-term preparation the main points to be focused on do not change. New surveys will be promoted, nevertheless, due to the huge logistic efforts of Antarctic surveys, coordination is organized well in advance and on a broad international basis. Within AntGG, the discussion on methods and rules of data exchange is in progress and has to be followed on. Compilations of metadata and databases have to cover certain aspects of gravity surveys in Antarctica (large-scale airborne surveys, ground-based relative gravimetry, absolute gravi-

metry at coastal stations). The main goal is finally to deliver a suitable grid of terrestrial gravity data.

With regard to new gravity surveys in Antarctica, aero-gravimetry provides the most powerful tool to survey larger areas. In this context, airborne gravimetry forms a core observation technique within an ensemble of aero-geophysical instrumentation. In continuation of the IPY several projects are in progress which include aero-gravimetry over Antarctica, from the US (e.g. Icebridge), from Germany, Denmark, the UK and other nations. Still it has to be stated that a lot of work has to be done, especially to close the polar data gap of (terrestrial and airborne) gravity. In view of the global gravity field this problem gets a special focus since the latest gravity satellite mission GOCE (launched March 17, 2009) features a data gap of about 1,400 km diameter at the poles (due to its inclination of 96.5°). Future airborne missions may help to solve this problem when adopting long-range aircrafts capable to fly under Antarctic conditions. In this respect, the chair of AntGG is acting as PI of a German project to utilize the German research aircraft HALO for an Antarctic airborne geodetic-geophysical survey (ANTHALO). In 2012 HALO could be successfully utilized for such a survey over Italy and adjacent seas demonstrating the feasibility of aero-gravimetry aboard HALO.

### **Selected conferences and workshops with participation of AntGG members**

- IUGG General Assembly, Melbourne (Australia), June 28 – July 07, 2011;
- International Symposium on Antarctic Earth Sciences (ISAES XI), Edinburgh (UK), July 10 – 16, 2011;
- XXXII SCAR Meeting and Open Science Conference, Portland (USA), July 13 – 25, 2012;
- Workshop “Geodesy and Geophysics on flying platforms (with special attention to HALO)”, Potsdam (Germany), 08-09 November 2012;
- AGU Fall Meetings (2011, 2012) and EGU General Assemblies (2011, 2012, 2013)

### **Membership**

*(active members)*

Mirko Scheinert (chair)	TU Dresden, Germany
Don Blankenship	UTIG, USA
Alessandro Capra	Universita di Modena a Reggio Emilia, Italy
Detlef Damaske	BGR Hannover, Germany
Fausto Ferraccioli	British Antarctic Survey, UK
Christoph Förste	GFZ Potsdam, Germany
René Forsberg	DTU Space, Denmark
Larry Hothem	USGS, USA
Wilfried Jokat	AWI Bremerhaven, Germany
Gary Johnston	Geoscience Australia
Steve Kenyon	National Geospatial-Intelligence Agency, USA
German L. Leitchenkov	VNIIOkeangeologia, Russia
Jaakko Mäkinen	Finnish Geodetic Institute, Finland
Yves Rogister	Université Strasbourg, France
Kazuo Shibuya	NIPR, Japan
Michael Studinger	NASA Goddard SFC, USA

*(corresponding members)*

Matt Amos

LINZ, New Zealand

### **Selected publications and presentations with relevance to AntGG (2011 – 2013)**

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## Sub-Commission 2.5: Satellite Altimetry

Chair: Xiaoli Deng (Australia)

### Satellite Altimetry: Towards 1 mGal Global Marine Gravity Field and Extreme Sea Level Studies

report by: Xiaoli Deng, Ole B Andersen, Cheinway Hwang, David Sandwell, Walter H.F. Smith and CK Shum

Over the past two years, we have developed new retracers and experimented with several retracers to improve altimeter range measurement accuracies globally and over shallow waters around Taiwan, Australia and the Arctic Ocean, as part of our contribution to IAG sub-commission 2.5. With newly available non-repeat altimeter data and recent progress in improvement of altimeter range precision, we have also made significant contributions towards the high-accuracy and high-resolution marine gravity field.

#### Improvement in Waveform Retracking and Studies of Extreme Sea Level

Waveform retracking is an important means that improves the retrieval of sea surface height (SSH) from altimetric range measurements. Idris and Deng (2012a and 2012b) focus on the coastal area where the existing MLE4 retracker usually fails. A sub-waveform retracker has been developed, which fits the Brown (1977) model to the truncated waveform samples that correspond to the returns reflected from the water surface. It has been used to improve altimeter-derived SSHs from Jason-1 and Jason-2 in the Great Barrier Reef, Australia. The study finds that the sub-waveform retracker when combining with other retrackers (i.e., MLE4) can retrieve SSHs closer to the coastline (Figure 1).

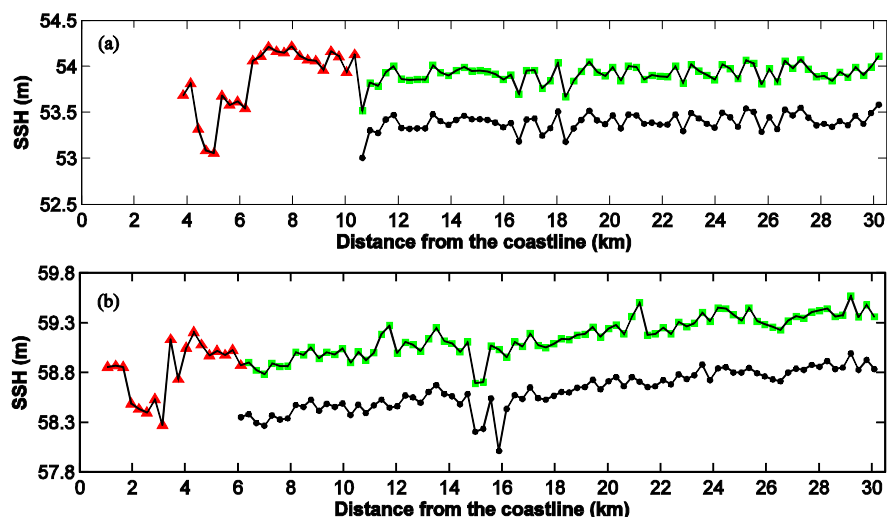


Figure 1: Jason-2 SSH profiles along passes 73 (a) and 175 (b). The SSHs retracked by the MLE4 retracker (in black and green) have been extended to the coast up to ~5 km by the sub-waveform retracker (in red). An arbitrary constant of -1 m is added to MLE4-retracked SSHs from SGDR for visual clarity (Idris and Deng, 2012).

To measure marine gravity anomalies at accuracy under 1 mGal, the error in the along-track slopes from the altimeter profiles must be about  $1 \times 10^{-6}$  rad, or there must be enough repeated tracks to achieve the 1  $\times 10^{-6}$  rad accuracy. Idris and Deng (2012) and Garcia et al. (2012) have used Jason-1 geodetic mission (GM) waveforms towards this goal. A simple, but approximate,

analytic model has been derived for the shape of the CryoSat-2 SAR waveform that can be used in an iterative least-squares algorithm for estimating range. For the conventional waveforms, the two-pass retracking procedure has resulted in a factor of  $\sim 1.5$  improvement in range precision (Table 1). This method was originally developed specifically for ERS-1 data with three and two parameters at the first and second retracking steps, respectively (Sandwell and Smith, 2005). The improved range precision and dense coverage from CryoSat-2, Envisat and Jason-1 GM should lead to a significant increase in the accuracy of the marine gravity field.

Table 1: 20 Hz altimeter noise (in mm) with significant wave heights of 2 m and 6 m\*

Altimeter	3-PAR @ 2 m	2-PAR @ 2 m	3-PAR/2-PAR	2 PAR @ 6 m
Geosat	88.0	57.0	1.54	105.4
ERS-1	93.6	61.8	1.51	111.8
Envisat	78.9	51.8	1.52	88.6
Jason-1	75.9	46.4	1.63	64.2
CryoSat-2 LRM	64.7	42.7	1.51	71.7
CryoSat-2 SAR	49.5	49.7	.996	110.9
CryoSat-2 SARIN	138.5	138.7	.998	148.6

\*Standard deviation of retracked 20 Hz height estimates with respect to EGM2008 (mean removed). The data are from a region of the North Atlantic with relatively high sea state. The values represent the median of thousands of estimates over a 0.4 m range of SWH. The 10 Hz Geosat estimates were scaled by 1.41 to approximate the errors at the 20 Hz sampling rate. Note in all cases except for the CryoSat-2 SAR and SARIN modes, the 3-PAR to 2-PAR noise ratio is close to the 1.57 value derived from a least-squares simulation (Garcia et al., 2013)

Tide gauge and satellite altimetry has vastly different spatial and temporal sampling. However the data can be integrated to take advantage of the high temporal sampling of the tide gauges with the high spatial sampling of the satellite. Our investigation demonstrates the importance of optimal tide modeling using the response method as well as careful use of the dynamic atmosphere correction delivered by the MOG2D model (Cheng and Andersen, 2012; Andersen and Scharroo, 2011). Data from TOPEX/Poseidon and Jason1/2 altimetry missions and tide gauges recorders over the past 20 years around both European and Australia coasts general exhibit temporal correlation of more than 90% for nearly all tide gauge stations. These data are combined using a multivariate regression method, which have been used to investigate both high frequency signals (e.g., surges) and annual to decadal sea level signal (Deng et al., 2011, Andersen and Cheng, 2013). The results suggest the existence of ability to capture surge (and cyclones) and sea level along the Northwest European and Australian coastlines (Cheng and Andersen, 2012; Deng et al., 2012a and 2012b). The results of this study open the way for further research into monitoring of extreme sea level events.

Our retracking techniques are also applied to altimeter data over areas with potential land subsidence for hazard mitigation (e.g., Lee et al., 2013; Gommenginger et al., 2011). Height changes over ice-covered areas, particularly in Tibet, high mountains of Central Asia and permafrost areas of Siberia, are improved by retracking.



*Improvement in Global Marine Gravity Field from Altimetric Geodetic Missions*

Gravity field accuracy depends on four factors: spatial track density; altimeter range precision; diverse track orientation; and the accuracy of the coastal tide models (Sandwell et al., 2013). Efforts to exploit the altimetric-derived marine gravity field started soon after the advent of the modern altimeter era in the 1990s, with data from early Geosat and ERS-1 GMs. Recently three new non-repeat altimeter data sets have become available that have a significant impact on marine gravity recovery. These are (1) the CryoSat-2 that provides three measurement modes from a 369-day repeat orbit and has an average ground track spacing of 3.5 km at the equator; (2) the Envisat that was placed in a new partly drifting-phase repeat orbit (~30 days) and collected 1.5 years of data with dense coverage in high latitudes by April 2012; and (3) the Jason-1 GM of a 406-day orbit that results in an average ground spacing of 3.9 km at the equator. These new altimeter data sets have been exploited for high-resolution and high-accuracy mapping of marine gravity filed globally, as well as in the Arctic Ocean (e.g., Stenseng and Andersen, 2011; Andersen, 2011; Andersen and Sandwell, 2012; Sandwell et al., 2013).

Stenseng and Andersen (2012) investigate three months, September to November 2010, of CryoSat-2 data from SAR L1b, LRM L1b and LRM L2 over the Baffin Bay (Figure 2). The L1b data has been retracked with three different retrackers and compared with an independent marine gravity dataset. From their first investigation it has found very promising results in the comparison with the mean sea surface for both LRM and SAR data, indicating that significant improvements in high-latitude marine gravity filed can be achieved. The inclusion of three months of CryoSat-2 data also improves the local gravity field compared with the ERS-1 derived benchmark gravity field.

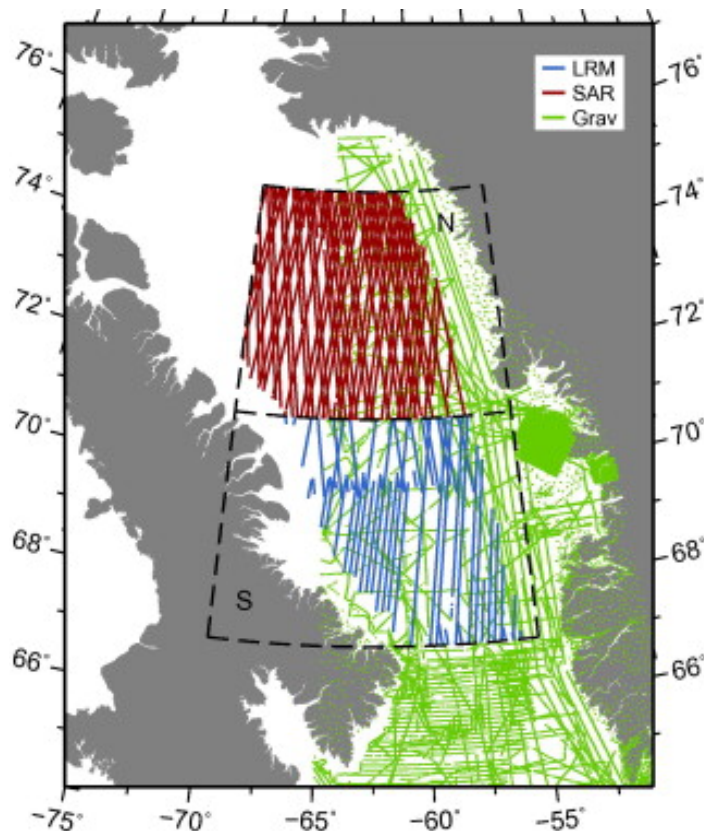


Figure 2: CryoSat-2 SAR (red), LRM (blue), and marine gravity (green) tracks in the Baffin Bay (Stenseng and Andersen, 2012).

Stenseng and Andersen (2012) also find that sea-ice and sea-ice debris are presented in the November SAR data, which increases the error on the residual geoid used for the gravity field calculation. A future editing scheme is planned to reject sea-ice contaminated data using SSMIS or equivalent data to avoid degradation of the derived sea surface and thereby the derived gravity field.

The National Chiao Tung University team, Taiwan, led by Hwang retracked waveforms from Geosat GM, ERS-1 GM, repeat Geosat/ERM, ERS-1/35d, ERS-2/35d and TOPEX/Poseidon. The results (Table 2) show that the sub-waveform threshold retracker (Yang et al. 2011) with a 20% of threshold value is the optimal retracker around the waters off Taiwan. Then, the inverse Vening Meinesz formula was used to compute gravity anomalies from along-track residual SSH slopes in a remove-compute-restore procedure with EGM2008 to degree 2190 as the reference field. Table 3 compares altimeter-derived gravity grids from Hwang's group (NCTU), Sandwell V18.1 and DTU10GRAV with ship-borne gravity around Taiwan (presented in EGU 2012). All models perform quite similarly, but The NCTU gravity performs slightly better than other models.

Table 2: Standard deviations of differenced SSHs (in m) around Taiwan using different retrackers

Data	Beta-5	Threshold <sup>a</sup>	sub-waveform threshold			
			0.1	0.2	0.3	0.5
Geosat/GM	0.0812	0.0742	0.0647	0.0633	0.0639	0.0745
ERS-1/GM	0.0805	0.0975	0.0523	0.0499	0.0531	0.0710

<sup>a</sup> full waveform and the threshold value equal to 0.5 are used

Sandwell et al. (2013) present a new global marine gravity field V21 based on all the available altimeter data. This includes the older Geosat GM and ERS-1 GM data that were used to construct the V18 global marine gravity widely used in the industry today (Sandwell and Smith, 2009), as well as newer Envisat, CryoSat-2 (until December 2012) and Jason-1 GM (until January 2013) data. The accuracy of the V21 gravity model is assessed through comparisons with industry-quality gravity data as well as lower quality data from the research cruises available at the National Geophysical Data Centre (NGDC). Through these comparisons it has demonstrated that the current accuracy is better than 1.6 mGal for latitudes less than 72 degrees and somewhat lower accuracy (2–3 mGal) at higher latitudes depending on ice cover. Finally based on this current analysis, the accuracy of altimeter-derived marine gravity in the year 2015, assuming Jason-1 and CryoSat-2 remain in operation, can be expected better than 1.4 mGal accuracy that is attainable in areas such as the Gulf of Mexico (Figure 3).

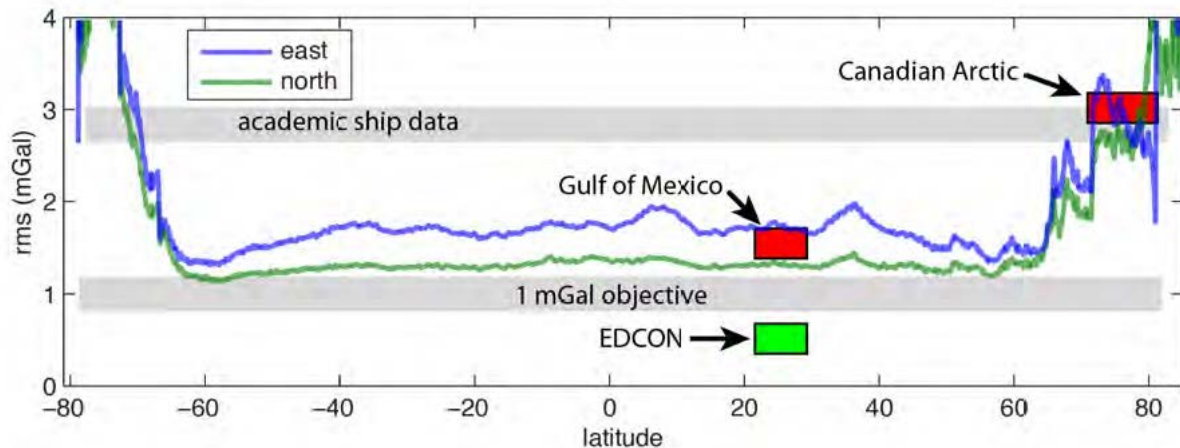


Figure 3: Jackknife estimate of the accuracy of the east (blue) and north (green) components of the marine gravity derived from satellite altimetry. Red boxes show the Gulf of Mexico and Canadian Arctic validations. Green box shows the precision of the EDCON gravity data. Marine gravity profiles collected by the academic fleet typically have gravity precision of 2.75 mGal. Our accuracy objective is 1 mGal. At latitudes less than 60° the north component of gravity is better determined than the east component because altimeter track-lines are preferentially oriented in the N-S direction. The availability of Jason-1 with its more E-W track orientation will continue to improve the accuracy of the gravity field, especially the east component. The steps in gravity accuracy at latitudes of 66°, 72°, and 81.5° reflect the sharp changes in track density associated with the maximum latitudes of the Jason-1, Geosat, and ERS-1/Envisat satellites, respectively (Sandwell et al., 2013).

Table 3: Statistics of differences (in mGal) between altimeter-derived and ship-borne gravity around Taiwan

Alt gravity	Max	Min	Mean	STD
NCTU12 <sup>a</sup>	83.771	-96.251	0.094	7.603
Sandwell V18.1	88.308	-110.160	0.263	7.745
DTU10	88.369	-100.649	0.385	7.624

<sup>a</sup> Altimeter-derived gravity from the National Chiao Tung University team

### Future Contributions

Before the next IUGG meeting (2015), we will continue to improve the retracking technique. Based on expected future data acquisitions, such as those from the Jason-1/GM and CryoSat-2 missions, and improved processing in the global geo-potential gravity field, we expect the accuracy of the marine gravity field to be better than 1.4 mGal.

### Some Publications

Andersen, O. B. and Y. Cheng (2013) Long term changes of altimeter range and geophysical corrections at altimetry calibration sites, *Advances in Space Research*, 51(8): 1468-1477.

Andersen O., and D. Sandwell (2012). Coastal and Arctic Marine Gravity from CryoSat-2 and Jason-1 Geodetic Mission Altimetry, 6th Coastal Altimetry Workshop, Riva Del Garda (Italy), 20-21 September 2012, available from <http://www.coastalt.eu/gardaworkshop12>

Andersen, O. B. (2011) Satellite altimetry for marine geodesy, in: Sanso et al. (eds.), *Geodesy*, Springer Verlag, Heidelberg.

Andersen, O. B., and R. Scharroo (2011), Range and geophysical corrections in coastal regions, in: Vignudelli S. Kostianoy A. and Cipollini P. (eds.), *Coastal Altimetry*, Springer, Berlin, Coastal altimetry, ISBN: 978-3-642-12795-3

- Cheng Y. and O.B. Andersen (2011), A new global ocean tide model and its improvements in shallow water and the Polar Regions, *J. Geophys. Res.* (submitted)
- Deng, X, O B Andersen, Y Cheng, M G Stewart, and Z Gharineiat (2012a) Integrated Mapping of Coastal Sea Level Using Altimetry and Tide Gauges for Monitoring Extreme Sea Levels, Proceedings of the 20 years of progress in radar altimetry symposium, Venice, Italy, 24-29 September 2012 (in press).
- Deng X., O. B. Andersen, Y. Cheng, M. G. Stewart and Z. Gharineiat (2012b). Estimation of extreme sea levels from altimetry and tide gauges at the coast, 6th Coastal Altimetry Workshop, Riva Del Garda (Italy), 20-21 September 2012, available from <http://www.coastalt.eu/gardaworkshop12>
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- Garcia, E., W. H. F. Smith, and D. T. Sandwell (2013) Retracking CryoSat-2, Envisat, and Jason-1 Radar Altimetry Waveforms for Improved Gravity Field Recovery, *Geophys. J. Int.* (Submitted in February 2013).
- Gommenginger, C, P. Thibaut, L. Fenoglio-Marc, X. Deng, J. Gomez-Enri Y. Gao (2011) Retracking altimeter waveforms near the coasts, in: Vignudelli S. Kostianoy A. and Cipollini P. (eds.), *Coastal Altimetry*, Springer, Berlin, DOI: 10.1007/978-3-642-12796-0\_4.
- Idris, N. H. and X. Deng (2012), The Retracking Technique on Multi-Peak and Quasi-Specular Waveforms for Jason-1 and Jason-2 Missions near the Coast. *Marine Geodesy*. 35(S1):217–237.
- Idris, N. H and X. Deng (2012) Coastal Waveform Retracking for Sea Surface Height Estimates: A Fuzzy Expert System Approach, Proceedings of the 20 years of progress in radar altimetry symposium, Venice, Italy, 24-29 September 2012 (in press).
- Lee, H.K., C.K. Shum, K.H. Tseng, Z. Huang, H.G. Sohn (2013) Elevation changes of Bering Glacier System, Alaska, from 1992 to 2010, observed by satellite radar altimetry, *Remote Sensing of Environment*, 132: 40-48.
- Sandwell, David, E. Garcia, K. Soofi, P. Wessel and W.H.F. Smith (2013) Towards 1 mGal Global Marine Gravity from CryoSat-2, Envisat, and Jason-1, *The Leading Edge* (submitted in March 2013).
- Stenseng, L. and O. B. Andersen (2012) Preliminary gravity recovery from CryoSat-2 data in the Baffin Bay, *Advances in Space Research*, 50(8): 1158-1163.

## **Sub-Commission 2.6: Gravity and Mass Displacements**

*Chair: Shuanggen Jin (China)*

Website: [http://202.127.29.4/geodesy/IAG\\_SC2.6/](http://202.127.29.4/geodesy/IAG_SC2.6/)

### *Steering Committee*

Chair: Shuanggen Jin (China)

Co-Chair: Jürgen Kusche (Germany)

Carla Braitenberg (Italy)

Annette Eicker (Germany)

Isabelle Panet (France)

Bert Wouters (UK/USA) (since 2013)

Séverine Rosat (France)

### **Activities**

The Sub-commission established Work Groups and Study Groups on relevant topics. It models and inverts gravity-Earth System coupling, structure and dynamics of the Earth's interior and their interactions. A Steering Committee works closely with members and other IAG Commissions/Sub-Commissions to obtain the mutual goals. Also it promotes and jointly sponsors special sessions at IAG Symposia and other workshops/conferences.

### *Established Working Groups by SC 2.6*

JWG 2.5: Physics and dynamics of the Earth's interior from gravimetry (joint with Comm. 3); Chair: Isabelle Panet (France)

JWG 2.6: Ice melting & ocean circulation from gravimetry (joint with Comm. 3); Chair until 2013: Jens Schröter (Germany); Chair since 2013: Bert Wouters (UK/USA)

JWG 2.7: Land hydrology from gravimetry (joint with Comm. 3) Chair: Annette Eicker (Germany)

JWG 2.8: Modeling and Inversion of Gravity-Solid Earth Coupling (joint with Comm. 3); Chair: Carla Braitenberg (Italy)

### *Established Study Groups by SC 2.6*

JSG 0.8: Earth System Interaction from Space Geodesy (joint with the ICCT, description see ICCT); Chair: Shuanggen Jin (China)

JSG 3.1: Gravity and height change intercomparison (joint with IGFS, Comm. 1, Comm. 3, description see Commission 3); Chair: S. Rosat (France)

### *Special Issue of Journal of Geodynamics*

SC 2.6 organized a Special Issue of the Journal of Geodynamics on "Earth System Observing and Modelling from Space Geodesy". This special issue focuses on assessing current technological capabilities and presenting recent results of space geodetic observations and understanding the physical processes and coupling in the Earth system, and future impacts on climate. Topics include data retrieval of space geodetic techniques, reference frame, atmospheric-ionospheric sounding and disturbance, gravity field, crustal deformation and earth-

quake geodesy, GIA, Earth rotation, hydrological cycle, ocean circulation, sea level change, and ice sheet mass balance as well as their coupling in the Earth system. This special issue consists not only of papers given at the International Symposium on Space Geodesy and Earth System (2012, Shanghai) but also includes other contributions on this topic that were submitted in response to an open call for contributions. All related papers are welcome to submit to Special issue of Journal of Geodynamics on "Earth System Observing and Modelling from Space Geodesy" via <http://ees.elsevier.com/geod>. To ensure that all manuscripts are correctly identified for inclusion into the special issue, authors must select "SI: Geodetic Earth System" when they reach the "Article Type" step in the submission process. Guest editors: Prof. Shuanggen Jin, Shanghai Astronomical Observatory, CAS, Shanghai, China; A/Prof. Tonie van Dam, University of Luxembourg, Luxembourg; Dr. Shimon Wdowinski, University of Miami, Miami, USA.

### *Academic Activities*

- 1-4 July 2013, Shuanggen Jin organized the International Symposium on Planetary Sciences (IAPS2013) as Co-Chair of the Symposium, Shanghai, China.
- 5-7 July 2013, Shuanggen Jin organized International Summer School on Planetary Geodesy and Remote Sensing and gave a half-day lecture on Planetary Geodesy and Science, Shanghai, China.
- 12 December 2012, Shuanggen Jin, Per Knudsen and Ole Andersen co-organized SHAO-DTU Workshop on Space Geodesy and discussed future possible collaboration, Shanghai, China
- 18-21 August 2012, Shuanggen Jin organized International Symposium on Space Geodesy and Earth System (SGES2012) as Chair of Symposium, Shanghai, China.
- 21-25 August 2012, Shuanggen Jin organized International Summer School on Space Geodesy and Earth System and gave a half-day lecture on GNSS and Gravity Geodesy, Shanghai, China.
- 13-17 August 2012, Shuanggen Jin attended the AOGS-AGU (WPGM) Joint Assembly with convening two sessions and giving one talk, Singapore
- 08-16 August 2011, Shuanggen Jin Convene one Session at Asia Oceania Geosciences Society (AOGS 2011) with one talk, Taiwan.
- 10-18 November 2011, Shuanggen Jin was invited to visit and give several talks at Taiwan National Chiao Tung University, National Cheng Kung University, National Central University and Institute of Earth Sciences, Academia Sinica, Taiwan.

### **Publications**

- Jin, S.G., and G. Feng (2013), Large-scale variations of global groundwater from satellite gravimetry and hydrological models, 2002-2012, *Global Planet. Change*, 106, 20-30, doi: 10.1016/j.gloplacha.2013.02.008.
- Wei, E., W. Yan, S.G. Jin, J. Liu, and J. Cai (2013), Improvement of Earth orientation parameters estimate with Chang'E-1  $\Delta$ VLBI Observations, *J. Geodyn.*, doi: 10.1016/j.jog.2013.04.001.
- Feng, G., S.G. Jin, and T. Zhang (2013), Coastal sea level changes in the Europe from GPS, Tide Gauge, Satellite Altimetry and GRACE, 1993-2011, *Adv. Space Res.*, 51(6), 1019-1028, doi: 10.1016/j.asr.2012.09.011.
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- Zhang, L., S.G. Jin, and T. Zhang (2012), Seasonal variations of Earth's surface loading deformation estimated from GPS and satellite gravimetry, *J. Geod. Geodyn.*, 32(2), 32-38.
- Sanchez-Reales, J., M. Vigo, S.G. Jin, and B. Chao (2012), Global surface geostrophic currents of ocean derived from satellite altimetry and GOCE geoid, *Mar. Geod.*, 35(S1), 175-189, doi: 10.1080/01490419.2012.718696.

Jin, S.G., and X. Zhang (2012), Variations and geophysical excitation of Earth's dynamic oblateness estimated from GPS, OBP, and GRACE, *Chin. Sci. Bull.*, 57(36), 3484-3492, doi: 10.1360/972011-1934.

Jin, S.G., Lijun Zhang, and B. Tapley (2011), The understanding of length-of-day variations from satellite gravity and laser ranging measurements, *Geophys. J. Int.*, 184(2), 651-660, doi: 10.1111/j.1365-246X.2010.04869.x.

## Conference Presentations

Jin, S.G., and F. Zou, Recent melting of Greenland's glaciers observed by InSAR and satellite gravimetry, *Proceeding of Progress In Electromagnetics Research Symposium (PIERS)*, 12-15 August, 2013, Stockholm, Sweden.

Feng, G., S.G. Jin, and F. Zou, Melting of ice-sheet in the Tien-Shan Mountains observed by satellite gravity measurements, *International Conference on Geoinformatics*, June 20-22, 2013, Kaifeng, China.

Jin, S.G., Y. Barkin, and W. Shen, Observation evidences on the northward drift of the Earth's core from space geodesy, *Japan Geoscience Union Meeting*, May 19-24, 2013, Makuhari Messe, Japan.

Hassan, A., and S.G. Jin, Water cycle and climate signals in Africa observed by satellite gravimetry, *Proceeding of the 35th International Symposium on Remote Sensing of Environment (ISRSE35)*, April 22-26, 2013, Beijing, China.

Jin, S.G., and G.P. Feng, Glacier melting in Tibet observed from satellite gravity measurement, *International Conference on Cryosphere: Changes, Impacts and Adaptation*, November 10-12, 2012, Sanya, China.

Jin, S.G., Observing and understanding the Earth system from space, *Redbud Forum on Global Change Science*, Tsinghua University, November 1, 2012, Beijing, China.

Jin, S.G., and G.P. Feng, Interannual variations of glacier melting in the Antarctic from satellite gravimetry, *Annual Conference of China Polar Science*, October 24-27, 2012, Hangzhou, China.

Feng, G., S.G. Jin, and J. Sanchez Reales, Antarctic circumpolar currents from satellite altimetry and GOCE, *Annual Conference of China Polar Science*, October 24-27, 2012, Hangzhou, China.

Jin, S.G., and G.P. Feng, Global groundwater changes and trends observed by satellite gravimetry, *International Symposium on Gravity, Geoid and Height Systems*, October 9-12, 2012, Venice, Italy

Zhang, T., and S.G. Jin, Glacial isostatic adjustment observed by GRACE, InsAR and GPS measurements, *Proceeding of Chinese Geophysical Society (CGS) Annual Meeting*, October 17-20, 2012, Beijing, China, p.655.

Jin, S.G., Space Geodesy: A window to the Earth Science, *Proceeding of Chinese Geophysical Society (CGS) Annual Meeting*, October 17-20, 2012, Beijing, China, pp.24-25.

Jin, S.G., What can Space Geodesy do? Recent Results and Challenges, *Forum on Geomatics Science and technology*, 12-14 October 2012, Lanzhou, China

Jin, S.G., and X.G. Zhang, Excitations of length-of-day variations determined from GPS, SLR and GRACE, *IAU XXVIII General Assembly*, 20-31 August, 2012, Beijing, China, pp.

Zhang, T., and S.G. Jin, Evaluation of glacial isostatic adjustment uplift rates in the Tibetan Plateau from satellite gravimetry, *International Symposium on Space Geodesy and Earth System*, August 18-20, 2012, Shanghai, China.

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Jin, S.G., Low degree gravitational changes and large scale mass transport from GPS, SLR and GRACE, *International Symposium on Space Geodesy and Earth System*, Aug. 18-20, 2012, Shanghai, China.

Hassan, A., and S.G. Jin, GRACE detection of water storage variation in Africa and its response to climate events, *Proceeding of International Symposium on Space Geodesy and Earth System*, Aug. 18-20, 2012, Shanghai, China, pp.

Jin, S.G., and L. Zhang, Seasonal and secular variation of hydrological loading displacements from GPS, GRACE and models, *AOGS-AGU (WPGM) Joint Assembly*, 13-17 August, 2012, Singapore. (Invited)

Jin, S.G., Variations of Earth's dynamic oblateness detected by GPS, OBP, and GRACE, *AOGS-AGU (WPGM) Joint Assembly*, 13-17 August, 2012, Singapore.

Jin, S.G., The Art of Space Geodesy: Recent Results and Challenge, Seminar at the Deutsches Geodätisches Forschungsinstitut (DGFI), 27 July 2012, Munich, Germany.

Jin, S.G., GNSS Atmospheric Seismology: A case study of the 2008 Mw7.9 Wenchuan Earthquake, Proceeding of IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 22-27 July 2012, Munich, Germany, pp. 7504-7507, doi: 10.1109/IGARSS.2012.6351896.

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Zhang, L., S.G. Jin, and G. Feng, Estimate of vertical water loading deformation from GPS, GRACE and hydrological models, Proceeding of Chinese Geophysical Society (CGS) Annual Meeting, October 18-21, 2011, Changsha, China, pp.861-862.

Sánchez-Reales, J., I. Vigo, S.G. Jin, and B. Chao, Global Surface Geostrophic Currents Derived from Satellite Ocean Altimetry and a GOCE Geoid, AGU Fall Meeting, 5-9 December 2011, San Francisco, CA, USA, Abstract #G43A-0757.

Zhang, L., S.G. Jin, and G. Feng, Effects of water loading deformation on GPS coordinates from GRACE and models, International Workshop on GNSS Remote Sensing for Future Sciences and Missions, August 7-9, 2011, Shanghai, China, pp.

Jin, S.G., V. Demyanov, R. Jin, GNSS seismo-ionospheric disturbances: Recent earthquakes observations and implications, International Workshop on GNSS Remote Sensing for Future Sciences and Missions, August 7-9, 2011, Shanghai, China, pp.

Feng, G., S.G. Jin, and L. Zhang, Hydrological cycle from GPS and GRACE measurements: Results and problems, International Workshop on GNSS Remote Sensing for Future Sciences and Missions, August 7-9, 2011, Shanghai, China.



## Joint Project 2.1: Geodetic Planetology

*Chairs: Oliver Baur (Austria), Shin-Chan Han (USA)*

### Activities and results until now

#### *Meetings*

Conference sessions on geodetic planetology (co-)organized by the joint project are summarized in Table 1. In preparation for GGHS, we (the project chairs) put considerable effort to motivate both the project members and other scientists for session contributions. The GGHS session 'reanimated' geodetic planetology within IAG conferences. The IAPS is mainly organized by Shuanggen Jin.

Table 1: Conference sessions dedicated to geodetic planetology and (co-)organized by the project chairs

Conference	Session	# presentations oral/poster
International Symposium on Gravity, Geoid and Height Systems (GGHS), Venice, Italy	Gravity Field of Planetary Bodies	4 / 1
International Symposium on Planetary Sciences (IAPS), Shanghai, China	Science and Exploration of the Moon	12 / 1

#### *Publications*

Peer-reviewed proceedings papers by project members include

Visser P.N.A.M. (2013) Observing the gravity field of different planets and moons by space-borne techniques: predictions by fast error propagation tools, IAG Symp. 141, accepted

Maier A., Baur O. (2013) Sensitivity of simulated LRO tracking data to the lunar gravity field, IAG Symp. 141, accepted

Peer-reviewed journal papers by project members include

Ardalan A.A., Karimi R., Grafarend E.W. (2010) A new reference equipotential surface, and reference ellipsoid for the planet Mars. *Earth Moon Planets* 106: 1-13

Mazarico E., Lemoine F., Han S.-C., Smith D.E. (2010) GLGM-3, A degree 150 lunar gravity model from the historical tracking data of NASA moon orbiters. *J. Geophys. Res.* 115, E05001

Han S.-C., Mazarico E., Rowlands D., Lemoine F., Goossens S. (2011) New analysis of Lunar Prospector radio tracking data brings the nearside gravity field of the Moon with an unprecedented resolution. *Icarus* 215: 455-459

Hirt C., Claessens S.J., Kuhn M., Featherstone W.E. (2012) Kilometer-resolution gravity field of Mars: MGM2011. *Planet. Space Sci.* 67: 147-154

Hirt C., Featherstone W.E. (2012) A 1.5 km-resolution gravity field model of the Moon. *Earth Planet. Sci. Lett.* 329-330: 22-30

Jin S., Arivazhagan S., Araki H. (2013) New results and questions of lunar exploration from SELENE, Chang'E-1, Chandrayaan-1 and LRO/LCROSS. *Adv. Space Res.* 52: 285-305

## Results

The GRAIL (Gravity Recovery And Interior Laboratory) mission can be considered as the present 'highlight' in geodetic planetology. The science data allows estimating the lunar gravity field (Fig. 1) with highly improved accuracy and resolution compared to previous missions. Knowledge about the gravity field will upgrade our understanding of the interior structure and thermal evolution of the Moon. The global gravity field model from the primary mission yielded nearly unity correlation with topography to degree and order 300 and indicated considerably smaller density of the crust such as  $2550 \text{ kg/m}^3$  with lateral variation of  $250 \text{ kg/m}^3$ . Since June 12, 2013, the primary and extended mission LIB data are publicly available.

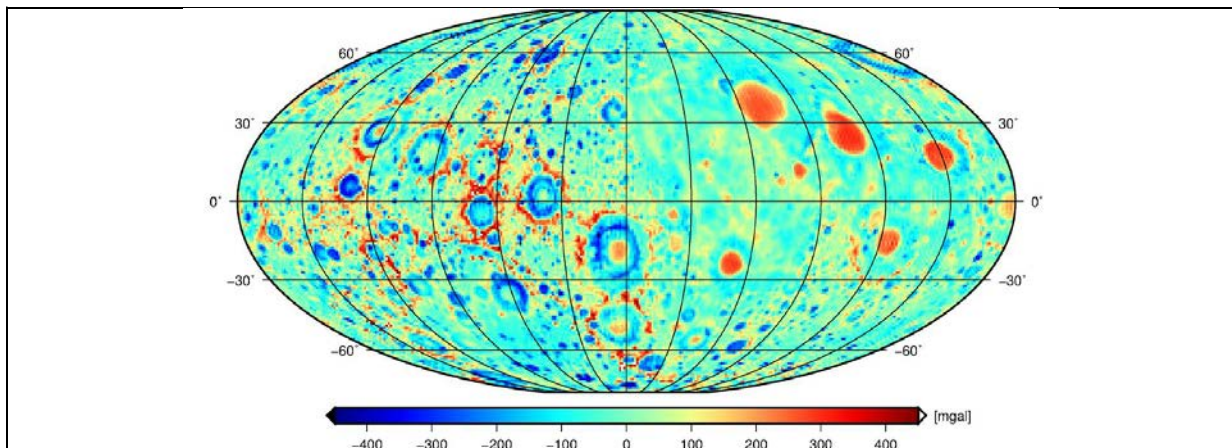


Figure 1: Lunar free-air anomalies from GRAIL (up to spherical harmonic degree and order 200) based on data collected during the primary mission phase; figure taken from Klinger B., Baur O., Mayer-Gürr T., Yan J. (2013) Lunar gravity field recovery: GRAIL simulations and real data analysis, EGU General Assembly, Vienna, Austria, 7.-12.04.2013

## Activities in the next two years

During the first two years of the joint project it turned out that enormous effort is required to motivate scientists to actively support and contribute to the project. Although several attempts have been undertaken to cooperate with scientists from GSFC/JPL (for instance, invitation to conference talks), the enquiries were not fruitful. As such, unfortunately, we made similar experience as made during the establishment of the project (list of members).

For the time being it remains unclear how the joint project should be continued. According to the ToR, we initially planned to organize a workshop with interdisciplinary emphasis. Against the background of the experience made during the last two years, we decided to abandon this intent. Moreover, the objective to "establish an Inter-Commission Committee on Geodetic Planetology for the period 2015-2019" (ToR) is likely to be revised.

## **Joint Working Group 2.1: Techniques and Metrology in Absolute Gravimetry**

*Chair: Vojtech Palinkas (Czech Republic)*

### **Primary Objectives**

The IAG Joint Working Group 2.1 (JWG 2.1) focuses on the technical and metrological aspects in absolute gravimetry and the realization an appropriate system of comparisons of absolute gravimeters to fulfil requirements especially in geodesy. JWG 2.1 works in cooperation with the “Joint Working Group 2.2: Absolute Gravimetry and Absolute Gravity Reference System” (JWG 2.2) and the “Working Group on Gravimetry of Consultative Committee for Mass and Related Quantities of International Committee of Weights and Measures” (CCM-WGG).

### **Main Activities (2011-2013)**

This section presents the intermediate report of the JWG 2.1 activities since its creation in 2011. During the period 2011-2013 the JWG 2.1 established its terms of reference, held one official meeting and contributed on realization of comparisons of absolute gravimeters.

#### *Meeting in Vienna 2012*

The discussion Meeting on Absolute Gravimetry, organized as a joint meeting of JWG 2.1 and JWG 2.2, was held in Vienna in February 2012. The meeting covered the following major topics related to the work of JWG 2.1:

- *Treatment of systematic effects in absolute gravity determination:* The scientific results of three systematic effects (self-attraction, diffraction, and finite speed of light) were presented by several authors related to papers of Biolcatti et al. (2012), Palinkas et. al. (2012), Rothleitner and Svitlov (2012), Rothleitner and Francis (2011), Nagorny et al. (2011). Important results of this meeting are recommendations concerning implementations of corrections to absolute measurements, which were consequently followed by processing of comparisons in 2009 (Jiang et al. 2012) and 2011 (Francis et al. 2013).
- *Determination of reference instrumental height.* Unclearness connected with the position where the gravity is determined as invariant of the vertical gravity gradient, causes several troubles with practical determination and application of measured gravity acceleration. The concept of the effective position of the free-fall was reintroduced at the meeting. Two publications (Rothleitner and Svitlov 2012, Palinkas et. al. 2012) are related to this topic.
- *International and Regional Comparisons of absolute gravimeters (ICAG and RCAG).* (a) The final results of ICAG-2009 were presented and discussed. The paper Jiang et al. (2012) were consequently prepared and published. (b) Preliminary results of European comparison held in Walferdange (ECAG-2011) were presented. The final results were recently published in Francis et al. (2013). (c) The Technical Protocol goes through continuous developments with each new regional and international comparison. (d) The function of the “comparison site requirements” document was discussed. The text was distributed to the members of JWG 2.1 and CCM-WGG. The final document was consequently prepared, named “Guide to evaluation of the sites for comparison of absolute gravimeters”, and approved by CCM-WGG. (e) The working groups JWG 2.1 and JWG 2.2 agreed with the present periodicity of comparisons, four-yearly ICAGs with intermediate RCAGs two years after the ICAG.

- *Reference gravity stations.* The capability of the reference stations with a superconducting gravimeter for an AG offset check was demonstrated. The reference stations should play a key role for validation of absolute gravimeters used in geodesy.

#### *Comparisons of absolute gravimeters*

In November 2011, the third European Comparison of Absolute Gravimeters (ECAG) was held in Walferdange. It was organized by the University of Luxembourg (O. Francis) and METAS (H. Baumann) as metrological Key Comparison EURAMET.M.G-K1. Twenty-two absolute gravimeters participated of which results were processed in two groups: 1) comparison of six teams coming from National Metrology Institutes (NMIs) and Designated Institutes (DIs), 2) common adjustment of all the gravimeters. Excellent results (as in previous comparisons in Walferdange and Sevres) were obtained for the second group with reference gravity values at standard uncertainty of 1.5  $\mu\text{Gal}$  (Francis et al. 2013). For the first time the influence of the geophysical gravity changes during the comparison has been implemented to the results of comparison.

#### *Cooperation with CCM-WGG*

Nine members of JWG 2.1 are also members of CCM-WGG of the BIPM. Both groups have several common goals, especially those connected with comparisons of absolute gravimeters. Activities as organization of comparisons, discussion concerning methodology of data processing etc. have been arranged in the period 2011-2013 within CCM-WGG meetings (Istanbul 2012, Paris 2013), because the comparisons have official metrological status at present.

#### **Future Activities (2013-2015)**

The future activities significantly depend on the final version of the strategic document “CCM-IAG strategy for gravimetry” of which draft was prepared by CCM President and commented by CCM-WGG members. It was proposed by chairmen of JWG 2.2 to include members of JWG 2.1 and 2.2 into the discussion. The draft of strategy, supported by CCM-President and the minority of CCM-WGG members, is aiming to establish a typical traceability path in gravimetry. This effort is needed for practical applications in gravimetry but it might have significant consequences to the geodetic community. The strategy is aiming to organize comparison only for NMIs and DIs. It is expected that the majority of gravimeters from geodesy community will calibrate their instruments against the national standards. This idea is generally not wrong and works in many fields of our life. However, NMIs and DIs currently do not have more accurate gravimeters or more sophisticated operators as it can be seen from results of comparisons in the past. Thus the future organization of metrological support of absolute gravimetry should be carefully discussed by both metrology and geodesy communities and the agreement should be reached on the ways on how to reach the confidence in gravity measurements.

In the near future, JWG 2.1 has to discuss the data processing of comparisons: 1) the construction of constraint condition within the least-square adjustment, 2) the construction of non-diagonal covariance matrix of the observation equations for solving the correlations between results of a particular gravimeter and type of gravimeters. JWG 2.1 in cooperation with JWG 2.2 have to prepare and present the existing reference stations (equipped with superconducting gravimeters and connected to the system of comparison by means of repeated absolute gravity measurements) to the wide geodetic community as a solution for practical purposes in geodesy – verification or determination of biases of absolute gravi-

meters. This effort might be done in cooperation with the former Global Geodynamic Project (GGP) which willing to be transformed into an IAG service.

## **Publications**

Biolcati E, Svitlov S, Germak A (2012). Self-attraction effect and correction on three absolute gravimeters, *Metrologia*, 49, 560–566.

Francis O et al. (2013). The European Comparison of Absolute Gravimeters 2011 (ECAG-2011) in Walferdange, Luxembourg: results and recommendations. *Metrologia*, 50, 257-268.

Jiang Z et al. (2012). The 8th International Comparison of Absolute Gravimeters 2009: the first Key Comparison (CCM.G-K1) in the field of absolute gravimetry, *Metrologia*, 49, 666–684.

Nagorny V D, Zanimonskiy Y M and Zanimonskiy Y Y (2011). Relativity, Doppler shifts and retarded times in deriving the correction for the finite speed of light: a comment on 'Second-order Doppler-shift corrections in free-fall absolute gravimeters', *Metrologia*, 48, 437-441.

Pálinkáš V, Liard J and Jiang Z (2012). On the effective position of the free-fall solution and the self-attraction effect of the FG5 gravimeters, *Metrologia*, 49, 552-559.

Rothleitner Ch and Francis O (2011). Second-order Doppler-shift corrections in free-fall absolute gravimeters, *Metrologia*, 48, 187-195.

Rothleitner Ch and Svitlov S (2012). On the evaluation of systematic effects in atom and corner-cube absolute gravimeters, *Phys. Lett. A*, 376, 1090–5.

## **Joint Working Group 2.2: Absolute Gravimetry and Absolute Gravity Reference Systems**

*Chair: Herbert Wilmes (Germany)*

### **Overview**

JWG 2.2 “Absolute Gravimetry and Absolute Gravity Reference System” is a part of IAG Sub-Commission 2.1 “Gravimetry and Gravity Networks” and joint with the International Gravity Field Service<sup>6</sup>, one of the permanent services of IAG. A close link is drawn also to the metrological community, especially to the “International Committee of Weights and Measures”<sup>7</sup> and to the “Working Group on Gravimetry of the Consultative Committee on Mass and Related Quantities”. This reflects the strong requirement to ensure the consistency of the absolute gravity measurements with the international metrological standards and with the SI quantities (International System of Units).

### **Motivation**

Geodesy requires long-term available geodetic reference systems for the establishment and control of its gravity reference networks and for deduced data products like improved Geoid models for precise height system realisation. Further questions related to environmental changes need to be answered which are related to the expected sea level and ground water changes, the melting of ice covers in form of glaciers and larger ice sheets, or to reaching a better understanding of the physical processes behind tectonic plates deformation. This requires improving the accuracy and robustness of the global geodetic reference frame.

### **Workshop 2012**

In 2012 a workshop has been organised cooperatively by JWG 2.1 and JWG 2.2 “Techniques and Metrology in Absolute Gravimetry” getting together experts from absolute gravimetry within the IAG community and also members of institutions responsible for metrological and calibration practices in gravimetry on national and international level. The workshop focussed on the continuation and further development of absolute gravity comparisons and on the benefit which the comparison stations can provide for the advancement of a future gravity reference system. An important aspect was the development of the technical protocol of future comparisons which shall fulfil the requirements and strategies of both, the metrological and the geodetic communities.

### **Absolute gravity database AGrav**

An important contribution of the working group to the activities of the international community of absolute gravimeter users is the development, improvement and operation of the AGrav database which is now jointly operated by the Federal Agency for Cartography and Geodesy (BKG), Germany and the International Gravimetric Bureau (BGI). The database runs on two mirrored servers with web-based frontend located at BGI: <http://bgi.dtp.obs-mip.fr/agrav-meta/> and at BKG: <http://agrav.bkg.bund.de/agrav-meta/>. This database now acts as the official BGI AG database. The continuously increasing number of participating institutions, instruments and observations reflect the growing acceptance and use of the database on international level. By June 2013 the number of participating institutions has reached 41,

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<sup>6</sup> cf. IGFS – <http://www.igfs.net/>

<sup>7</sup> cf. CIPM – <http://www.bipm.org/en/committees/>

global stations 760 and stored absolute measurements 2560. This includes metadata and full results (cf. Fig. 1).

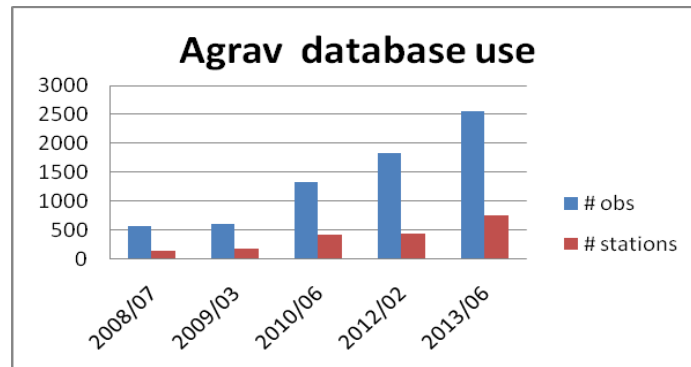


Figure 1: Increasing acceptance of the AGrav database

Further effort was invested in the development of improved or new functions of the database, like an optimized user interface, the replacement of earlier commercial map products by OSM graphical data (OpenStreetMap) and the handling of time series into the database. In future it will be possible to display time series of repeated absolute gravity measurements which is helpful for judging the stability of a reference station or for checking the reliability of instruments and for comparing gravimeters and measurement results.

A new data type has been included in the database for time series of superconducting gravimeters operating at gravity reference stations.



Figure 2: New design of the AGrav web interface 2013

## **Steps to a consistent global reference system**

Recent comparisons of absolute gravimeters included continuous superconducting gravity measurements at the comparison sites. These additional observations allow determining and reducing gravity variations during the comparison period by providing a comparison reference function. Such successful experiments have been carried out in the regional comparisons 2010 and 2013 in Wettzell (Germany) and during the European comparison 2011 in Walferdange (Luxembourg). Another AG comparison should be mentioned here which has been conducted at Table Mountain Gravity Observatory in Boulder (USA) which focussed upon the AG instruments in North America in 2010. A participation of additional AG instruments from other continents and from other regional comparisons supports the transfer of comparison results and contributes to the realisation a global gravity standard. In 2013, a repetition of the comparisons in Boulder and Walferdange are in preparation.

The connection between the comparisons at distributed sites and the set of reliably operating gravity reference stations are the condition for the realisation of a consistent global reference system. Gravity variations can be bridged with high resolution Superconducting gravimeter time series and repeated AG observations between the comparison events and by this complete the system in the time domain.

## **Cooperation with the new GGP-ICET Service of IAG**

Several groups operating AG instruments carry out repeated measurements at the sites of the network of superconducting gravimeters. The chair persons of the new GGP-ICET Service project have asked the community of AG owners to contribute with repeated AG measurements for the determination of SG instrumental drift parameters and calibration factors. It is planned to support this request using the AGrav database.

## **Cooperation with the metrological community**

This working group supports the cooperation of the institutions which are responsible for geodetic and metrological reference measurements and calibrations. In this context we look back to a very successful period of four-yearly AG comparisons hosted by the BIPM. Also in the future, comparisons are necessary and shall be continued. Only in a cooperation where the best instrumental standards from metrology and geodesy can participate in the comparisons, we shall be able to maintain the global metrological and geodetic gravity standard with highest accuracy, which is a precondition for the realisation of a consistent and precise global gravity reference frame.

## **Continuation of the work**

As mentioned above, the standardisation of AG observations and its evaluation are an important condition for providing consistent and robust results.

In the following period the working group will need to focus upon the agreement of the necessary standards and the establishment of the new International Gravity Reference System based upon distributed AG comparison sites and with the aim to replace IGSN71.

Another challenge will be to fulfil the requirement of GGOS to combine absolute gravity data with geometric observations.



## **Joint Working Group 2.3: Assessment of GOCE Geopotential Models**

*Chairs: Jianliang Huang (Canada), Christopher Kotsakis (Greece)*

### **Presentations and discussions at GGHS2012**

There were about 19 presentations/posters from members on assessment of GRACE and GOCE models in various sessions, most of them in Session II (13). These assessments indicated that the third releases of GOCE and GOCE&GRACE-based satellite models showed improvement over previous releases. They suggested that recent GOCE models had an accuracy of 3-5 cm for the baseline of about 100 km.

Some discussions were held between a few members and chairs on publication of the special issue of Newton's Bulletin. Based on these discussions, it was proposed that the JWG published all assessment reports in the special issue of NB after the Release 4 models were made available so that all reports could reflect the best and final quality of GOCE models. A tentative deadline for submitting a manuscript was set as the end of 2013 after the IAG2013. The JWG targeted to publish the special issue of NB by the end of March, 2014. Members may choose to publish their assessment results in other scientific journals and proceedings. These reports may not be suitable for the special issue of NB if no significant new results are added.

Another initiative is synthesizing assessments from publications (not limited to those in the special NB) into one or a few papers, and publishes them as either an ESA report or journal papers. To achieve this objective, the JWG needs to form a few topic groups. Further discussions on this issue will resume in the upcoming IAG 2013 in Potsdam, Germany.

### **Highlights from members**

Christopher Jekeli et al (2013) have determined for the Bolivian Andes that the new global gravity models derived from GOCE may be used directly to study lithospheric structure. A numerical comparison of the spherical harmonic models to conventional three-dimensional modelling based on topographic data and newly acquired surface gravity data in Bolivia confirmed their suitability for lithospheric interpretation. Specifically, the relatively high and uniform resolution of the satellite gravitational model (better than 83 km) produces detailed maps of the isostatic anomaly that clearly delineate the flexure of the Brazilian shield that is thrust under the Sub-Andes. Inferred values of the thickness of Airy-type roots and the flexural rigidity of the elastic lithosphere agree reasonably with published results based on seismic and surface gravity data. In addition, the GOCE model generates high resolution isostatic anomaly maps that offer additional structural detail not seen as clearly from previous seismic and gravity investigations in this region.

Heiner Denker et al. concentrated on the use of the GOCE global geopotential models, which were first evaluated by the existing terrestrial gravity field data sets, showing that the GOCE models improved from release to release with the inclusion of longer observation time series. The agreement between the release 3 GOCE models and terrestrial data up to degree and order 200 is about 5.5 cm for height anomalies, 1.7 mGal for gravity anomalies, and 0.55" for vertical deflections, respectively, being fully compatible with the relevant error estimates. So far, the combination solutions based on GOCE and terrestrial data mostly perform similar to corresponding calculations relying on EGM2008, which is due to the high quality of the European data sets utilized in the EGM2008 development; however, in selected areas with known weaknesses in the terrestrial gravity data (e.g., Bulgaria, Romania), the inclusion of

the GOCE models instead of EGM2008 leads to some improvements in terms of GPS/leveling fits. Most of the GOCE investigations were carried out in the framework of the REAL GOCE project funded by the German Ministry of Education and Research (BMBF) and the German Research Foundation (DFG); for further details see Ihde et al. (2010) as well as Voigt and Denker (2011 and 2013).

Pavel Novák et al. compared gravitational gradients observed by the GOCE gradiometer to gradients forward modelled from mass components/layers of the CRUST2.0 model and to gradients computed from ground and satellite altimetry-derived gravity data. Within the ESA's STSE project GOCE-GDC, main results of these studies will be reported to ESA by the end of August 2013.

For the geoid as well as for geopotential models the most common way to analyse their quality and consistency is to compare with GPS observations on Bench Marks of the spirit leveling network (GPS/BM). Due to a PhD thesis developed at the University of São Paulo, Laboratory of Surveying and Geodesy (LTG), an effort for many different comparisons was undertaken. Looking to the RMS difference the conclusion is that we are below half meter in the state of São Paulo and surrounding areas.

Hussein Abd-Elmotaal et al. have examined GOCE models for both Egypt and Africa in the frame work of the African Geoid Project (<http://www.minia.edu.eg/Geodesy/AFRgeo>).

During the period 20011-2013, BENAHMED DAHO Sid Ahmed focused on the evaluation of the performances of the latest GOCE-based GGMs models. The terrestrial gravity data over Algeria supplied by BGI and new set of GPS/leveling-derived geoid heights were used as ground-truth data sets for the new GOCE-based GGMs evaluation. Analysis of the root mean square (RMS) residuals between the terrestrial data sets and spectrally enhanced GGM functionals showed that the GOCE-based models improved knowledge in the spectral bands ~160 to ~180 for with respect to GRACE. Furthermore, when analyzing the results obtained with the high-quality GPS/levelling data, it can be concluded that the global geoid accuracy is at the level of 9 cm at degree and order 180. It is about to 5 to 6 cm if we take into account the error level of the GPS/levelling data. This indicates that the objectives of mission have not been reached yet.

As a member of the European GOCE Gravity Consortium EGG-C and ESA's GOCE High Level Processing Facility GOCE-HPF, Christoph Foerste routinely assesses and evaluates all global GOCE gravity field models including GOCE models which were jointly generated by GFZ Potsdam and CNES/GRGS Toulouse.

Jaroslav Klokocnik et al. focused on the inversion from kinematic orbits of GRACE and GOCE to the parameters of the gravity field of the Earth and their time variations and on experimental application of EGM 2008 in geomorphology, using the gravity disturbances, Marussi tensor, the gravity invariants and their various combinations as well as newly defined virtual deformations in selected areas of the Earth.

Nikolaos N Pavlis has been doing various comparisons with the GOCE models, as those become available. He plans to continue performing these tests and comparisons in the future, and will show the results at some meeting, or for possible publication.

C Hwang and HJ Hsu use gravity data and GPS-levelling data in Taiwan (Figure 1; the GPS-levelling data are on the first-order benchmarks with distinct line patterns in Figure 1) to

assess the GOCE-Tim3 and –Tim4 models, which are independent of all terrestrial data. The omission error is reduced by using the EGM2008 high degree terms and we remove the residual terrain effect. Figure 2 shows that GOCE-TIM4 has a reliable degree to 220, compared with degree 180 for GOCE-TIM3. GOCE-TIM4 uses ~26.5 months of mission data, whereas GOCE-TIM3 uses only ~12 months of data. In conclusion, the best harmonic expansion degree for the GOCE-TIM4 model is 220.

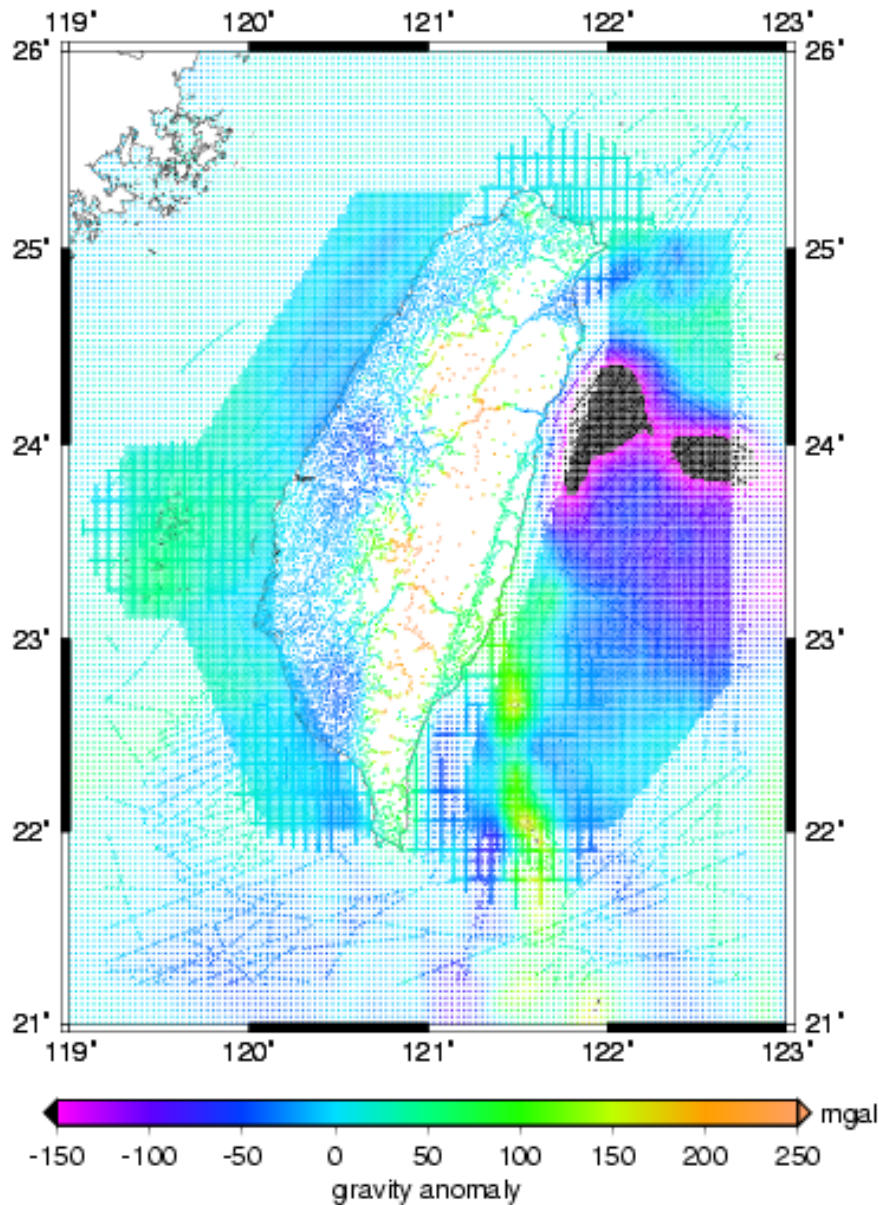


Figure 1: Marine and land data used to assess GOCE model (V4)

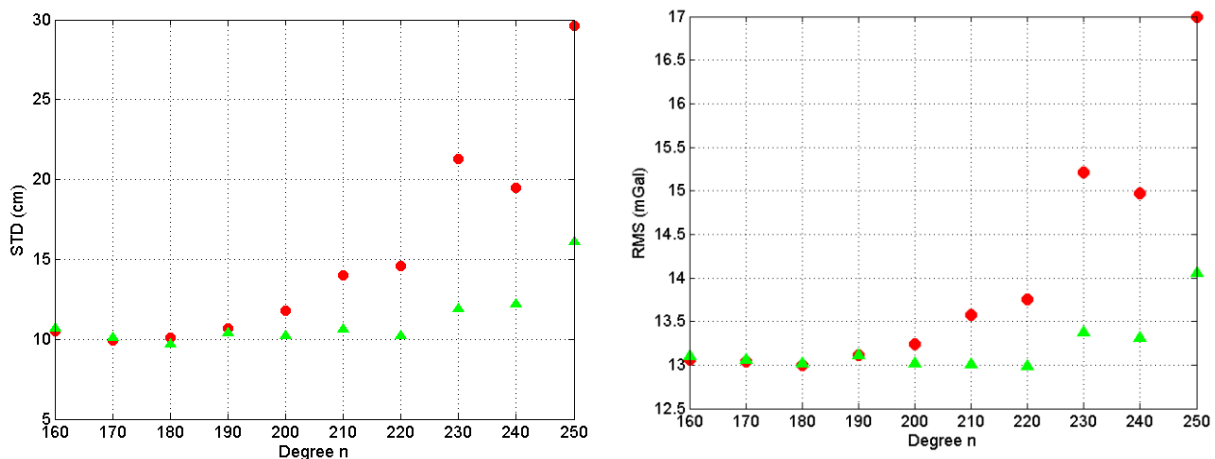


Figure 2: RMS difference between GOCE-TIM3 (red circles) and GOCE-TIM4 (green triangles) augmented by EGM2008 where  $n$  indicates the degree to which the GOCE models replace the low-degrees of EGM2008 and (a) 186 GPS-levelling points, and (b) 4,373 land free-air anomalies (Dataset C in Table 2) and including residual terrain modelling from the 9''x9'' DEM.

Additional assessments can be found under the Publications section.

## Publications by members

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### *Conference proceedings papers*

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### *Conference presentations/posters*

Benahmed Daho S. A. – Evaluation of GRACE/GOCE geopotential models in Algeria. Communication accepted for presentation in upcoming IAG General Assembly – Potsdam - Germany

Blitzkow, D.; Matos, A. C. O. C.; Guimarães, G. N.; Pacino, M. C.; Barzaghi, R.; Gravity surveys and geoid models in South America – Present status, 14–17 Maio, 2013. AGU Meeting of the Americas, Cancun, México.

Blitzkow, D.; Matos, A. C. O. C.; Guimarães, G. N.; Lobianco, M. C. B.; Pacino, M. C.; Present and Future of the gravity surveys and geoid model in South America. SIRGAS, 2012, Universidad Concepción; Cidade: Concepción – Chile;

Blitzkow, D.; Matos, A. C. O. C.; An attempt for comparisons of the geoid in south America - recent geopotential models. Primer Taller de Geomática en Ciencias de la Tierra 2012. Facultad de Ciencias Exactas, Universidad Nacional de Tucumán; Cidade: Tucumán – Argentina.

Bollini, M.C., Tocho, C., del Cogliano, D.: Evaluación de Modelos Geopotenciales Globales de GOCE en Argentina, SIRGAS2012 General Meeting, October 29 - 31, 2012

Guimarães, G. N.; Blitzkow, D.; Matos, A. C. O. C.; A Comparison between FFT and numerical integration of the geoid model in the state of Sao Paulo – Brazil, The XXV IUGG General Assembly, 2011. Melbourne Convention & Exhibition Centre, Melbourne – Australia.

Lobianco, M. C. B.; Matos, A. C. O. C.; Blitzkow, D.; Improvements in South American geoid model with different GOCE geopotential models. AGU Fall Meeting, 2011, San Francisco – EUA.

Matos, A. C. O. C.; Blitzkow, D.; Guimaraes, G. N.; Lobianco, M. C. B.; GOCE and the geoid in South America. The XXV IUGG General Assembly, 2011. Melbourne Convention & Exhibition Centre; Melbourne, Australia;

Matos, A. C. O. C.; Blitzkow, D.; Guimarães, G. N.; Lobianco, M. C. B.; Costa, S. M. A.; Validação do MAPGEO2010 e comparação com modelos recentes do geopotencial. VII Colóquio Brasileiro de Ciências Geodésicas, 2011. Universidade Federal do Paraná; Cidade: Curitiba – Brazil.

Lyszkowicz A., Biryło M., Becek K., 2012, Evaluation of geopotential models using terrestrial data over the territory of Poland and Brunei Darussalam, symposium “Gravity, Geoid and Height Systems GGHS2012”, Venice, Italy, 9-12 October 2012

Li, X., J.L. Huang, Y.M. Wang, M. Véronneau, and D. Roman (2012) Geoid improvement over Alaska/Yukon area by GRACE and GOCE models, Geophysical Research Abstracts, Vol. 14, EGU2012-2974, 2012 EGU General Assembly 2012

Pettersen BR, Šprlák M, Lysaker DI, Omang OCD, Sekowski M, Dykowski P (2012) Validation of GOCE by Absolute and Relative Gravimetry. Poster presented at the European Geosciences Union General Assembly, April 22-29, Vienna, Austria.

Pettersen BR, Šprlák M, Omang OCD, Lysaker DI, Sekowski M, Dykowski P (2012) Comparison of GOCE Gravity Field Models to Test Fields in Norway. Poster presented at the International Association of Geodesy Symposium: Gravity, Geoid and Height Systems GGHS2012, October 9-12, Venice, Italy.

Roman D.R., Li X., and Smith D.A. (2013) GRAV-D for Puerto Rico and the U.S. Virgin Islands, Abstract G33C-03, presented at the Meeting of the Americas in Cancun, Mexico 14-17 May 2013

Santos, M. C. , D. Avalos, T. Peet, J. Huang and P. Vaniček (2012). “Assessment of GOCE models over Mexico and Canada.” International Symposium on Gravity, Geoid and Height Systems, Venice, Italy, October 9-12.

Šprlák M, Gerlach C, Pettersen BR (2012) Evaluation of Residuals Between GOCE Global Gravity Field Models and GOCE Gravity Gradient Observations. Poster presented at the International Association of Geodesy Symposium: Gravity, Geoid and Height Systems, October 9-12, Venice, Italy.

Šprlák M, Gerlach C, Pettersen BR, Omang OCD (2012) Validation of GOCE Global Gravitational Field Models by Comparison with Regional Geoid and Gravity Anomaly Surfaces. Poster presented at the European Geosciences Union General Assembly, April 22-29, Vienna, Austria.

Šprlák M, Gerlach C, Omang OCD, Pettersen BR (2011) Comparison of GOCE Derived Satellite Global Gravity Models with EGM2008, the OCTAS Geoid and Terrestrial Gravity Data: Case Study for Norway. Poster presented at the 4th International GOCE User Workshop, March 31 - April 1, TUM, Munich, Germany.

Šprlák M, Pettersen BR, Gerlach C (2011) Validation of the GOCE Level 2 Gravity Gradients by Upward Continuation: Software Testing and Preliminary Results for Norway. Poster presented at the European Geosciences Union General Assembly, April 3-8, Vienna, Austria.

## **Joint Working Group 2.4: Multiple Geodetic Observations and Interpretations over Tibet, Xinjiang and Siberia**

*Chair: Cheinway Hwang (Taiwan)*

*Vice-Chair: Wenbin Shen (China)*

### **Introduction**

This joint working group is dedicated to studies of geodynamic process and climate change over the Tibet, Xinjiang and Siberia (TibXS), using geodetic tools ranging from satellite altimetry to satellite gravimetry. Additional techniques, such as GPS, terrestrial gravimetry, and interferometry SAR are also used. The members, as listed in the geodesy handbook 2012, are all very active in this JWG, with activities ranging from personnel exchange, to attending the annual meetings, and to publishing papers in special issues of this JWG (see below).

### **Activities**

Starting from 2011, we hold annual meetings to exchange research results and ideas, and propose new directions of study over TibXS, as the major activity of JWG2.4. We have published special issues in the journal of Terrestrial, Atmospheric and Oceanic Sciences (TAO), with papers from the meetings (with enhancements) and from outside. Highlights of the meetings and special issues are:

*TibXS2011 meeting (22-26 July, 2011)*

(<http://space.cv.nctu.edu.tw/altimetryworkshop/TibXS2011/TibXS2011.htm>).

This meeting was held in Xining, Qinghai Province of China, with more than 60 participants. Several landmark papers on GRACE determination of mass change over TibXS were presented. The TAO special issue, "Geodynamic process and Climate Change in TibXS" was launched to publish 13 papers on research results mainly from GRACE, satellite altimetry and terrestrial gravimetry (TAO, Vol. 22, No.2, April 2011).

*TibXS 2012 meeting (26-30, August, 2012)*

(<http://space.cv.nctu.edu.tw/altimetryworkshop/TibXS2011/TibXS2011.htm>).

Held in Chengdu, Sichuan Province of China, the meeting is another important activity of JWG2.4. Another TAO special issue was published (TAO, Vol. 24, No. 4, August 2013) . The highlights of the activities reported in the papers are:

- (1) An updated Moho depth model and a new geoid model over Tibet from recent GRACE/GOCE gravity models and CRUST2.0 crust model.
- (2) Improved methods of retracking altimeter waveforms and improved method of lake level determination and prediction; TibXS hydrology variability and climate variability from height and backscatter observations of TOPEX.
- (3) Crustal movements in China and tsunami simulations related to the Tohoku-Oki earthquake of March 11, 2011, Japan.

- (4) Changes in ice mass and in seasonal ocean tide over arctic islands and subarctic oceans (near Siberia) from GRACE and satellite altimetry.
- (5) A distinct crustal structure of Tibet compared to PREM, using GOCE and GPS data.
- (6) A new SG is installed at Lhasa, Tibet. The preliminary result reported in this special issue both contrasts or confirms the model predictions, depending on the subjects. A long-term SG record here is needed to enhance the current determinations of tidal amplitude factors and the SG calibration function.

We will hold the 2013 annual meeting on July 28 to Aug 1, 2013 in Yining, Xianjiang, China (<http://space.cv.nctu.edu.tw/altimetryworkshop/TibXS2013/TibXS2013.htm>).

All these meetings are kindly supported by Wuhan University (financially) and IAG (spiritually). In the meetings, we have some international participants outside of China, but more are encouraged.

Due to the vast area and the remoteness of TibXS, in situ data here are quite limited in spatial coverage and temporal coverage. We believe the discussions in the annual meetings and the papers in the special issues will provide important references for strategic plans of in situ observations over TibXS. In turn, such observations are critical to substantiating and validating current and future geodetic results. We will continue the effort to promote geodetic and geophysical studies in such a climate-sensitive and geodynamic-active region as TibXS.



**Joint Working Group 2.5: Physics and Dynamics  
of the Earth's Interior from Gravimetry**

*Chair: Isabelle Panet (France)*

This WG will be closed. The chair does not see any possibility for activities for it.

## **Joint Working Group 2.6: Ice Melting and Ocean Circulation from Gravimetry**

*Chair: Bert Wouters (UK/USA) (as of April 9, 2013)*

*Active members: Jennifer Bonin, Carmen Boening, Don Chambers, Annette Eicker, Martin Horwarth, Felix Landerer, Scott Luthcke, Jürgen Kusche, Roelof Rietbroek, Riccardo Riva, Ingo Sasgen, Jens Schroeter, Clark Wilson, Bert Wouters.*

### **Goals and priorities of JWG 2.6**

The mission statement in the IAG JWG 2.6 document is rather general. The goals of the JWG 2.6 have been discussed at the past two meetings and the following was concluded: Since the process of land ice melting includes signals in many geodetic observations and solid earth processes as well as oceanography is important as well, it was found that all aspects of the process should be addressed. Although this group combines a lot of knowledge and expertise in various fields, time and funding to initiate such a project is lacking. Therefore, a large-scale, communal science project is ruled out. Considering the topics of other working groups and of large funded projects concerned with land ice and sea level we agreed that our strength lies in combining different experts and aspects i.e. in networking and in providing advice, setting up guidelines and best practices and communication/outreach of results to scientists in other fields (i.e., non-geodesists).

### **Past meetings of JWG 2.6**

- European Geosciences Union General Assembly 2012. Vienna (Austria) April 22 – 27, 2012
- European Geosciences Union General Assembly 2013. Vienna (Austria) April 7 – 12, 2013

### **Current projects of JWG 2.6**

- The members of the WG recognize that working towards a grand inversion including all processes and measurements represents an ambitious and challenging goal that the WG should support. On this background several specific (sub)tasks were discussed at the meetings. One of them was to identify where to locate future measurements and what to measure in order to address a well-defined issue. E.g. when measuring total ocean mass where to place an ocean bottom pressure recorder such that land ice processes have the least influence on the data
- In early GRACE years, there was a wide spread in published values of mass loss of the ice sheets. Despite the recent convergence (e.g., IMBIE, see Shepherd et al, Science, 2012), there are still outliers (e.g., Wu et al. 2009, Bergmann et al. 2012). Geodesists are generally aware of reasons for differences. Non-geodesists do not always understand why there is no agreement, since this requires knowledge of methods and GRACE processing. JWG 2.6 will work on an overview paper that reviews published estimates and explains the differences. The format of the article has been discussed at the past EGU 2013 meeting and the following was concluded:
  - article should focus on non-geodesists, so a short introduction to GRACE should be included. Possible journal: The Cryosphere
  - focus should be on GRACE

- give an overview of published estimates (no new methods) and a short description of the methods used. Authors will be invited to provide this short description or comment.
- article should not give a judgement of which estimates are 'correct' and which not, but explain reason for differences and explain outliers.
- Compare different estimates over same period. Proposed period is March 2003 – February 2013.
- should stress that there will always be differences in the estimates because of natural variability (-> different time spans will give different results, even with same method), differences in GIA models, improvement in GRACE data (e.g., RL04 vs. RL05) etc.
- possibly also include analysis of residuals (scatter, autocorrelation)
- Although GRACE observations are becoming increasingly popular to estimate the mass balance of glaciers and ice caps (GICS) the group members agrees that it is too early to do an IMBIE-like intercomparison project for GICS (only two GRACE studies addressing all major GICS published so far: Jacob et al, 2012; Gardner et al., 2013 (in press)). This may be picked up in the future.
- GRACE mission may be coming to an end, JWG 2.6 encourages researchers to think about methods to fill up gap with follow-on mission, e.g. using SLR. Within the framework of the e.motion project a model of time variable gravity has been developed which may act as a test bed for such methods. Felix Landerer is PI of the new NASA MEaSURES project 'Earth Surface Mass Changes' (essentially the Tellus website and all its data products), which is looking into this issue and is supposed to provide data products (like EOF-based reconstruction using lower order SLR etc.)
- Guidelines and best practices: M. Horwath proposes to look at sensitivity kernels of methods used to estimates mass loss. This could also be included in overview paper, or in a separate work if too technical.
- At a later stage (after completion of overview paper), a web site could be set up where researchers can upload their Antarctica and Greenland time series and users can compare different estimates. Not much experience with setting up web sites in group, so R. Rietbroek proposes to use an existing wiki-like interface.

### **Collaboration with JWG 2.7 on hydrology**

- Hydrological correction is important when estimating mass balance of continental ice caps and glaciers. Likewise, GRACE needs to be corrected for glacier signal when studying hydrology (For example, in High Mountain Asia region, see presentation). Hydrological models show very different trends in some regions and are one of the main causes of uncertainty in glacier mass balance estimates. A collaboration between JWG 2.7 and JWG 2.6 is therefore logical.
- A. Eicker (Chair of JWG 2.7) informed us that currently the hydrology group is still determining its goals and priorities. Will contact group members and provide overview of reasons for large discrepancies in trends of models.

### **Points of action**

- overview paper:
  - contact the editors of "The Cryosphere" about interest for overview paper (summer 2013)

- compile list of published GRACE estimates mass loss Greenland and Antarctica and send out to group (summer 2013)
- prepare draft outline of paper and send out to group for comments (summer/fall 2013)
- hydrology: A. Eicker will contact JWG 2.7 group members and provide overview of reasons for large discrepancies in trends of models in High Mountain Asia region.

### **Future meetings**

- Next meeting will be at AGU 2013 or EGU 2014

## **Joint Working Group 2.7: Land Hydrology from Gravimetry**

*Chair: Annette Eicker (Germany)*

*Members:*

Jean-Paul Boy (University of Strasbourg), jeanpaul.boy@unistra.fr

Petra Döll (University of Frankfurt), P.Doell@em.uni-frankfurt.de

Andreas Güntner (GFZ Potsdam), guentner@gfz-potsdam.de

Laurent Longuevergne (University of Rennes), laurent.longuevergne@univ-rennes1.fr

Matt Rodell (Goddard Space Flight Center, NASA), matthew.rodell@nasa.gov

Himanshu Save (University of Texas), save@csr.utexas.edu

Bridget Scanlon (University of Texas), bridget.scanlon@beg.utexas.edu

Ben Zaitchik (Johns Hopkins University Baltimore), zaitchik@jhu.edu

*Webpage:*

A website was set up to coordinate and document the group activities:

<http://www.igg.uni-bonn.de/apmg/index.php?id=535>

It includes the terms of references, contact information of the working group members and a complete list of publications originating from the years 2011-2013. It will be complemented by reports and joint results.

### **Activities**

*General activities*

During the previous two years, working group members have been involved in various research areas associated with “Land hydrology from gravimetry”. Activities comprised tailored GRACE data analysis and signal interpretation, hydrological model development, model validation and calibration, as well as assimilation of GRACE data into hydrological and land surface models. Further research interests include water resource analysis and ground water monitoring, and the use of local, superconducting gravity observations to monitor local water storage variations. Additionally, assistance has been provided by working group members to the hydrological community via preparation of easy-to-use GRACE products and pedagogy on the use of GRACE data.

An email list has been set up and a discussion was started regarding individual research goals and unresolved topics associated with the above research activities.

*Future Gravity Workshop*

In 2014 a workshop will be held on future gravity missions with the goal “Consolidation of science requirements”, which was initiated, among others, by Sub-Commission 2.3 (Dedicated satellite gravity mapping missions). Preparations have already started 2013 and will be continued during the course of the next year by thematic sub-groups. The hydrology sub-group will be covered by JWG 2.7.

### *Collaboration with IAG JWG 2.6 (Ice melting and ocean circulation from gravimetry)*

A cooperation was established during a joint splinter meeting at EGU 2013 between working groups 2.6 and 2.7 to work together on a better understanding of hydrological and glaciological effects in the Himalayan region. Different hydrological models show very different output in this region. As these models are applied to disaggregate the gravity signal and to isolate the ice melting effects, they represent a large source of uncertainty to the glaciological community. The reasons for the different hydrological modeling results are currently under discussion.

### **Future plans**

An important task for the upcoming year will be the preparation and realization of the future gravity mission workshop, as mentioned above. This implies, as a first step, the inventory and review of various previous studies on future mission scenarios from a hydrological perspective. The next step will be the formulation of hydrological research goals that could be achieved with the different mission designs. Furthermore, the cooperation with JWG 2.6 and the joint discussion e.g. on the Himalayan glaciers will be continued. The discussion within the hydrology working group (e.g. regarding signal interpretation, preparation of dedicated GRACE products to hydrologists and data assimilation techniques) shall be intensified. Splinter meetings are planned at the IAG Meeting in Potsdam 2013 and at AGU 2013 in San Francisco.

### **Bibliography**

A list of publications with contributions from working group members in 2011-2013 can be found on the WGs webpage.

## **Joint Working Group 2.8: Modelling and Inversion of Gravity-Solid Earth Coupling**

*Chair: Carla Braitenberg (Italy)*

Here follows the complete report of the activities and main results.

The activities were decided in the three regular meetings of the Working Group and reported in the circulars. The circulars are deposited in the homepage of the WG described below.

### **Definition of activities for Working Group**

The planned activities of the working group (WG) were published in the first and second circular:

1. Create a platform in which density models can be tested through geodynamic models. This needs the interaction of the geodynamic modeller with the geophysical modeller, and allows a consistency check of the density models from the point of view of observations of the potential field and of geodynamics. Vice versa the geodynamic models producing density variations are checked against consistency with density models constrained by further geophysical observations.
2. Create a reference database covering the subject of gravity-solid earth coupling (mass loading, under-plating, isostatic Moho, crustal thickness, lithospheric thickness, dynamic topography versus mass loading).
3. Create a database on methodology of gravity forward and inversion calculations, spherical calculations
4. Create a kit of software tools that have been tested and verified by the WG and that will be shared among the members of the working group. It shall cover the different aspects of the goals of the WG. If several software-programs are made available they can be benchmarked against each other.
5. Set up a social networking page for the members of the WG.
6. Organize dedicated yearly meeting of the WG.
7. Organize a practical-theoretical school on Modeling and Inversion of Gravity-Solid Earth Coupling
8. Apply for funding of activity of WG through international agency.

### *Final goal for 2011-2015*

At the end of the WG period (2011-2015) the WG shall have set up a variety of tools that allow to tackle and improve understanding of solid earth-gravity coupling processes. In particular the efforts will be summarized in a home-page that shall contain an exhaustive overview of the most important and relevant papers on a few key topics necessary for fulfilling the scientific task. Secondly the page will house a useful collection of software tools that will have been validated by the WG, and that are recommended as useful tools for gravity forward and inverse modelling. Ideally the WG will give the opportunity to give a platform on which to exchange news and information regarding gravity modeling.

These actions have started and are in a good stage of development. Three meetings have been held, detailed in Table 1, and the homepage has been set up, as described in the next section.

Table 1: The meetings of the Workgroup were held at various conferences relevant to potential fields.

Convention	Title	Date
Splinter meeting at EGU2012, SPM1.30.	First Meeting of the Joint Working Group JWG2.8 (IAG) Modeling and Inversion of Gravity-Solid Earth	26 Apr, 2012, 19:00–20:00
Splinter meeting at the Symposium Gravity, Geoid and Height Systems GGHS2012, 09-12 October 2012, San Servolo Island, Venice, Italy	Second Meeting of the Joint Working Group JWG2.8 (IAG) Modeling and Inversion of Gravity-Solid Earth	10 October 2012
Splinter meeting at EGU2013, SPM1.30.	Third Meeting of the Joint Working Group JWG2.8 (IAG) Modeling and Inversion of Gravity-Solid Earth	11 Apr, 2013 12:15–13:15

### Working Group Discussion page

We have set up a discussion page for the Work group, located here:  
<http://www.lithoflex.org/IAGc2>

The scope of the homepage and the responsibility from side of the members for the different topics were defined in the GGHS2012 meeting in Venice.

In Venice it was decided that the page shall contain an exhaustive overview of the most important and relevant papers on a few key topics necessary for fulfilling the scientific task. Secondly the page will house a useful collection of software tools that will have been validated by the WG, and which are recommended as useful tools for gravity forward and inverse modeling. Ideally the WG will give the opportunity to give a platform on which to exchange news and information regarding gravity modelling.

Throughout the period of the WG the page will be in development and updated. The accredited members of the WG are able to edit the pages after registering and can post messages. News include an interesting paper, or a recent publication, or a topic of discussion.

The homepage should allow the WG-members to discuss the topics of the WG at ease.

The pages dedicated to relevant publications have been divided among the WG-members as follows:

- *Properties of rocks*: Density, velocity, correlation between density and seismic velocity, mineral composition, dependence on pressure and temperature. Jörg Ebbing (Norway), Javier Fulla (Spain), Richard Lane (Australia)
- *Gravity forward modeling*: Spatial-domain techniques (flat vs. spherical. prisms, tesseroids), and spectral-domain techniques (spherical harmonic expansion), Resp. Leonardo Uieda (Brazil), Rezene Mahatsente (Germany), Thomas Grombein (Germany), Christian Hirt (Australia)
- *GOCE and other satellites*: Application of GOCE satellite gravimetry in solid Earth investigations, GOCE mission overviews, GOCE gradients and gravity recovery, and GOCE model quality, Christian Hirt (Australia), Carla Braitenberg (Italy).
- *Gravity Associations*: Gravity associations, gravity discussion groups (all members)
- *Inverse gravity modeling*: Flat, spherical, spectral approach, Surface harmonics (Valeria Barbosa (Brazil), Riccardo Barzaghi (Italy)



- *Isostatic modeling*: Different techniques on isostatic modeling. John Kirby (Australia)
- *Topographic Corrections*: Methods for calculation of mass effect of topography; cartesian and spherical coordinates, Orlando Alvarez (Argentina) , Nils Köther (Germany)

The Opening page is shown in Figure 1.

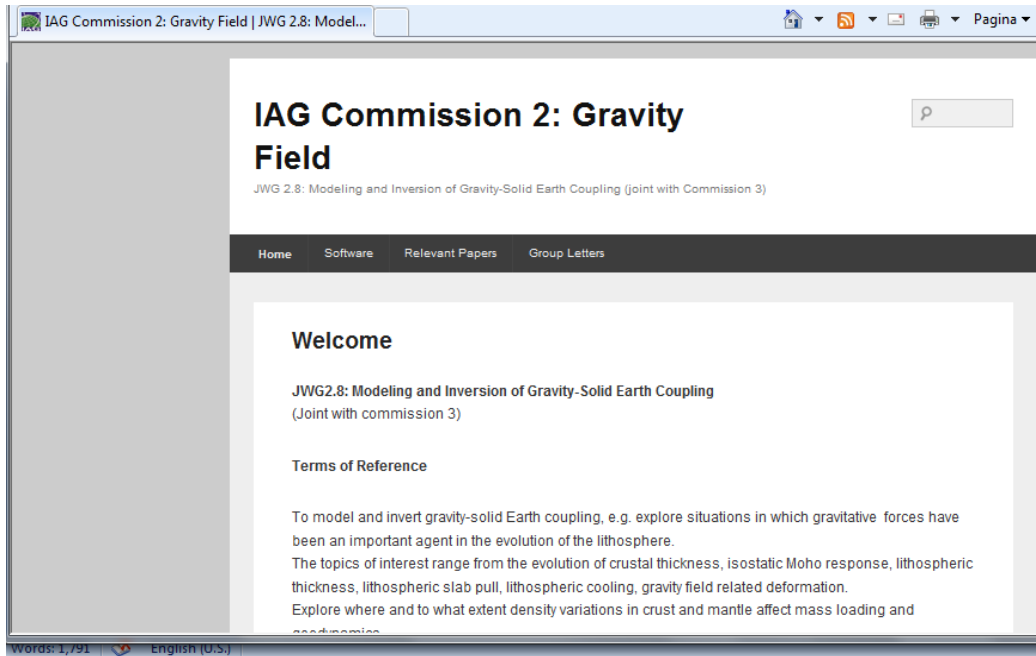


Figure 1: Welcome page of the IAG JWG 2.8 homepage, which includes a depository of software, relevant-publications-list and the possibility of making discussions.

## Software tools

The goal is to create a set of software tools useful in gravity inverse and forward modeling. The software should have passed validation criteria, so as to achieve a control on reliability. The software shall have the following requisites:

- it runs on Windows or Linux.
- It is freely distributed
- It must include a documentation with description of routines and usage, and a set of testing files, that allows all routines to be tested by the user.
- The person or group of persons that provide the software also demonstrate that the SW has been validated on a standard dataset. The WG will house a few standard models that contain a density model and the gravity and gradient field it produces, which will be the means to validate the software.
- The SW will be distributed by its owner, the IAG WG accepts the SW as having been validated by the standards set up by the WG.

It is intended to set up some benchmark models. The first standard model will be a lithospheric model of North Atlantic margin. It will be created by Jörg Ebbing.

The home-page will also house a collection of commercial software considered to be useful in this scientific context.

## Commission 3 – Earth Rotation and Geodynamics

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

*President: Richard Gross (USA)*

*Vice President: Aleksander Brzezinski (Poland)*

### Structure

Sub-Commission 3.1:	Earth tides and geodynamics
Sub-Commission 3.2:	Crustal deformation
Sub-Commission 3.2a:	Global crustal deformation
Sub-Commission 3.2b:	Regional crustal deformation
Sub-Commission 3.3:	Earth rotation and geophysical fluids
Sub-Commission 3.4:	Cryospheric deformation
Sub-Commission 3.5:	Tectonics and earthquake geodesy
Joint Study Group 3.1:	Gravity and height change intercomparison
Joint Working Group 3.1:	Theory of Earth rotation

### 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>

<http://www.agu.org/cgi-bin/sessions5?meeting=fm12&part=G53A>

## **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.

## Commission 4 – Positioning and Applications

<http://www2.ccegs.ohio-state.edu/IAG-Comm4>

*President: Dorota A. Grejner-Brzezinska (USA)*

*Vice President: Allison Kealy (Australia)*

### Structure

- Sub-Commission 4.1: Alternatives and backups to GNSS
- Sub-Commission 4.2: Geodesy in geospatial mapping and engineering
- Sub-Commission 4.3: Remote sensing and modelling of the atmosphere
- Sub-Commission 4.4: Applications of satellite and airborne imaging systems
- Sub-Commission 4.5: High-precision GNSS algorithms and applications
- Sub-Commission 4.6: GNSS-reflectometry and applications

### Overview

The primary mission of Commission 4 is to promote research that leverages current and emerging positioning techniques and technologies with a goal to deliver practical and theoretical solutions for engineering, scientific and mapping applications. Commission 4 carries out its work in close cooperation with the IAG Services and other IAG entities, as well as via linkages with relevant entities within scientific and professional sister organizations. Commission 4 closely collaborates with the International Society for Photogrammetry and Remote Sensing (ISPRS) Commission 1 “Sensors and Platforms for Remote Sensing,” the International Federation of Surveyors (FIG) commission 5 “Positioning and Measurement,” WG 5.5 “Ubiquitous positioning” in particular, as well as with the Institute of Navigation (ION). Representatives of these sister organizations serve on the Commission 4 Steering Committee.

Recognizing the central role of Global Navigation Satellite Systems (GNSS) in providing high accuracy positioning information today and into the future, Commission 4 is focused on developing tools that enhance and assure the positioning performance of GNSS-based positioning solutions for a range of geodetic, engineering and scientific applications. In particular, the Commission 4 activities aim at developing theory, strategies and tools for modeling and/or mitigating the effects of interference, signal loss and atmospheric effects, as they apply to precise GNSS positioning technology. Our goal is to address the technical and institutional issues necessary for developing backups for GNSS, integrated positioning solutions, automated processing capabilities, and quality control measures. Commission 4 also deals with geodetic remote sensing, using Synthetic Aperture Radar (SAR), Light Detection And Ranging (LiDAR) and Satellite Altimetry (SA) systems for geodetic applications.

In achieving these goals, a major recognition has been the need to integrate activities of all the sub-commissions as well as with those of other professional bodies. This multi and interdisciplinary approach has been adopted by many of the sub commissions under Commission 4 and full listings of activities and publications can be found in the following sections. Some of the major collaborative events and outcomes for the time period 2011-2013 are listed here:

- Commission 4 co-sponsored the 1<sup>st</sup> International School on Mobile Mapping Technology, National Cheng-Kung University, Tainan, Taiwan, June 11-15, 2012  
<http://conf.ncku.edu.tw/mmt2013/intro01.htm>

- Commission 4, together with the FIG/IAG/ISPRS Collaborative WG 5.5, *Ubiquitous Positioning*, co-sponsored and co-organized, a field campaign on Collaborative Navigation, at the University of Nottingham, UK, May 14-18, 2012; [http://info.tuwien.ac.at/ingeo/sc4/Collaborative\\_nav\\_may2012.html](http://info.tuwien.ac.at/ingeo/sc4/Collaborative_nav_may2012.html)
- Commission 4, together with the FIG/IAG/ISPRS Collaborative WG 5.5, *Ubiquitous Positioning*, co-sponsored and co-organized, a field campaign on Indoor Positioning, at the RMIT and Melbourne Universities, Australia, July 8-12, 2013.
- Commission 4 together with FIG and ISPRS co-sponsored the 7<sup>th</sup> International Mobile Mapping Symposium, Tainan, Taiwan, May 1-3, 2013; <http://conf.ncku.edu.tw/mmt2013/>
- Commission 4 had a significant involvement and presence at the ION Pacific PNT Conference, Honolulu, Hawaii, April 22-25, 2013; <http://www.ion.org/meetings/pnt2013program.cfm>. Several papers authored collaboratively with FIG/ISPRS/IAG members were presented.
- Commission 4 had a significant involvement and presence at the International GNSS Symposium, Gold Coast, Australia, July 12-19; <http://www.ignss.org/Conferences/IGNSS2013Conference/2013ConferenceVenueInformation/tabid/113/Default.aspx>
- Representative Commission 4 Publications
  - IAG Commission 4: Mission and contributions to observing and modeling dynamic earth, *Journal of Applied Geodesy*, DOI 10.1515/jag-2012-0032
  - IAG Commission 4: Positioning and Applications, *GIM International*, July 2013, p. 47
- 2013 Special edition of the *Journal of Applied Geodesy*: co-sponsored by FIG WGs 5.4 and 5.5 and IAG Sub-commission IAG 4.1; Editors: A. Kealy and G. Retscher
- Special issue of the *Central European Journal of Engineering* on Disaster monitoring and management, Editors: J. Doukas and G. Retscher
- Upcoming Commission 4 events
  - Pecora 19 & ISPRS Commission I Symposium, co-sponsored by IAG Commission 4, Renaissance Denver Hotel, Denver, Colorado, November 17-20, 2014
  - Multi-sensor and multi-platform navigation: workshop and field-testing, The Ohio State University, May 2014. Co-sponsored by IAG Commission 4 and ISPRS Commission I

## **Sub-Commission 4.1: Alternatives and Backups to GNSS**

*Chair: Günther Retscher (Austria)*

As most mobile positioning applications rely heavily on GNSS nowadays alternative approaches for location determination of users in GNSS denied environments or indoors are needed. These alternatives and backups are the main focus of the Sub-Commission. The Working Groups of the Sub-Commission thereby focus on the use of multi-sensor systems and their integration. For ubiquitous positioning several technologies are researched and further developed. In this context Working Group 4.1.1 lays its emphasis on collaborative positioning and navigation using a variety of sensors on different platforms. New emerging technologies as alternative to GNSS positioning are investigated by WG 4.1.3. In addition, the investigation of location technologies for smartphone positioning plays an important role in the interdisciplinary research conducted under the umbrella of Sub-Commission 4.1.

The Sub-Commission 4.1 maintained a strong and active presence at the following international events through participation in coordinating workshops, scientific and organizing committees, delivering short courses and tutorial, publishing papers and presentations, session chairing, etc.

1. PLANS 2012, Myrtle Beach, South Carolina, USA, Apr. 24-26, 2012

Themes: Adaptable Navigation System Technology; Commercial Aviation Positioning and Navigation Applications; Consumer, Smartphone and Personal Navigation Applications; Emerging Atom-Based Sensor Technologies; Environmental Features and Novel Navigation Sensors; GNSS Augmentation Systems; High Assurance GNSS; High-Performance Inertial Sensor Technology; Indoor Personal and First-Responder Navigation; Interference, Spectrum Issues and Robust Navigation; Low-Cost Inertial Sensor Technologies; Marine Positioning and Navigation Applications; Micro-technology for PNT; Modernized GNSS; Multisensor Integrated Systems and Sensor Fusion Technologies; Precise Positioning; Weak Signal, and Advanced Processing Algorithms; Receiver and Antenna Technology; Robotic Guidance, Navigation and Control Applications; Sensor Manufacturing; Error Modeling and Testing; Small UAV Positioning and Navigation Applications; Terrestrial and Automotive Positioning and Navigation Applications; Terrestrial Radionavigation and RF-Positioning; Urban Personal and Vehicular Navigation; Vision/Integrated Navigation Systems. <http://www.ion.org/plans/>

2. FIG Working Week: May 6-10, 2012 in Rome, Italy

Themes of Commission 5: Geodetic and positioning measurement – infrastructure, methodology, adjustment and analysis; Standards, best practice guidelines, quality assurance and calibration for survey (including geodetic) measuring instruments; National or geospatial reference systems and associated infrastructure; Reference systems, frames and datums in practice; GNSS CORS RTK networks and infrastructure - the impact of these networks, their operations and applications; Terrestrial and airborne laserscanning; Cost-effective surveying (GNSS and other survey methods); Ubiquitous positioning techniques and applications - such as RFID, WiFi, AGPS, mobile phones, MEMS inertial sensors, Locata; Kinematic measurements – including GNSS and Multi Sensors Systems; GNSS modernisation and its effect on surveying; Geoids and gravity - modelling, measurements and applications; eGeodesy; GGOS (Global Geodetic Observing System). <http://www.fig.net/fig2012/>

3. ION GNSS, Nashville, Tennessee, USA, Sep. 17-21, 2012  
Themes: Advanced Inertial Sensing and Applications; Advances in Military GNSS Systems and Applications; Algorithms and Methods; Alternatives and Backups to GNSS; Aviation Applications; Clock Technologies; Emerging GNSS (Galileo, COMPASS, QZSS, IRNSS); Future PNT and its Applications; Geodesy, Surveying and RTK for Civil Applications; GNSS Algorithms and Methods; GNSS and the Atmosphere; GNSS Compatibility, Interoperability, and Interchangeability; GNSS Ground Based Augmentation Systems (GBAS); GNSS Simulation and Testing; GNSS Space Based Augmentation Systems (SBAS); GNSS-MEMS Integration; GPS and GLONASS Modernization; Indoor Navigation and Timing; Interference and Spectrum Issues; Land Based Applications; Marine Navigation and Applications; Multi-Constellation User Receivers; Multi-Sensor and Integrated Navigation in GNSS-Challenged Environments; New Products and Commercial Services, Next Generation GNSS Integrity; Non Traditional PNT Applications; Portable Navigation Devices; Precise Point Positioning; Receiver/Antenna Technology; Remote Sensing with GNSS and Integrated Systems; Safety Critical Applications; Software Receivers; Space Applications; Standalone GNSS Services in Challenging Environments; Timing and Scientific Applications; Urban Navigation Technologies. <http://www.ion.org/gnss/>
4. UPINLBS 2012, Helsinki, Finland, Oct. 3-4, 2012.  
Themes: GNSS based positioning for indoors and outdoors; RAN (Radio Access Network) based positioning in smart phones; Positioning solutions based on signals of opportunity; Hybrid positioning solutions with multiple sensors and RF signals; Emerging sensor technologies for positioning; Vision-aided navigation; Smart phone navigation and LBS technologies; Innovative LBS services and applications; Context awareness. <http://upinlbs.fgi.fi/>
5. LBS 2012, Munich, Germany, Oct. 16-18, 2012.  
Themes: Positioning/Indoor positioning; Smart environments and spatial intelligence; Spatio-temporal data acquisition, processing, and analysis; Data mining and knowledge discovery; Personalization and context-aware adaptation; Visualization techniques for LBS; Novel user interfaces and interaction techniques; Smart mobile phone navigation and LBS technologies; Three-dimensional visualization in the LBS context; Augmented reality in an LBS context; Innovative LBS systems and applications; Wayfinding/Navigation (indoor/outdoor); Indoor Navigation Databases; User studies and evaluations; Privacy issues in LBS; Usability issues in LBS; Legal and business aspects in LBS; LBS and Web 2.0; Open source solutions and standards. <http://www.lbs2012.tum.de/>
6. IPIN 2012, Sydney, Australia, Nov. 13-15, 2012.  
Themes: User requirements; Security & Privacy; Hybrid IMU Pedestrian Navigation & Foot Mounted Navigation; High Sensitivity GNSS, GNSS Indoors, IMES; Pseudolites & Locata; Signal Strength Based Methods, Fingerprinting; Ultra Wide Band; Passive & Active RFID; Optical Systems; Ultra Sound Systems; TOF, TDOA based localisation; Localisation & Algorithms for WSN; Framework for Hybrid Positioning; Applications of Location Awareness & Context Detection; Industrial Metrology & Geodetic Systems, iGPS; Radar Systems; Mapping, SLAM (Simultaneous Localization And Mapping); Magnetic Localization; Innovative Systems <http://www.surveying.unsw.edu.au/ipin2012/>
7. ION Pacific PNT 2013, Honolulu, Hawaii, USA, Apr. 22-25, 2013  
Themes: Navigation System Technology; Smartphone and Personal Navigation Applications; Novel Navigation Sensors; GNSS Augmentation Systems; High Assurance



GNSS; High-Performance Inertial Sensor Technology; Indoor Personal and First-Responder Navigation; Interference, Spectrum Issues and Robust Navigation; Low-Cost Inertial Sensor Technologies; Multisensor Integrated Systems and Sensor Fusion Technologies; Precise Point Positioning; Navigation and Control Applications; UAV Positioning and Navigation Applications; Terrestrial and Automotive Positioning and Navigation Applications; Terrestrial Radionavigation and RF-Positioning; Urban Personal and Vehicular Navigation; Vision/Integrated Navigation Systems. <http://www.ion.org/pnt/>

8. European Navigation Conference 2013, Vienna, Austria, Apr. 23-25, 2013  
Themes: Ubiquitous Positioning; Indoor Navigation and Positioning; Location-based Services (LBS); Modernized GNSS; Vehicle Navigation and Intelligent Transport Systems; Ground and Space Based Augmentation Systems; Aviation; Marine Navigation; Inertial Navigation Systems; Inertial Sensor Technologies; Precise Point Positioning; Receiver and Antenna Design; Autonomous Navigation Systems; Multi-sensor Integrated Systems and Sensor Fusion Technologies. <http://www.enc2013.org/>.
9. 8th International Symposium on Mobile Mapping Technologies MMT 2013, Tainan, Taiwan, May 1-3, 2013  
Themes: 3D Landscape and City Modeling; Alternative Sensor and Data Integration Algorithms; Automated and Semi-Automated Image Segmentation; Data Fusion and Data Mining; Data Integration of Multi-Platform Systems; Direct Georeferencing and Sensor Calibration; Estimation and Optimization Algorithms; Feature Extraction and Object Recognition; Image Sequence Analysis; Large Datasets: Management, Query and Transmission; LiDAR Data Processing; Location Based Service; Mobile Mapping and GIS Integration; Mobile Mapping Technology and Applications; Personal and Pedestrian Navigation; Positioning and Orientation Systems; Rapid Disaster Relief and Monitoring Applications; Standard Testing Procedure for Mobile Mapping Systems; Terrestrial, Mobile and Airborne LiDAR Systems; UAV Systems and Data Processing; Wireless Positioning and MEMS. <http://conf.ncku.edu.tw/mmt2013/>

#### *Publications:*

1. Mok E., G. Retscher, D. Wang, L. Xia (2011): Use of Smartphones for Tracking and Trip Recording. in: Papers presented at the 8th International Symposium on Location-Based Services LBS 2011, November 21-23, 2011, Vienna, Austria, pp. 137-152.
2. Mok E., G. Retscher, C. Wen (2012): Initial Test on the Use of GPS and Sensor Data of Modern Smartphones for Vehicle Tracking in Dense High Rise Environments. IEEE Xplore, 2012 Ubiquitous Positioning Indoor Navigation and Location Based Service (UPINLBS), ISBN: 978-1-4673-1909-6, 7 pgs.
3. Retscher G. (2012): Wi-Fi Positioning with Smartphones. in: Papers presented at the 9th International Symposium on Location-Based Services LBS 2012, October 16-18, 2012, Munich, Germany, 9 pgs.
4. Retscher G., T. Hecht (2012): Investigation of Location Capabilities of four Different Smartphones for LBS Navigation Applications. IEEE Xplore, 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN), ISBN: 978-1-4673-1954-6, 6 pgs.
5. Retscher G., T. Hecht, E. Mok (2013): Location Capabilities and Performance of Smartphones for LBS Navigation Applications. in: Papers presented at the 8th International Symposium on Mobile Mapping Technology, May 1-3, 2013, Tainan.

### WG 4.1.1: Ubiquitous Positioning Systems

*Chair: Allison Kealy (Australia)*

*Co-Chair: Günther Retscher (Austria)*

In 2012 a major activity undertaken by members of the joint IAG Working Group WG 4.1.1 and FIG WG 5.5 was field experiments at the University of Nottingham from May 14 to 18, 2012. These revolved around the concept of collaborative navigation, and partially indoor navigation. Collaborative positioning is an integrated positioning solution which employs multiple location sensors with different accuracy on different platforms for sharing of their absolute and relative localizations. Typical application scenarios are dismounted soldiers, swarms of UAV's, team of robots, emergency crews and first responders. The stakeholders of the solution (i.e., mobile sensors, users, fixed stations and external databases) are involved in an iterative algorithm to estimate or improve the accuracy of each node's position based on statistical models. For this purpose different sensor platforms have been fitted with similar type of sensors, such as geodetic and low-cost high-sensitivity GNSS receivers, tactical grade IMU's, MEMS-based IMU's, miscellaneous sensors, including magnetometers, barometric pressure and step sensors, as well as image sensors, such as digital cameras and Flash LiDAR, and ultra-wide band (UWB) receivers. The employed platforms in the tests include a train on the roof of the Nottingham geospatial building, mobile mapping vans, a personal navigator and a foot tracker unit.

In terms of the tests, the data from the different platforms are recorded simultaneously. The personal navigator and a foot tracker unit moved on the building roof, then through the building down to where it logged data simultaneously with the vans, all of them moving together and relative to each other. The platforms then logged data simultaneously covering various accelerations, dynamics, etc. over longer trajectories. First test results of the field experiments showed that a positioning accuracy on the few meter level can be achieved for the navigation of the different platforms.

Further information about the Working Group and the field experiments may be found at <http://ubpos.net>. Measurement data from the campaign are freely accessible from this website.

#### *Publications*

1. Kealy A., G. Retscher, D. Grejner-Brzezinska, V. Gikas, G. Roberts (2011): Evaluating the Performance of MEMS based Inertial Navigation Sensors for Land Mobile Applications. Archives of Photogrammetry, Cartography and Remote Sensing, Vol. 22, ISSN 2083-2214, pp. 237-248.
2. Kealy A., G. Retscher, N. Alam, A. Hasnur-Rabiain, C. Toth, D. A. Grejner-Brzezinska, T. Moore, C. Hill, V. Gikas, C. Hide, C. Danezis, L. Bonenberg, G. W. Roberts (2012): Collaborative Navigation with Ground Vehicles and Personal Navigators. IEEE Xplore, 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN), ISBN: 978-1-4673-1954-6, 8 pgs.
3. Kealy A., G. Retscher, A. Hasnur-Rabiain, N. Alam, C. Toth, D. A. Grejner-Brzezinska, T. Moore, C. Hill, V. Gikas, C. Hide, C. Danezis, L. Bonenberg, G. W. Roberts (2013): Collaborative Navigation Field Trials with Different Sensor Platforms. in: Papers presented at the 10th Workshop on Positioning, Navigation and Communication WPNC 2013, March 20-21, 2013, University of Applied Sciences Dresden, Germany, 6 pgs.
4. Kealy A., A. Hasnur-Rabiain, N. Alam, C. Toth, D. A. Grejner-Brzezinska, V. Gikas, C. Danezis, G. Retscher (2013): Cooperative Positioning using GPS, Low-cost INS and Dedicated Short Range Communications. in: Papers presented at ION Pacific PNT 2013, April 22-25, 2013, Honolulu, Hawaii, USA.
5. Kealy A., A. Hasnur-Rabiain, N. Alam, C. Toth, D. A. Grejner-Brzezinska, V. Gikas, G. Retscher (2013): Cooperative Positioning Algorithms and Techniques for Land Mobile Applications. in: Papers presented at the 8th International Symposium on Mobile Mapping Technology, May 1-3, 2013, Tainan, Taiwan, 6 pgs.

### **WG 4.1.2: Interference and Jamming**

*Chair: Andrey Soloviev (USA)*

The Working Group was inactive in the report period from the start. Therefore it recommended to either appoint a new chair or close the WG.

### **WG 4.1.3: Emerging Technologies**

*Chair: Kefei Zhang (Australia)*

*Co-Chair: Lukasz Bonenberg (UK)*

The Working Group 4.1.3 and its associated key players from Australia and Europe has been active in the past 12 months in investigating emerging technologies for innovative positioning and tracking, theoretical frame, field evaluations and practical industrial applications. The key sensors involved include both traditional and emerging systems such as, RFID (active and passive), INS, WiFi, magnetometer, Pseudolite (e.g. Locata), smart phone, UWB, etc.

#### *Major Activities*

Participation in the initialised working group proposing OFFCOM into ECC Report 128 Compatibility Studies Between Pseudolites And Services In The Frequency Bands 1164-1215, 1215-1300 And 1559-1610 MHz, September 2012

May 2012 Collaborative Navigation with Ground Vehicles and Personal Navigators, experiment in Nottingham, UK.

A series of UWB trials were conducted in the University of Nottingham in Dec 2012 and RMIT University in April 2013.

Recently, three major Australian universities (RMIT, University of Melbourne and UNSW) has worked together and established a dedicated Australian indoor positioning laboratory through major funding attracted from Australian Research Council and capital budget from both RMIT and University of Melbourne. The key researchers involved include Prof Kefei Zhang (RMIT University), A/Prof Allison Kealy (University of Melbourne) and Thomas Gallagher and Dr Binghao Li (UNSW).

This laboratory is hosted in RMIT Design Hub Building in Melbourne and a large number of sensors systems have been procured. Several initial testings that involve smart phones and laptops as a mobile platform and UWB, USRP, RFID, WiFi, magnetometers and INS as sensors were carried out. Part of the experiments results is expected to be reported in MMT 2013.

An Australian Research Council project entitled with "TRIIBE - TRacking Indoor Information BEhaviour" was awarded a team in RMIT University that involves researchers from geo-spatial, computer science and communication backgrounds. This project will research the passive tracking of user's mobile devices in indoor spaces correlating their spatial behaviour with their information needs to deliver personalised information. The project aims to create a system that enables owners of large buildings (for example, shopping malls, airports, univer-

sities) to better manage their spaces and services and provide value-added information to their customers.

The University of Nottingham team is currently working on the indoor positioning project using UWB, with external partner, which should feed into JISDM conference in Nottingham. If this initial study is successful I expect to establish a larger collaboration. Nottingham Geospatial Institute has a successful indoor positioning group and RMIT hosted Australian laboratory hopes to get further involved with them as well. We arranged with Guenther Retscher that further trials will be conducted at the laboratory in July 2013.

### *Publications*

1. Bonenberg L. K., G. W. Roberts, C. M. Hancock (2011): Using Locata to Augment GNSS, Civil Engineering Surveyor, GIS-GPS supplement, pp. 19-23.
2. Bonenberg L. K., G. W. Roberts, C. M. Hancock (2012): Using Locata To Augment GNSS In A Kinematic Urban Environment, Archives of Photogrammetry, Cartography and Remote Sensing, Vol. 22, ISSN 2083-2214, pp. 63-74.
3. Gunawan M, B. Li, T. Gallagher, A. G. Dempster, G. Retscher (2012): A New Method to Generate and Maintain a WiFi Fingerprinting Database Automatically by Using RFID. IEEE Xplore, 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN), ISBN: 978-1-4673-1954-6, 6 pgs.
4. Mok E., F. Lau, L. Xia, G. Retscher, H. Tian (2012): Influential Factors for Decimetre Level Positioning Using Ultra Wide Band Technology. Survey Review, Vol. 44, No. 324, January 2012, pp. 37-44.
5. Retscher G., M. Zhu, K. Zhang (2012): RFID Positioning. Chapter 4 in: Chen R. (Ed.): Ubiquitous Positioning and Mobile Location-Based Services in Smart Phones. IGI Global, Hershey PA, USA, ISBN: 978-1-4666-1827-5, DOI: 10.4018/978-1-4666-1827-5.ch004, pp. 69-95.
6. Xia L., D. Wu, E. Mok, G. Retscher (2011): Adaptive Indoor Hybrid Positioning for LBS. in: Papers presented at the 8th International Symposium on Location-Based Services LBS 2011, November 21-23, 2011, Vienna, Austria, pp. 61-75.
7. Zhu M., G. Retscher, K. Zhang (2011): Integrated Algorithms for RFID-based Multi-sensor Indoor/Outdoor Positioning Solutions. Archives of Photogrammetry, Cartography and Remote Sensing, Vol. 22, ISSN 2083-2214, pp. 451-465.

### **WG 4.1.4: Imaging Techniques**

*Chair: Mohamed Elhabiby (Egypt and Canada)*

*Co-Chair: Jens-André Paffenholz (Germany)*

The Working Group had a good start and a few members were recruited. A report, however, could not be provided in time by the chairs. Mr. Paffenholz who did most of the work in the reported period shall be considered to overtake the lead role in the Working Group so that the WG will be more active in the next period.

## **Sub-Commission 4.2: Geodesy in Geospatial Mapping and Engineering**

*Chair: Jinling Wang (Australia)*

Since the establishment of the sub-commission in 2011, the objectives for the five working groups have been developed and the website for the sub-commission was set up at <http://www.gmat.unsw.edu.au/iag-sc4.2>. Since then, the working groups have started developing memberships as well as to coordinating and participating in the professional activities. This report will present a brief update on the activities.

### **WG 4.2.1 Mobile Mapping Technologies and Applications**

*Chair: J. Skaloud (Switzerland)*

*Co-Chair: K.-W. Chiang (Taiwan)*

The IAG Sub Commission 4.2 and Working Group 4.2.1 have actively participated in organization of the International Symposium on Unmanned Airborne Vehicles for Geomatics, **UAV-g 2011** to be held in Zurich, September 14-16.

IAG Commission 4 and Working Group 4.2.1 have sponsored and actively participated “The International Summer School on Mobile Mapping Technology in 2012 and 2013, 11-15 June 2012; 29-30 April, 2013, National Cheng Kung University (NCKU), Tainan, Taiwan.

Program Details: <http://conf.ncku.edu.tw/mmt2013/course01.htm>



The 2013 Summer School on Mobile Mapping Technology (MMT 2013) was held right before the MMT symposium. The courses of this summer school were focused on the themes of inertial navigation and multi sensor integration, mobile mapping systems, photogrammetric and LiDAR Technologies, and various applications. President of IAG Commission 4, Prof. Dorota A. Grejner-Brzezinska, and Co-Chair of IAG Working Group 4.2.1, Associate Professor Kai-Wei Chiang, were among the invited lecturers for the Summer School on MMT in Tainan, 2012/2013.

The IAG Sub Commission 4.2 and Working Group 4.2.1 have sponsored and actively participated The 8<sup>th</sup> International Symposium on Mobile Mapping Technology – **MMT2013**, 1 – 2 May, Tainan, 201 (see the photo below).



The IAG Sub Commission 4.2 and Working Group 4.2.1 will actively participate in the International Symposium on Unmanned Airborne Vehicles for Geomatics, UAV-g 2013 to be held in Rostock, Germany, September 4-6.

The chair of IAG Working Group 4.2.1 is co-organizing the European Calibration and Orientation Workshop, EuroCOW 2014 to be held in Calstelldefels, Spain, 12-14 February where he is responsible for the session on Integrated Systems for Sensor Geo-referencing and Navigation.

The IAG Sub Commission 4.2 and Working Group 4.2.1 will actively participate The 9<sup>th</sup> International Symposium on Mobile Mapping Technology, MMT2015, to be held in Sydney, Australia (the dates: TBD). Prof Jinling Wang, Chair of the IAG Sub Commission 4.2, will be the convenor for the MMT2015.

#### *Publications:*

1. Chiang, K.-W.; Duong, T.T.; Liao, J.-K.; Lai, Y.-C.; Chang, C.-C.; Cai, J.-M.; Huang, S.-C. (2012) On-Line Smoothing for an Integrated Navigation System with Low-Cost MEMS Inertial Sensors. *Sensors*, 12(12), 17372-17389.
2. Chiang K-W, Tsai M-L, Chu C-H. (2012) The Development of an UAV Borne Direct Georeferenced Photogrammetric Platform for Ground Control Point Free Applications. *Sensors*, 12(7):9161-9180.
3. Chiang K-W, Duong TT, Liao J-K. (2013) The Performance Analysis of a Real-Time Integrated INS/GPS Vehicle Navigation System with Abnormal GPS Measurement Elimination. *Sensors*, 13(8):10599-10622.
4. Chiang ,K.W., Duong ,T.T., Liao J.k.,(2013), Performance of Real-Time Land-Based GPS-Aided MEMS Inertial Navigator with Interference from Reflected GPS Signals, *Sensors* 2013, 13(8), 10599-10622
5. Chu, H.J., Tsai, G.J., Chiang ,K.W., Duong ,T.T.,(2013), GPS/ MEMS INS data fusion and map matching in urban areas, *Sensors* 2013, 13(9), 11280-11288;

6. Lin C-A., Chiang, K-W., Chu, C-H. (2013), The Performance Evaluation of Pure Inertial Navigation System Aiding from DTM for Land Vehicular Applications: ION GNSS 2013 Meeting, Nashville, Tennessee, USA
7. Chu, C-H., Chiang, K-W., Lin C-A. (2013), The Performance Analysis of a Portable Mobile Mapping System with Different GNSS Processing Strategies: ION GNSS 2013 Meeting, Nashville, Tennessee, USA
8. Chu, C.H., and Chiang, K.W., (2013), The Performance Analysis of a Portable Mobile Mapping System, 2013 International Symposium on Mobile Mapping Technologies, Tainan, Taiwan
9. Guerrier, S., Waegli, A., Skaloud J., and Victoria-Feser M.-P. (2012) Fault Detection and Isolation in Multiple MEMS-IMUs Configurations, in IEEE Transactions On Aerospace And Electronic Systems, vol. 48, p. 2015-2031, 2012.
10. Kersting, A. P., Ayman, F. H., Ki-In B. and Skaloud J (2012). Automated approach for rigorous light detection and ranging system calibration without preprocessing and strict terrain coverage requirements, in Optical Engineering -Bellingham- International Society for Optical Engineering-, vol. 51, num. 7, p. 076201-1 – 19
11. Li, X., Wang J., Liu, W., & Li, R. (2013) Geo-referenced 3D map: Concept & experiments. 8<sup>th</sup> Int. Symp. on Mobile Mapping Technology, Tainan, Taiwan, 1-3 May. Paper 102
12. Skaloud J. and Schär P. (2012) Automated Assessment of Digital Terrain Models Derived From Airborne Laser Scanning, in PFG, vol. 2, p.0105-0114.
13. Wu, Y., & Wang J. (2013) Stochastic modeling of inertial errors for mobile mapping applications. 8<sup>th</sup> Int. Symp. on Mobile Mapping Technology, Tainan, Taiwan, 1-3 May. Paper 48
14. P. Molina, I. Colomina, T. Victoria, J. Skaloud, W. Kornus, R. Prades and C. Aguilera (2012) Searching lost people with UAVS: The system and results of the CLOSE-SEARCH project. XXII Congress of the International Society for Photogrammetry and Remote Sensing, Melbourne, Australia, August 25 - September 1, 2012.
15. Y. Stebler, S. Guerrier, J. Skaloud and M.-P. Victoria-Feser. A Framework for Inertial Sensor Calibration Using Complex Stochastic Error Models. ION/IEEE PLANS, Session A5, Myrtle Beach, SC, USA, April 2012. IEEE-ION Position Location and Navigation Symposium.
16. P. Molina, I. Colomina, P. Victoria, J. Skaloud, W. Kornus, R. Prades and C. Aguilera. Drones to the Rescue! Inside GNSS, vol. July/August, 2012.
17. R. Filliger, Y. Stebler, J. Skaloud and K. Hug. Autarktic and Inertial Measurement based Low-cost Reconstruction of Motorcycle forward Speed. Proceedings of the ENC GNSS 2013, Vienna, Austria, 2013.
18. M. Rehak, J. Skaloud, R. Mabillard, A Micro-UAV with the Capability of Direct. Georeferencing. UAV-g 2013, Rostock, Sep. 4-6.
19. S. Guerrier, R. Molinari, J. Skaloud and M.-P. Victoria-Feser. An algorithm for automatic inertial sensor calibration. ION GNSS+, Nashville, Tennessee, USA, September 16-20, 2013.

## **WG 4.2.2: Applications of Geodesy in Mining Engineering**

*Chair: A. Jarosz (Australia)*

*Co-Chair: J. Gao (China)*

Chair of IAG Working Group 4.2.2, Dr. Andrew Jarosz organised “2012 International Symposium on Mine Surveying and Mapping for Sustainable Mining”, The Symposium coincided with National Convention organised annually by the Australian Institute of Mine Surveyors on 9 August 2012 in the Sebel Hotel in Cairns, Queensland, Australia.

The Symposium was co-sponsored by Commission VI of the International Society for Mine Surveying, Australian Institute of Mine Surveyors and the Engineering and Mine Surveying Commission of Surveying and Spatial Sciences Institute, Australia, as well as the IAG Working Group 4.2.2. It attracted 25 international participants.

Program included the following presentations:

1. Jennifer Joi Field and Andrew Jarosz, WA School of Mines (Curtin University), Kalgoorlie, Australia: How Mapping and Spatial Information Can Contribute to Sustainability of Mining Projects
2. Zhengfu Bian, School of Environment Science and Spatial Informatics, CUMT, Xuzhou, China: Monitoring Land Subsidence due to Underground Coal Mining by means of Multiple Bands SAR Datasets in Mountainous Area
3. Guo Guangli, School of Environment Science and Spatial Informatics, CUMT, Xuzhou, China: Subsidence Prediction Method for Coal Mining with Solid Waste Backfill
4. Yang Fan and Wang Li-nan, School of Geomatics, Liaoning Technical University, Fuxin, China: Study on Formation Mechanism of Ground Fissures Induced by Coal Mining Under Complex Geological Conditions
5. Li Shuzhi (1) and Bingcheng Li (2), (1) Tangshan Branch of China Coal Research Institute, China, (2) The University of Queensland, Australia: Restoring and Maintaining Secondary Wetland Areas Caused by Mining Subsidence
6. Anatoly Okhotin, Alexander Zagibalov, Irkutsk State Technical University, Russia: Unmanned Aerial Vehicles (UAVs) in Mine Surveying
7. Yu Chang Xing, ISM Commission 6: Contents Extension and New Tasks in Mine Surveying

Dr. A. Jarosz was the Chairman of the Scientific Committee, and Associate Professor Jinling Wang, Chair of IAG Sub-Commission 4.2 was a member of the Scientific Committee for the Symposium.

#### *Publications:*

Jarosz, A., 2011. Mine Surveying, Chapter 9.4 in SME Mining Engineering Handbook, 3rd Edition, pp. 731 – 742, Society for Mining, Metallurgy and Exploration (SME), Englewood, CO.

Jarosz, A. and T. Snow, 2011. Geometric and Surveying Data, Chapter 13 in Monograph 9 - Field Geologists' Manual, 5th Edition, pp. 363 – 397, ISBN: 978 1 921522 48 2 (CD), 978 1 921522 47 5 (hardcopy), The Australian Institute of Mining and Metallurgy, Melbourne.

Lian XG, A. Jarosz, J. Saavedra-Rosas and Dai HY, 2011. Extending dynamic models of mining subsidence. Transactions of Nonferrous Metals Society of China (English Edition): 21 (SUPPL. 3), pp. 536-542.

Rowswell, S. and A. Jarosz, 2012. Deep-Sea Mining of Sea Floor Massive Sulphides in the Pacific Ocean, in MEA Research Project Review 2011 edited by P. Hogan, pp. 45-50, ISBN: 978 1 92152267 3, Mining Education Australia, Published by: The Australian Institute of Mining and Metallurgy, Melbourne.

Saavedra-Rosas, J. and A. Jarosz, 2012. From Analytical to Computational: Revisiting Subsidence Prediction with New Tools, *Proceedings, SOMP2012 -- Annual General Meeting of Society of Mining Professors*, in Cuprum Magazine, NR 2 (63), pp. 75-83, ISSN: 0137-2815, Published by: KGHM CUPRUM, Wrocław, Poland

### **WG 4.2.3: Geodetic technologies in Precision Farming**

*Chair: R. Bill (Germany)*

The new working group WG 4.2.3: “Geodetic technologies in Precision Farming“ has been established in 2011. WG 4.2.3 is chaired by R. Bill (University of Rostock, Germany). WG 4.2.3 is open for members from various disciplines, dealing with positioning, navigation and controlling of devices supporting precision farming technologies in agriculture. At the moment ca. 10 members are involved in the WG activities More details can be found on the web page: <http://www.iag-wg423-pf.auf.uni-rostock.de/iag.aspx>



Major objectives of this WG are to study, and report the use of geodetic tools in precision farming, in particular:

- Precise positioning and orientation of agricultural land-machinery and acquisition devices (such as geo-sensor networks, unmanned airborne vehicles, field robotics etc.).
- Precise navigation and guidance for intelligent agricultural vehicles capable of automating tasks.
- Precise mapping, interpretation of space-time heterogeneities in the field, derivation of agricultural application maps.
- Web-based data infrastructures and services used in agricultural environment.

The following highlights should be mentioned:

### ***UAV-g 2013 conference***

In the last years we saw a tremendously increasing use of so-called unmanned aerial vehicles, UAV (aka UAS, RPAS), in photogrammetric and geoinformatics research and development. The bi-annual conference series “UAV-g - Unmanned Aerial Vehicles in Geomatics” addresses this extended field of research and the first conference, which took place in Zurich, Switzerland, in 2011 was a great success (See report of WG 4.2.1). In 2013 the conference was held in Rostock, Germany, from September 4 to 6.

In total 230 participants from 35 countries followed the invitation of the chair for Geodesy and Geoinformatics at the Rostock University. There were 69 oral and 15 poster presentations, and as a special event on the Thursday, September 5, an airshow was organized on the airfield Barth. Here, 15 manufacturers, service providers and software companies demonstrated their systems.

IAG Sub Commission 4.2 members are actively participating in this conference and have been members of the Scientific Committee.

All conference papers appeared in the ISPRS archives, see <http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-1-W2/>. Selected publications will be prepared for special issues of dedicated scientific journals (Photogrammetrie, Fernerkundung und Geoinformation (PFG), International Journal of Image and Data Fusion (IJIDF) and GIS.SCIENCE).

In early September 2015 the next UAV-g will be held at York University in Toronto, Canada

### ***Research projects***

The chairman (and some members of the WG 4.2.3) has been involved in larger European research activities on web-based data infrastructures and services used in agricultural environment.

- Future Farm (2008-2010, <http://www.futurefarm.eu>): Meeting the challenges of the farm of tomorrow by integrating Farm Management Information Systems to support real-time management decisions and compliance to standards
- AgriXchange (2010-2012, <http://agrixchange.eu/>): Setup a network for developing a system for common data exchange in the agricultural sector.
- GeoWebAgri (2011-2012, <http://geowebagri.eu/>): Geospatial ICT infrastructure for agricultural machines and FMIS in planning and operation of precision farming
- FarmFUSE (2013-2016, <http://www.farmfuse.eu/>): Fusion of multi-source and multi-sensor information on soil and crop for optimised crop.

Individual research aspects of the group were related to precise positioning with low-cost GNSS (Stempfhuber, 2011, 2013), precise navigation and guidance, precise mapping as well interpretation of space-time heterogeneities in the field.

### ***Selected publications:***

Prof. Bill and members of his team have been invited to write the chapter on “GIS in Agriculture” for the Springer Handbook of Geographic Information.

1. Bill, R., Nash, E., Grenzdörffer, G. (2012): GIS in Agriculture. In: Kresse, W., Danko, D.M.: Handbook of Geographic Information. Springer. Page 795 - 819.
2. Behnke, R., Born, A., Salzmann, J., Timmermann, D., Bill, R. (2011): Combining Scalability and Resource Awareness in Wireless Sensor Network Localization. In: IEEE Conference on Computer Communications Workshops: IEEE INFOCOM 2011. Proceedings of the Third International Workshop on Wireless Sensor, Actuator and Robot Networks (WiSARN 2011). Page 531 - 536.
3. Grenzdörffer, G., Niemeyer, F., (2011) UAV Based BRDF Measurements of Agricultural Surfaces with PFIFFIKUS. In: Eisenbeiss, H. et al. [eds], *Int. Arch. Photogrammetry Remote Sens. Spatial Inf. Sci. Proceedings of the International Conference on Unmanned Aerial Vehicle in Geomatics (UAVg)*, Zürich.
4. Grenzdörffer, G., Niemeyer, F., Schmidt, F. (2012): Development of Four Vision Camera System for a Micro-UAV. In: Shortis, M., El-Sheimy, N. (Ed.): International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences : XXII ISPRS Congress Melbourne. Volume XXXIX-B1. : Copernicus Publications, Page 369 - 374.
5. ISPRS archives, see <http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-1-W2/>.
6. Nash, E., Nikkilä, R., Wiebenson, J., Walter, K., Bill, R. (2011): Interchange of Geospatial Rules - Towards Georules Interchange Format (GeoRIF)? In: *gis.Science*. 24. Jahrgang, Nr. 3, S. 82 - 94.
7. Nash, E., Wiebenson, J., Nikkilä, R., Vatsanidou, A., Fountas, S., Bill, R. (2011): Towards automated compliance checking based on a formal representation of agricultural production standards. In: *Computers and Electronics in Agriculture*. 78 Nr. 1, S. 28 - 37.
8. Nikkilä, R., Wiebenson, J. Nash, E., Seilonen, I., Koskinen, K. (2012): A service infrastructure for the representation, discovery, distribution and evaluation of agricultural production standards for automated compliance control. In: *Computer and Electronics in Agriculture*. 80, Nr. 0, S. 80 - 88.
9. Peets, S., Mouazen, A., Blackburn, K., Kuang, B., Wiebenson, J. (2012): Methods and procedures for automatic collection and management of data acquired from on-the-go sensors with application to on-the-go soil sensors. In: *Computer and Electronics in Agriculture*. 81, Nr. 0, S. 104 - 112.
10. Stempfhuber, W., Buchholz, M. (2011): High-End and Low-Cost RTK GNSS in Machine Control and Precision Farming Applications, FIG Working Week 2011 Bridging the Gap between Cultures, Marrakech, Morocco, 18-22 May 2011.
11. Stempfhuber, W. (2013): Geodätische Monitoringsysteme mit RTK Low-Cost-GNSS, tech 13 - Trends im Vermessungswesen: Aktuelle Trends und Herausforderungen in der Ingenieurgeodäsie
12. Wiebenson, J., Sørensen, C.A.G. (2011): Aspects of the Farm Management Information System related to standards and regulations. In: Nordic Association of Agricultural Scientists (Hrsg.): Automation and System Technology in Plant Production: NJF Report. 7, 5. Herning, Denmark.

### **WG 4.2.4: Monitoring of Landslides & System Analysis**

*Chair: G. Mentes (Hungary)*

*Co-Chair: J. Guo (China)*

According to the research aims the group worked intensively on the next research areas:

1. Different terrestrial and space measurement techniques were combined for continuous observation of surface movements. As terrestrial geodetic measurement techniques new instruments and methods were developed and tested. Instead of geodetic measurements carried out in periodical campaigns a great stress was laid on the continuous geodetic measurements techniques to get data series directly comparable with continuously collected hydrological (water table, stream stage, pore pressure, etc.), meteorological (e.g. precipitation, temperature), etc. data series for the study of dynamic processes of landslides and to get more reliable and comprehensive information for development of early warning systems.
2. Use of terrestrial radar systems for slope monitoring, meanwhile we have an IBIS-L system.
3. Investigation on different satellite radar bands for the estimation of the "normal behaviour" of the region of interest.
4. A special stress was laid on the combination of monitoring data with a numerical model which represents the structure and the kinematic and dynamic behaviour of the slope. Landslide modelling with support vector machines
5. The effect of the vegetation on the slope stability was also intensively investigated.

### **Some of the research projects which were /are carried out:**

P20137 KASIP - Knowledge-Based Alarm System with Identified Deformation Predictor Research project alpEWAS (Sudelfeld, Bayern): combined sensor network on landslide Anggenalm/Sulderfeld. Observation by PS Radarinterferometrie by DLR and Infoterra (EADS Astrium), GNSS+TPS.

Landslide Hornbergle (Reutte Tirol): test measurements by gbSAR, combined campaign measurements by GNSS+TPS.

EU FP7 Forschungsprojekt De-Montes (Deformation Monitoring by High Resolution Terrestrial Long Range Sensing) for further research of adoption of IATS and a combined photogrammetric/tahymetric/TLS measurement conception.

OTKA K78332 Kinematic and dynamic models of landslides by means of geodetic observations along the high bank of the Danube at Dunaszekcső, Hungary

OTKA K 81295 Development of measuring methods for detection of very small surface mass movements

IAG Sub Commission 4.2 and Working Group 4.2.4 will actively participate in "The Second Joint International Symposium on Deformation Monitoring" (JISDM), 9-11 September 2013, University of Nottingham, Nottingham, UK.

The conference details can be found at:

<http://www.nottingham.ac.uk/ngi/newsandevents/events/second-joint-international-symposium-on-deformation-monitoring.aspx>

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## **WG 4.2.5: Applications of Artificial Intelligence in Geospatial Mapping and Engineering Geodesy**

*Chair: H.-B. Neuner (Austria)*

*Co-Chair: U. Egly (Austria)*

IAG Working Group 4.2.5 organised the Workshop on “Applications of Artificial Intelligence in Engineering Geodesy”, 10-12 September 2012, Technical University of Munich, Munich, Germany. The proceedings of the workshop can be found at: <http://www.geo.bgu.tum.de/index.php?id=27>

Due to the change of his working environment, the previous WG Chair Dr R. Reiterer retired from the Chair position on 16 October 2013, but he still a member of the working group. The new Chair for this working group is Prof Hans-Berndt Neuner, Vienna University of Technology (<https://geo.tuwien.ac.at/staff/hans-berndt-neuner/>)

## **Sub-Commission 4.3: Remote Sensing and Modelling of the Atmosphere**

*Chair: Marcelo Santos (Canada)*

*Co-Chair: Jens Wickert (Germany)*

A summary of activities is presented covering the period of 2011 to 2013. SC 4.3 is composed of one Study Group and three Working Groups.

### **SG 4.3.1 Ionosphere Modelling and Analysis**

*Chair: Michael Schmidt (Germany),*

*Co-Chair: Mahmut O. Kararlioglu (Turkey),*

*Members:*

Lung-Chih Tsai (Taiwan), Dieter Bilitza (USA), Denise Dettmering (Germany), Mahdi Alizadeh (Austria), C.K. Shum (USA), Kuo-Hsin Tseng (USA), Norbert Jakowski (Germany), Robert Heinkelmann (Germany), Andrzej Krankowski (Poland), Pawel Wielgosz (Poland), Lee-Anne McKinnell (South Africa), Marco Limberger (Germany), Wenjing Liang (Germany), Shin-Chan Han (USA), Manuel Hernandez-Pajares (Spain), Claudio Brunini (Argentina)

*Research Activities:*

- At TUM, DGFI and DLR the electron density distribution within the ionosphere is described vertically by an adapted Chapman function which consists of an F2 Chapman profile and a plasma-sphere layer. To account for the horizontal and the temporal behaviour, the fundamental key parameters of this physics-motivated approach, such as the maximum electron density NmF2, the corresponding height hmF2 and the F2 scale height HF2, are each modelled by series expansions in terms of tensor products of localizing B-spline functions depending on longitude, latitude and time. For testing the procedure the model is applied to an appropriate region in South America, which covers relevant ionospheric processes and phenomena such as the Equatorial Anomaly. Due to their individual sensitivities with respect to the key parameters, different observation techniques are used and combined. Relevant validations have been carried out for STEC data from ground-based GPS and electron density profiles derived from GPS radio occultation on FORMOSAT-3/COSMIC, GRACE and CHAMP.
- The main activity at GESA is focused on developing a suitable model and a numerical strategy for combining ionospheric information derived from different beacon satellites measurements to generate a global representation of the electron density. Ground-based GNSS measurements, VTEC estimations derived from satellite altimetry missions and electron density estimations derived from space-based GPS receivers, are consistently combined on the observation level to determine the parameters of the empirical functions that describe the 4-D (latitude, longitude, height and time) electron density distribution of the different ionospheric layers. Several years were analysed in order to assess the performance of the combination technique under low solar activity conditions.
- The focus of another study at DGFI and TUM is the evaluation of DORIS data for ionosphere modeling. Recently launched satellite missions such as JASON-2, Cryosat, HY-2A and Saral have DGXX instruments on board which allow for tracking continuous dual-frequency phase observations and, hence, the extraction of STEC. A single layer model

approach has been used to derive VTEC where the spatio-temporal TEC distribution is described by mathematical B-spline functions. The validation of the derived VTEC has been carried out by comparisons with other models, for instance, the IGS GIMs where significant improvements due to the combination of GPS and DORIS can be observed.

- GPS radio occultation measurements allow for sounding the Earth's atmosphere, in particular the ionosphere. The physical observables estimated with this technique allow for testing theoretical models of the ionosphere, for example, the Chapman and the Vary-Chap models. The former is traditionally characterized by a constant scale height HF2, whereas the latter considers a more general function of the scale height and the height. At UPC the feasibility of a novel and simple model was investigated where the scale height varies linearly with the height. The scale height data provided by the radio occultation measurements from a LEO satellite is used in a linear least squares fit to test this hypothesis. Preliminary results, based on FORMOSAT-3/COSMIC GPS occultation data, show that the scale height presents a clear linear trend above hmF2. Moreover, according to this preliminary analysis, the parameters of the linear fit do not depend significantly on the local time, but on the latitude.
- The International Reference Ionosphere (IRI) describes the monthly average behaviour of the Earth's ionosphere based on most of the accessible and reliable ground- and space-based observations of ionospheric parameters. With the ever-increasing dependence on space technology the IRI development is going beyond the monthly averages in order to provide a quantitative description of ionospheric day-to-day variability depending on altitude, time of day, time of year, latitude as well as solar and magnetic activity. The IRI team is also pursuing the development of the IRI Real-Time (IRI-RT) that uses assimilative algorithms or updating procedures to combine IRI with real-time data for a more accurate picture of current ionospheric conditions.
- The Satellite Geodesy Group at the Department of Geodesy and Geoinformation Science of the Technical University of Berlin (TUB) is effectively contributing to the aims IAG Study Group 4.3.1 in a variety of fields. In the field of combination, TUB is developing combined global maps of VTEC using various space geodetic techniques, e.g. GNSS, satellite altimetry, Formosat-3/Cosmic, etc. In the field of physics-motivated modeling of the ionospheric parameters, TUB has achieved global modeling of F2-peak electron density (NmF2) and F2-peak height (hmF2) by applying a combined electron density representation to the GNSS ionospheric observables. The electron density representation at TUB is comprised from combination of multi-layer Chapman function for the bottom-side and topside ionosphere, and Topside Ionosphere/Plasma-sphere (TIP) model for the plasma-spheric contribution.
- At METU studies have been performed on the non-parametric forward-backward stage wise algorithms MARS and BMARS for VTEC estimation; related results are published. Currently, iterative algorithms for tomographic reconstruction of the ionosphere using heterogeneous data collected from ground and satellite based observations are investigated. The main purpose of the current research is to find flexible, efficient, accurate and stable reconstruction of the spatio-temporal ionospheric electron density in 4 dimensions based on multivariate adaptive regression B-Splines. Moreover, estimation of the instrumental biases of the satellites and receivers inside the algorithm or by a combination of parametric and non-parametric approaches will be investigated. Additionally we are working on station based modeling of the ionospheric VTEC estimation using particle filters for near real time applications particularly during geomagnetic storms, since particle filters are effective algorithms for the estimation of nonlinear and non- Gaussian high dynamic systems .

The connection of the individual research topics is the most important issue of the next two years. In order to define a road map we organized a splinter meeting during the EGU 2012 General Assembly in Vienna. As a first outcome Lung-Chi Tsai (NCU) organized in the framework of the IAG SG 4.3.1 the Session GFH-2 entitled as “Developments and/or applications of a multi-dimensional ionospheric electron density model” which will be held at the Asia-Pacific Radio Science Conference AP-RASC'13, September 3-7, 2013 in Taipei, Taiwan. As in the ToR of the SG 4.3.1 the overall intention of the announced session is the combination of physics, mathematics and statistics to derive a high-resolution multi-dimensional ionosphere model. Several members of SG 4.3.1 will attend the conference.

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### **WG4.3.1 Standards for space weather products for geodetic and ionospheric studies**

*Chair: Andrzej Krankowski (Poland)*

*Members:*

Dieter Bilitza (USA), Manuel Hernandez-Pajares (Spain), Atilla Komjathy (USA), Michael Schmidt (Germany), Hanna Rothkaehl (Poland), Iurii Cherniak (Russia), Irina Zakharenkova (Russia)

*Reports on activities*

The objective of this WG is to suggest common international standards for the dissemination of space weather products used in geodesy and ionospheric studies. This WG works in close scientific collaboration with IGS, URSI and COSPAR IRI group.

Special session G5.5 and G5.1 “Monitoring and modelling of the ionosphere from space-geodetic techniques” was organized during General Assembly EGU 2012 and EGU 2013, respectively.

During the last IGS Workshop 2012 held at the University of Warmia and Mazury in Olsztyn, Poland from 23 – 27 July 2012 was also organized by members the special session “Atmospheric Delay Modeling and Applications” and the Ionosphere Working Group Splinter Session. After this IGS Workshop the following recommendations from IGS WG were prepared:

- Starting a new official/operational product – TEC fluctuation changes over North Pole to study the dynamic of oval irregularities (carried out by UWM to be started as official/routine product after performance evaluation period,
- Higher temporal and spatial resolution of IGS combined GIMs - the IAACs (UPC and JPL) agreed on providing their maps in IONEX format, with a resolution of 15 min, 1 degrees and 1 degrees in time, longitude and latitude respectively,
- The new the IAAC from GNSS Research Center (GRC), Wuhan University, China
- Close cooperation with IRI COSPAR group.

Recently the International Standardization Organization, ISO, recommends the International Reference Ionosphere (IRI) for the specification of ionosphere plasma densities and temperatures and indicates necessity for extending IRI to the plasma-sphere’s altitudes. At the IRI Workshop 2013 “IRI and GNSS”, organized in Olsztyn, Poland, the IRI Working Group recommends to adjust IRI-Plas model to IRI 2012 version and adjust GPS TEC into IRI Real Time (IRTAM).

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12. Zakharenkova I.E., Krankowski A., Shagimuratov I.I., Cherniak Yu.V., Krypiak-Gregorczyk A., Wielgosz P., Lagovsky A.F., 2012, Observation of the ionospheric storm of October 11, 2008 using FORMOSAT-3/COSMIC data, *Earth, Planets and Space (EPS)*, Vol. 64 (No. 6), pp. 505-512, DOI 10.5047/eps.2011.05.019.
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### **WG4.3.2 Inter-comparison and cross-validation of tomography models**

*Chair: Alain Geiger (Switzerland)*

*Co-Chair: Witold Rohm (Australia)*

#### *Reports on activities*

The IAG working group was established in spring 2012 and its aim is to address main deficiencies in the tomography model construction. In order to successfully achieve this objective, the members decided to split up the work into several logical steps, outlined below. Firstly identification of critical steps in GNSS tomography processing the discussion held mainly by e-mail resulted in following list (not exclusive): slant delay calculation based on DD or PPP solution, the model structure definition (voxel model, node model, outer model, nested models), inversion technique and linked with this topic constraints applications and finally the benefits and flaws of Least Squares approach or Kalman Filter approach. Therefore in multi-model solution these points will be reviewed carefully. Members decided that tomography solution should cover wet refractivity and integrated water vapour content;

therefore both Slant Wet Delay (SWD) as well as Slant Integrated Water Vapour (SIWV) are to be utilised. This decision generated fair amount of coding works since not all models have the dual capability. The observations conversion (ZTD to SWD/SIWV) between models varies significantly and testing revealed bugs in some model codes. Secondly, the reference database covering meteorological parameters as well as ground based observations was established. It has been decided to use Numerical Weather Prediction data for state of Victoria in Australia and GNSS observations from the state's CORS network over a period of Mesoscale Convection System occurrence. Common Slant Delay data source have been established covering two types of data simulated (based on NWP data) and real world (based on ZTD estimation). Thirdly, common model setup (size, number and domain of the model) has been chosen as a proper way to establish reference for inter-comparison studies. Again, this decision involved large amount of work, not all models have the same flexibility in setting up the model structure, and some new functionalities had to be introduced. In meanwhile new members joined the group adding new interesting 2D tomography capability to the inter-comparison studies. Currently, all modifications to the model codes are finished and the WG is in the process of running simulations observations with different strategies, it will be followed by real a world experiment. The WG submitted an abstract of a paper based on the outcomes of this inter comparison study to be presented at the IAG General Assembly in Potsdam 2013 and will be published as a Journal Paper by the end of 2013.

#### *Publications:*

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### **WG4.3.3 Integration of GNSS atmosphere models with NWP models**

*Chair: Jaroslaw Bosa (Poland)*

*Co-Chair: Henrik Vedel (Denmark)*

#### *Members:*

Jonathan Jones (UK), Jan Dousa (Czech Republic), Rosa Pacione (Italy), Guergana Guerova (Bulgaria), Norman Teferle (Luxembourg), Shuli Song (China), Szabolcs Rozsa (Hungary), Yuei-An Liou (Taiwan), Ryuichi Ichikawa (Japan), Joseph Awange (Australia), Jean-Pierre Barriot (French Polynesia), Shuanggen Jin (China), Ambrus Kenyeres (Hungary), Ahmed Furqan (Luxembourg), Jan Kaplon (Poland), Gemma Bennitt (UK)

#### *Report on activities*

Activities through 2011 and 2012 involved in the problems: a) assimilation of GNSS data processing products in NWP models and validation and comparison of different of GNSS atmosphere models using NWP outputs. Determine the nature and extent meteorological data, that could be used by GNSS community to improve the atmosphere used in GNSS data pro-

cessing in postprocessing and real time mode. (*Bennitt and Jupp, 2012, Chen et al., 2011, Dousa and Bennitt, 2012, Pacione et al., 2011, Song et al., 2012*), b) use of GNSS atmosphere and NWP models in real-time positioning methods: RTK and PPP. Comparison of GNSS and meteorological and MWP products (*Hadas et al., 2013*), c) development of GNSS data processing strategies for new tropospheric products to move for Near Real Time to Real Time availability (*Dousa, 2012, Bosy et al., 2012*).

Since 2012, started collaboration with members of E-GVAP The EUMETNET EIG GNSS water vapour programme (<http://egvap.dmi.dk/> (represented by Henrik Vedel) in area of GNSS models assimilation in NWP models. WG members joined to the COST Action 1206 “Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)” (managed by Jonathan Jones) for the construction of real-time GNSS tropospheric products.

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2. Bosy J., Kapłan J., Rohm W., Sierny J., Hadaś T.: Near real-time estimation of water vapour in the troposphere using ground GNSS and the meteorological data. *Annales Geophysicae*, Vol. 30 No. , Göttingen, Germany 2012, pp. 1379-1391, DOI: 10.5194/angeo-30-1379-2012;
3. Dousa J.: Development of the GLONASS Ultra-Rapid Orbit Determination at Geodetic Observatory Pecny, [in] S. Kenyon et al. (eds.), *Geodesy for Planet Earth*, International Association of Geodesy Symposia 136, DOI 10.1007/978-3-642-20338-1\_129, # Springer-Verlag Berlin Heidelberg 2012;
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#### *Conferences:*

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3. Bennitt G.V. and Schueler T.: An assessment of zenith total delay corrections from numerical weather prediction models. *European Geosciences Union General Assembly 2012*, Vienna, Austria, 22-27 April 2012;

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10. Vedel H. and Amstrup B.: Impact of gb GNSS data in NWP, as case study. European Geosciences Union General Assembly 2012, Vienna, Austria, 22-27 April 2012;
11. Zus, F., G. Dick, S. Heise and J. Wickert: Monitoring of GPS slant total delays at GFZ Potsdam, European Geosciences Union General Assembly 2012, Vienna, Austria, 22-27 April 2012;

## **Sub-Commission 4.4: Applications of Satellite and Airborne Imaging Systems**

*Chair: Zhenhong Li (UK)*

In the past decades, satellite and airborne imaging systems, e.g. Synthetic Aperture Radar (SAR), Light Detection And Ranging (LiDAR) and Satellite Altimetry (SA), have been increasingly employed to gain insights into geophysical and engineering processes such as earthquakes, landslides, volcanoes, and structural deformation of infrastructure. The main objectives of this SC are to promote collaborative research in the development of imaging systems for geodetic applications, and to facilitate communications and exchange of data, information and research results through coordinated efforts. There are five working groups in SC4.4. Since their establishments in 2011, all the working groups have been actively recruiting new members and coordinating/participating in research and professional activities. This report attempts to summarize the major activities conducted during the period from 2001 to 2013.

### **WG 4.4.1: Quality Control Framework for InSAR Measurements.**

*Chair: Z. Li (UK)*

*Co-Chair: S. Samsonov (Canada)*

#### *Main Research Activities*

A variety of advanced InSAR techniques have been developed to separate deformation signals from error sources such as atmospheric effects, orbital ramps and DEM errors: (1) MERIS atmospheric correction model for reducing tropospheric water vapour effects on Wide Swath InSAR measurements (Li et al., 2012); (2) Multidimensional Small BAseline Subset (MSBAS) InSAR for estimating 2D or 3D time-series of deformation (Samsonov and d'Oreye, 2012); (3)  $\pi$ -RATE (Poly-Interferogram Rate And Time-series Estimator) for estimating displacement rate, time series and their associated uncertainties (Wang et al., 2012).

### **WG 4.4.2: InSAR Observation and Modelling of Earthquakes, Volcanoes and Tectonics**

*Chair: T. Wright (UK)*

*Co-Chair: A. Hooper (UK)*

#### *Main Research Activities*

This WG has successfully responded to several recent large earthquakes, e.g. the 2010 Yushu earthquake (Li et al., 2011), the 2010-2011 Canterbury Earthquakes (Elliott et al., 2012), and the 2011 Tohoku-Oki (Japan) earthquake (Wright et al., 2012). A new algorithm has been developed to combine geodetic data with satellite gravity measurements to model the source parameters of the 2011 Tohoku-Oki (Japan) earthquake (Feng et al., 2013). The postseismic motion following the large Kokoxili event has been mapped using InSAR (Wen et al., 2012).



### **WG 4.4.3: Landslide Monitoring and Modelling with InSAR observations**

*Chair: R. Tomás-Jover (Spain)*

*Co-Chair: R. Furuta (Japan)*

#### *Main Research Activities*

Firstly, a webpage has been created to provide a meeting point to the worldwide researchers who are interested in InSAR and landslide monitoring and modelling. The WG organized a monographic session focused on Natural Hazards in the International Workshop in Environmental Security, Geological Hazards and Management held in Tenerife, Canary Islands, Spain on 10-12 April 2013. Finally, the Chairmen of this WG have published more than ten papers on SCI indexed journals, most of which focus on the application of DInSAR for landslide monitoring and modelling.

### **WG 4.4.4: Vertical crustal motion from Satellite Altimetry**

*Chair: H. Lee (USA)*

*Co-Chair: H. Wang (China)*

#### *Main Research Activities*

This WG has focused on improving retracking and surface gradient correction algorithms for satellite radar altimeter measurements over non-ocean surfaces towards estimating: (1) Topographic vertical motion over the Qinghai-Tibetan Plateau; (2) Ice mass balance over West Antarctica; (3) Glacier elevation changes over Bering Glacier, Alaska; (4) Coastal sea surface heights; (5) Water elevation changes over inland water bodies (river, lake, and wetlands) under different climate regimes (Congo, Ganges-Brahmaputra-Meghna basins, and Qinghai-Tibetan Plateau). This WG will continue to work on these various types of topographic surfaces, and test the new Ka-band measurements from recently launched SARAL/AltiKa satellite radar altimeter.

### **WG 4.4.5: LiDAR, Laser Scanning and Surface Generation**

*Chair: B. Yang (China)*

*Co-Chair: N. Tate (UK)*

#### *Main Research Activities*

The main research activities of this WG include: (1) Integration of Laser Scanning Point Clouds and panoramic imagery for 3D reconstruction, texture mapping and classification; (2) UAV Mapping for Transportation, LBS, and GIS applications; A spatial pattern based method has been developed to match and fuse imagery, point clouds, and GIS database for 3D mapping and database updating.

#### *Conferences:*

1. Joint International Symposium on Deformation Monitoring, Hong Kong, China, 2-4 November 2011 (Jointly organised by IAG SC4.4 and FIG: <http://dma.lsgi.polyu.edu.hk>)

2. The International Earth Science Colloquium on the Aegean Region, Dokuz Eylül University, Izmir, Turkey, 1-5 October 2012 (one InSAR special session organised by IAG WG 4.4.1: <http://web.deu.edu.tr/iesca/ocs/index.php/iesca/2012>)
3. The 3rd International Workshop on Gravity, GPS and Satellite Altimetry Observations of Tibet, Xinjiang and Siberia (TibXS), Chengdu, Sichuan, China, 26-30 August 2012 (Co-organized by: IAG WG 4.4.4: [http://www.sgg.whu.edu.cn/tibxs/tibxs2012/pdf/Proceedings\\_of\\_the\\_3rd\\_TibXS\\_workshop.pdf](http://www.sgg.whu.edu.cn/tibxs/tibxs2012/pdf/Proceedings_of_the_3rd_TibXS_workshop.pdf))
4. International Workshop in Environmental Security, Geological Hazards and Management, Tenerife, Canary Islands, Spain, 10-12 April 2013 (one landslide special session organized by IAG WG 4.4.3: <http://eventos.ull.es/entornamentalsecurity2013/>)

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8. ERKAN, K., C. SHUM, H. LEE, C. JEKELI, W.R. PANERO, L. WANG, H. WANG, Possible constraints on the vertical processes interior of the Qinghai-Tibetan Plateau and their effects on satellite geodetic signals, *Terrestrial Atmospheric and Oceanic Sciences*, 22, 241-253, 2011.
9. Ferguson DJ; Calvert AT; Pyle DM; Blundy JD; Yirgu G; Wright TJ (2013) Constraining timescales of focused magmatic accretion and extension in the Afar crust using lava geochronology., *Nat Commun*, 4, pp.1416.
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## **Sub-Commission 4.5: High-Precision GNSS Algorithms and Applications**

*Chair: Yang Gao (Canada)*

- **WG4.5.1 Quality Measures for Network Based GNSS Positioning**

*Chair: Xiaolin Meng (UK)*

*Co-Chair: Hans-Juergen Euler (Switzerland)*

- **WG4.5.2 Precise Point Positioning and Network-RTK**

*Chair: Sunil Bisnath (Canada)*

*Co-Chair: Sue Lynn Choy (Australia)*

- **WG4.5.3 Integer Ambiguity Resolution for PPP and PPP-RTK**

*Chair: Xiaohong Zhang (China)*

*Co-Chair: Patrick Henkel (Germany)*

- **WG4.5.4 Multi-frequency, Multi-constellation Sub-cm RTK**

*Chair: Bofeng Li (Australia)*

*Co-Chair: Yanming Feng (Australia)*

*Academic Activities, Conference, Workshop, Technical Session*

- The Global Navigation Satellite System (GNSS) School on “New GNSS Algorithms and Techniques for Earth Observations 2012 (nGATEo 2012)” was successfully held in 14-15 May 2012, Polytechnic University (PolyU), Hong Kong. Sponsored by IAG and organized by Dr. George Liu, Secretary of SC4.5, it has more than 50 international participants from academia, industry and government agencies in Hong Kong, Mainland China, Australia, and Korea attended this GNSS School, including many in-school MSc/PhD students from mainland China. Five internationally distinguished scholars from Australia, China, Germany and USA were invited to give lectures during the two-day events.



- Beidou/GNSS Summer School on GNSS Frontier Technologies was successfully held at Beihang University, Beijing China during 25-31 August 2012. The summer school has been sponsored by IAG, CPGPS and Beihang University. The summer school has attracted 65 participants from 24 organisations in mainland China, Taiwan, Hongkong, and Pakistan. Eight internationally distinguished scholars from Australia, China, Canada, Finland, Germany and USA were invited to give lectures.



- SC4.5 contributed to the organization of the 2012 International Forum on Advanced Theory and Technologies in Geomatics (2012 IFATTG), May 19–21, 2012, Liaoning Technical University, Fuxin, China.



- SC4.5 contributed to the organization of GNSS Precise Point Positioning Workshop: Reaching Full Potential, 12-14 June 2013, Ottawa, Canada, sponsored by York University, Natural Resources Canada (NRCan), the IAG, the IGS, Natural Sciences and Engineering Research Council of Canada (NSERC). The purpose of the workshop was to bring together leading academic, government and industry researchers from across the globe to present the latest research findings and developments in GNSS PPP; to discuss issues related to advancing PPP technology; and, to contemplate the potential of PPP as the future positioning technique for high-accuracy satellite positioning, navigation and timing. The workshop attracted approximately 100 participants from 20 countries, representing over 50 different academic, government and industrial organizations. Attendees included data product producers, solution providers, technology users, and interested parties. The structure of the workshop consisted of oral sessions as well as moderated discussion sessions. Further information, including the complete post-workshop report (to be completed), the submitted presentations and posters, list of registrants, and photographs from the event can be found on the workshop website: [www.yorku.ca/pppworkshop2013](http://www.yorku.ca/pppworkshop2013).



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**GNSS PRECISE POINT POSITIONING WORKSHOP:  
REACHING FULL POTENTIAL**

12-14 June 2013  
Ottawa, Canada



- SC4.5 proposed and organized a session G1.3 "High-Precision GNSS Algorithms and Applications in Geosciences", European Geosciences Union General Assembly 2013, Vienna, Austria, 7-12 April 2013, chaired by Drs. Pawel Wielgosz and Marong Ge. The session has attracted 29 abstract submission with 12 oral presentations: 12 and 14 poster presentations, nearly half of them are from young scientists.
- Prof. Yanming Feng chaired a session at International Symposium on GPS/GNSS 2012, Oct.30 - Nov.2, 2012, Xi'an, China
- Dr. Dennis Odijk is a session chair at 12th Australia Space Science Conference, 24-26 September. 2012, Melbourne, Australia.
- Dr. Nobuaki Kubo is a session co-chair at ION GNSS 2012, September 18–21, 2012, Nashville, Tennessee, USA
- Dr. Bofeng Li is a session chair at the summer school with celebrating 100 anniversary of Shanghai Ocean University, 9 July 2012, Shanghai, China.
- Dr. Xiaohong Zhang chaired a session on International symposium on GPS/GNSS 2012, October 30 – November 2, 2012, Xi'an, China
- Curtin University (Prof. Peter Teunissen) and the Technical University of Munich (Dr. Patrick Henkel) collaborated on Integer Ambiguity Resolution for Precise Point Positioning and Attitude Determination.
- Drs. Yang Gao and Maorong Ge chaired the session "Precise Point Positioning at ION GNSS 2012, Nashville, Tennessee, September 17-21, 2012.
- Dr. Choy co-chaired a session "Precise Point Positioning and RTK" at ION GNSS 2011, September 19-23, 2011, Portland, Oregon, USA.
- Dr. L. Dai co-chaired a session "Precise Positioning, Multipath Mitigation and Advanced Processing Algorithms" at PLANS 2012, April 24-26, 2012, Myrtle Beach, South Carolina, USA.
- Dr. L. Dai co-chaired a session "Marine Navigation and Applications" at ION GNSS 2012, Nashville, Tennessee, September 17-21, 2012.
- Dr. Dai co-chaired a session on "Agricultural and Land Vehicle Applications" at ION Pacific PNT 2013, April 22-25, 2013, Hawaii, USA.



- WG4.5.1 “Quality Measures for Network Based GNSS Positioning” will organize the second Joint FIG/IAG International Symposium on Deformation Monitoring (JISDM), 9-11 September 2013, Nottingham, UK.
- WG4.5.2 “Precise Point Positioning and Network-RTK” will contribute to the organization of the 2013 International Conference on Earth Observation for Global Changes (EOGC'2013) and the 2013 Canadian Institute of Geomatics Annual Conference, 5-7 June 2013, Toronto, Canada
- WG4.5.2 “Precise Point Positioning and Network-RTK” will organize the PPP Workshop, 12-14 June 2013, Ottawa, Canada
- WG4.5.3 “Integer Ambiguity Resolution for PPP and PPP-RTK” will organize a Special Session on PPP at the 55-th International Symposium ELMAR-2013, 25-27 September 2013, Zadar, Croatia
- WG4.5.4 “Multi-frequency, Multi-constellation Sub-cm RTK” will contribute to the organization of the second GNSS Summer School, August, 2013, Beijing, China

### *Publications*

1. Xiaohong Zhang, Pan Li, Assessment of Correct Fixing Rate for Precise Point Positioning Ambiguity Resolution on Global Scale, *Journal of Geodesy* (online)
2. Xingxing Li, Maorong Ge, Xiaohong Zhang, Yong Zhang, Bofeng Guo, Rongjiang Wang, Jürgen Klotz, Jens Wickert, Real-time high-rate coseismic displacement from ambiguity-fixed PPP: Application to earthquake early warning, *Geophysical Research Letter* (2013)
3. Xiaohong Zhang, Fei Guo, An Approach to Improve Precise Point Positioning Performance under the Presence of Ionospheric Scintillation, *GPS Solutions* (online)
4. Fei Guo, Xiaohong Zhang, Real-time Clock Jump Compensation for Precise Point Positioning, *GPS Solutions* (online), DOI: 10.1007/s10291-012-0307-3
5. Zhang Xiaohong, Guo Bofeng, Guo Fei, Du Conghui, Influence of clock jump on the velocity and acceleration estimation with a single GPS receiver, *GPS Solutions* (online)
6. Xiaohong Zhang, Pan Li, Single Receiver, *Advances in Space Research* (2012), DOI: 10.1007/s11664-012-1611-1, Volume 51, Issue 1:153–161
7. Xiaohong Zhang, Fei Guo, Xingxing Li. A novel Stop&Go GPS precise point positioning (PPP) method and its application in geophysical exploration and prospecting, *Survey Review* (2012), DOI: 10.1179/1752270611Y.0000000016
8. Xiaohong Zhang, Xingxing Li. Instantaneous re-initialization in real-time kinematic PPP with cycle slip fixing, *GPS Solutions* (2012) 16:315–327
9. Xingxing Li, Xiaohong Zhang, Improving the Estimation of Uncalibrated Fractional Phase Offsets for PPP Ambiguity Resolution, *Journal of Navigation* (2012), 65, 513–529, doi:10.1017/S0373463
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16. Brack, P. Henkel and C. Günther, Sequential Best Integer-Equivariant Estimation for Geodetic Network Solutions, *Proc. of ION ITM*, San Diego, Jan. 2013
17. Zhibo Wen, Patrick Henkel, Andreas Brack, and Christoph Günther. Best Integer Equivariant Estimator for Precise Point Positioning. In *Proc. of 54th Intern. IEEE Symposium ELMAR*, Zadar, Croatia, 2012.
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of ION GNSS 2011, Portland, OR, Sept 2011.

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44. Zhang Y, S Lee (2011) "Nexteq i-PPP: A Low-cost world-wide Precise Point Positioning System and Service," Proceedings of ION GNSS 2011, Portland, OR, September 2011.
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## **Sub-Commission 4.6: GNSS-Reflectometry and Applications**

*Chair: Shuanggen Jin (China)*

*Website: [http://202.127.29.4/geodesy/IAG\\_SC4.6/](http://202.127.29.4/geodesy/IAG_SC4.6/)*

### *Terms of Reference*

The Global Navigation Satellite System (GNSS) is a highly precise, continuous, all-weather and near-real-time microwave (L-band) technique, which implies more and wider applications and potentials. Recently, the versatile reflected and scattered signals of GNSS have been successfully demonstrated to sound the land surfaces (including soil moisture), ocean, and the cryosphere as a new remote sensing tool. The GNSS reflected signals from the ocean and land surface could determine the ocean height, wind speed and wind direction of ocean surface, soil moisture, ice and snow thickness, which could supplement the traditional remote sensing techniques, e.g., radar altimetry. The focus of this Sub-Commission (SC4.6) is to facilitate collaboration and communication, and to support joint researches with promising GNSS-Reflectometry (GNSS-R) technique. Specific objectives will be achieved through closely collaborating with working groups and other IAG Commissions/Sub-Commissions. Meanwhile, close collaboration with the International GNSS Service (IGS), Institute of Navigation (ION) and IEEE Geoscience and Remote Sensing Society (IGRASS) will be promoted, such as joint sponsorship of international professional workshops and conferences.

### *Objectives*

- To promote and extend GNSS Reflectometry/Scatterometry developments and tests as well as environment remote sensing applications;
- To improve the existing estimation algorithms, inversion theory and temporal-spatial resolution in GNSS reflectometry from the ocean and land surface and supplement the traditional remote sensors, e.g., Satellite Altimetry;
- To coordinate data from GNSS-R campaign experiments and provide environment remote sensing products through fusing with other terrestrial and satellite observations;
- To address coastal ocean topography, ocean surface roughness characteristics (wind speed/direction and wave height), ice motion, wetland monitoring and surface soil moisture and snow/ice thickness as well as the condition of sea ice, glacial melting and the freezing/thaw state of frozen ground;
- To facilitate collaboration and communication with mutual Remote Sensing related communities (Oceanography, Hydrology, Cryosphere, Geodesy...)

### *Program of Activities*

The Sub-commission will establish Work Groups (WGs) on relevant topics, and promote GNSS Reflectometry/Scatterometry developments and remote sensing applications. Chair/Co-Chair will work closely with members and other IAG Commissions/Sub-Commissions to obtain mutual goals. Also we will organize international workshops and symposiums to provide a platform for GNSS-R communication and collaboration and jointly sponsor special sessions at IAG Symposia and other workshop/conferences with IGRASS and ION.

## Working Groups

### WG 4.6.1 GNSS-R System and Development

*Chair: Manuel Martin-Neira (The Netherlands)*

*Co-Chair: Fran Fabra (Spain)*

Within these 3 years (2011-2013) the *interferometric* technique of the Passive Reflectometry and Interferometry concept (PARIS), under study within the European Space Agency, has been well consolidated. This technique consists of the straight correlation between direct and reflected signals, without the use of any clean code replica on-board. Satellite discrimination is performed through the antenna beam, delay and Doppler diversity, particular to each satellite of each GNSS constellation. Spatial selectivity is achieved through the use of parallel high gain antenna beams, i.e. beam-forming antennas in both, up- and down-looking receiving antennas. Because of the use of the maximum bandwidth of the GNSS signals, this technique is thought to provide the best altimetric performance for GNSS reflectometry.

Following a successful bridge experiment 7-8 July 2010, in 11 November 2011 the first airborne experiment of the PARIS interferometric technique was carried out. The data were processed by IEEC and the 2 cm/km slope of the geoid in the Baltic Sea area of the experiment was clearly measured, with a standard deviation of about 13 cm after 20 s. The waveforms retrieved matched well the expected ones for low wind speed, in line with the actual weather conditions during the test. The test set-up had to be restricted to one single high gain antenna beam looking up, and the same looking down. Therefore, this airborne experiment could show precise altimetry only within 15 degrees away from the aircraft track. A future experiment is being planned that will demonstrate altimetry over a wider swath of up to 35 degrees. The way this will be achieved is through making the beam-former on ground in post-processing (on-board raw data are simply grabbed and recorded for later post-processing). The 11 November 2011 experiment is thought to be the most accurate altimetry test carried out so far in GNSS reflectometry by the European Space Agency.

Within the reporting period, ESA carried out two Phase A studies of a PARIS In-orbit Demonstration mission which showed the feasibility of a small demonstration mission dedicated to mesoscale ocean altimetry. Two additional Phase A studies will be started later in 2013 to consider a GNSS reflectometry experiment aboard the International Space Station (the GEROS experiment). The GEROS experiment is an opportunity to test the GNSS-R technology developed for the PARIS-IoD mission.

Also within 2011-2013 ESA has performed also other various studies on different applications of GNSS-R such as biomass, snow sounding, sea ice thickness and soil moisture with promising results all of them.

### WG 4.6.2: GNSS Scatterometry

*Chair: Scott Gleason (Canada)*

*Co-Chair: Maria Clarizia (UK)*

Primarily focused on the study of ocean wind and wave retrieval using scattered GNSS signals as well as ocean sensing applications, including looking into the signal scattering sta-

tistics and analyzing the achievable surface resolution for different instrument configurations. The primary goal of this WG is to improve the scattering signal quality and estimated theory for ocean wind and wave retrieval using different instrument and GNSS-R carrier configurations.

### WG 4.6.3 GNSS Ocean Altimetry

*Chair: Salvatore D'Addio (The Netherlands)*

*Co-Chair: Estel Cardellach (Spain)*

On one hand, the *interferometric* technique of the Passive Reflectometry and Interferometry concept (PARIS), under study within the European Space Agency, explained in Report Sub-commission WG 4.6.1, was tested for the first time under dynamic conditions. A dedicated GNSS-R interferometric receiver was developed and installed in the Finnish Skyvan aircraft, to perform, in 11 November 2011, the first airborne experiment of the PARIS interferometric technique. The data were processed by IEEC and the 2 cm/km slope of the geoid in the Baltic Sea area of the experiment was clearly measured, with a standard deviation of about 13 cm after 20 s. The waveforms retrieved matched well the expected ones for low wind speed, in line with the actual weather conditions during the test. The test set-up had to be restricted to one single high gain antenna beam looking up, and the same looking down. Therefore, this airborne experiment could show precise altimetry only within 15 degrees away from the aircraft track. A future experiment is being planned that will demonstrate altimetry over a wider swath of up to 35 degrees. The 11 November 2011 experiment is thought to be the most accurate altimetry test carried out so far in GNSS reflectometry by the European Space Agency. See references [2, 3, 8]. Conventional processing of GPS CA code signals was also carried out in the same experiment, showing an altimetry performance degradation of about a factor 2, mainly due to the reduced bandwidth of the open access CA code signal. However, the observed waveform matched very well the models also in this case.

- In 2012, two Phase A studies have been conducted by ESA, about the feasibility of a PARIS interferometric small mission for Ocean altimetric applications. See mission overview at [1].
- The proposal “GNSS Reflectometry, Radio Occultation and Scatterometry onboard ISS” (GEROS-ISS), submitted to the 2011 European Space Agency Research Announcement for ISS Experiments relevant to study of Global Climate Change, was selected in September 2012, among more than 20 competing proposals. The Scientific Advisory Group is being formed (Spring 2013), to contribute defining the terms and requirements of two Phase A (feasibility) studies for such experiment.
- During 2013, a collaboration between the National Remote Sensing Center of China (NRSCC); Chinese Universities; IEEC/ICE-CSIC (Spain); and ESA has been established to conduct an experiment in the Chinese coast during the Typhoon season (July-September 2013), with the goal of capturing both scatterometric and altimetries features of the Typhoon in GNSS-R data. See [10].
- During this period, new processing techniques for Ocean altimetry have also been envisaged: in references [4, 6, 7] Ocean tide signatures were captured from 700 meter cliff using carrier-phase delays at low elevation angles of observation, with a few cm precision (data available at [5]); [9] tested a carrier-Doppler approach for altimetric applications that might work over rougher waters (less restrictive than phase-delay observations).
- The GNSS+R 2012 workshop was conducted at Purdue University (West Lafayette, IN, USA), in October 2012. Eight papers were presented related to Ocean altimetry: Yu et al.;

Larson; Rius et al.; Beckheinrich et al.; Carreno-Luengo et al.; D'Addio et al.; Stienne et al.; and Semmling, Beyerle and Wickert (not listed below, please visit <http://www.gnssr2012.org>)

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### **WG 4.6.4: Soil and Cryosphere detection by GNSS-R**

*Chair: Mark Jacobson (USA)*

*Co-Chair: Nicolas Floury (The Netherlands)*

The soil moisture, ice and snow thickness are related to the amplitude of the reflected signal as a function of the incidence angle or relative amplitudes between different polarizations, which can be retrieved from the GNSS reflected signals. This effort is to develop GNSS reflectometry and multipath for land surface mapping, wetland monitoring and surface soil moisture and snow/ice thickness as well as the condition of sea ice, glacial melting and the frozen state. The main goal is to improve the estimate theory and sensitivity to soil moisture,

snow and ice condition from the GNSS reflected signals and to precisely determine the soil moisture, ice status and features.

### *Activites*

#### *2012*

- 12 December 2012, Shuanggen Jin, Per Knudsen and Ole Andersen co-organized SHAO-DTU Workshop on Space Geodesy and discussed future possible collaboration, Shanghai, China
- 16-20 October 2012, Shuanggen Jin attended the 28th Meeting of Chinese Geophysical Society (CGS) with receiving Fu Chengyi Award in Beijing and 56th Anniversary of SGG, Wuhan University and 80th Birthday of Academician Prof. Jinsheng Ning in Wuhan, China.
- 21-25 August 2012, Shuanggen Jin organized International Summer School on Space Geodesy and Earth System, Shanghai, China.
- 18-21 August 2012, Shuanggen Jin organized International Symposium on Space Geodesy and Earth System (SGES2012) as Chair of Symposium, Shanghai, China



Figure 1. International Symposium on Space Geodesy and Earth System (SGES2012)

- 13-17 August 2012, Shuanggen Jin attended the AOGS-AGU (WPGM) Joint Assembly with convening two sessions and giving one talk, Singapore
- 21-29 July 2012, Shuanggen Jin attended the IEEE International Geoscience and Remote Sensing Symposium (IGARSS2012) with chairing one session in Munich, Germany and was invited to visit Czech Geodetic Observatory Pecny (GOP) and Deutsches Geodatisches Forschungsinstitut (DGFI) with one talk, respectively.
- 6-14 June 2012, Shuanggen Jin attended the 34th Canadian Remote Sensing Symposium, Ottawa and visited University of Calgary and Geodetic Survey Division, Canada Centre for Remote Sensing, Natural Resources Canadian with two talks, Canada.
- 25-31 March 2012, Shuanggen Jin was invited to give a talk at Universiti Teknologi Malaysia (UTM), Johor, Malaysia and Chaired one Session with one talk at Progress In Electromagnetics Research Symposium (PIERS), Kuala Lumpur, Malaysia.

#### *2011*

- 12 December 2011, Prof. Shuanggen Jin and Prof. Ching-Yuang Huang co-convened Cross-Strait Forum on GNSS Remote Sensing with full day talks and discussion, Shanghai, China.



- 10-18 November 2011, Shuanggen Jin was invited to visit and gave several talks at Taiwan National Chiao Tung University, National Cheng Kung University, National Central University and Institute of Earth Sciences, Academia Sinica, Taiwan.
- 29 September 2011, Seventeen members from ETH Zurich, Switzerland visited the SHAO and participated in a ETHZ-SHAO Forum on Space Geodesy, Shanghai, China
- 15 September 2011, Prof. Shuanggen Jin and Prof. Valery Mironov Co-Chaired Shanghai-Siberia Workshop on Remote Sensing and discussed future cooperation in Radiowave Remote Sensing, Shanghai, China
- 20 August 2011, Satellite Navigation and Remote Sensing Group with 14 members has travelled the ancient Fengjing Town and Jinshan Beach, Shanghai, China
- 7-9 August 2011, Shuanggen Jin organized the International Workshop on GNSS Remote Sensing for Future Missions and Sciences as Chair of Workshop, Shanghai, China



Figure 2. International Workshop on GNSS Remote Sensing for Future Missions and Sciences

- 08-16 August 2011, Shuanggen Jin Convene one Session at Asia Oceania Geosciences Society (AOGS 2011) with one talk, Taiwan.
- 24-29 July 2011, Shuanggen Jin received IEEE GRSS Travel Grant Award to attend IEEE Int. Geosci. & Remote Sens. Symp (IGARSS 2011) and Chaired one Session with two talks, Vancouver, Canada.

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## **Inter-Commission on Theory (ICCT)**

<http://icct.kma.zcu.cz>

*President: Nico Sneeuw (Germany)*  
*Vice President: Pavel Novák (Czech Republic)*

### **Structure**

- Joint Study Group 0.1: Application of time series analysis in geodesy
- Joint Study Group 0.2: Gravity field modelling in support of height system realization
- Joint Study Group 0.3: Comparison of current methodologies in regional gravity field modelling
- Joint Study Group 0.4: Coordinate systems in numerical weather models
- Joint Study Group 0.5: Multi-sensor combination for the separation of integral geodetic signals
- Joint Study Group 0.6: Applicability of current GRACE solution strategies to the next generation of inter-satellite range observations
- Joint Study Group 0.7: Computational methods for high-resolution gravity field modelling and nonlinear diffusion filtering
- Joint Study Group 0.8: Earth system interaction from space geodesy
- Joint Study Group 0.9: Future developments of ITRF models and their geophysical interpretation

### **Overview**

All joint study groups show a good level of activities, be it in organizing workshops, in comparing software through a common data set or in participating in international research teams. As such, it is recommended that all JSG's complete their 4-year period. Internal group communication runs through various channels JSG06 even issues a periodical bulletin (JSG06 Newsletter).

An ICCT Splinter Meeting was held during the EGU 2012 (Vienna). Most of the Study Group chairs were able to participate. They reported on the on-going and future activities of their respective groups. Moreover, the initial plans for the Hotine-Marussi meeting were discussed.

### **VIII Hotine-Marussi Symposium**

The main highlight of ICCT is the organization of the VIII Hotine-Marussi Symposium in Rome. Since the inception of ICCT, the already existing series of Hotine-Marussi Symposia falls under the responsibility of ICCT. Earlier ICCT-organized Symposia were the numbers VI (2006, Wuhan) and VII (2009, Rome).

June 17–21, 2013, the VIII Hotine-Marussi Symposium took place in Rome. The venue was the same as 2009, namely at the Faculty of Engineering of the Sapienza University of Rome. Also the local organization was in the hands of Prof. Mattia Crespi again. From a total attendance of about 100 participants about 70 oral presentations and 15 posters were contributed to the following sessions:

1. Geodetic Data Analysis (W. Kosek, R. Gross, C. Kreemer)
2. Theoretical aspects of reference frames (A. Dermanis, T. Van Dam)
3. Digital Terrain Modeling, Synthetic Aperture Radar and new sensors: theory and methods (M. Crespi, E. Pottier)
4. Geopotential modeling, boundary value problems and height systems (P. Novák, M. Schmidt, C. Gerlach)
5. Atmospheric modeling in geodesy (T. Hobiger, M. Schindelegger)
6. Gravity field mapping methodology from GRACE and future gravity missions (M. Weigelt, A. Jäggi)
7. Inverse modeling, estimation theory (P. Xu)
8. Computational geodesy (R. Čunderlík, K. Mikula)
9. Special Session at Accademia Nazionale dei Lincei (F. Sansò, R. Barzaghi, N. Sneeuw)

The session topics follow roughly the study group structure of ICCT. Conveners (in brackets) were recruited (mostly) from the study group chairs and members.

True to the InterCommission nature of ICCT, the sessions dealt with the full width of topics in theoretical geodesy. During the special session at the Accademia Nazionale dei Lincei Fernando Sansò was honoured for his long-term involvement in the organization of the series of Hotine-Marussi Symposium, after taking over the baton from Antonio Marussi in 1985. It was decided to rename the VIII Hotine-Marussi Symposium by adding “*in honour of Fernando Sansò*” to its title.

### **Other meetings**

The individual study groups organized several workshops, a summer school and conference sessions:

- EGU session G1.1 “Recent Developments in Geodetic Theory” over the past several years.
- EGU session G1.2 “Mathematical methods in the analysis and interpretation of potential field data and other geodetic time series” (EGU 2011, 2012, 2013).
- International Workshop on “Regional Gravity and Geomagnetic Field Modelling” Munich, Germany, 2012.
- Session G5.1 “Observing and understanding Earth rotation variability and its geophysical excitation” at EGU 2012; Science Meeting of IAU Commission 19 “Rotation of the Earth” at IAU 2012; Session G3.3 “Observing and understanding Earth rotation variability and its geophysical excitation” at EGU 2013.
- International Symposium on “Space Geodesy and Earth System” (SGES2012), Shanghai, 2012; International Summer School on “Space Geodesy and Earth System”, Shanghai, 2012.

## **Joint Study Group 0.1: Application of Time Series Analysis in Geodesy**

*Chair: Westlaw Kosek (Poland)*

In October 2010 the US Naval Observatory (USNO 2013) together with the Space Research Centre (SRC 2013) in Warsaw initiated the IERS Earth Orientation Parameters Combination of Prediction Pilot Project (EOPCPPP). The goal of this project is to determine the feasibility of combining Earth Orientation Parameters (EOP) predictions on an operational basis. The pole coordinate data predictions from different prediction contributors and ensemble predictions computed by the USNO were studied to determine the statistical properties of polar motion forecasts (Kosek et al. 2012). Short term prediction errors of pole coordinates data are caused by wideband short period oscillations in joint atmospheric-ocean excitation functions and their increase can be also caused by the change of phase of the annual oscillation in this function (Kosek 2012). The combination of the least-squares and multivariate autoregressive prediction using the axial component of the atmospheric angular momentum excitation function method was applied to predict UT1–UTC data which improved their prediction accuracy in relation to the combination of the least-squares and the autoregressive prediction of the univariate time series (Niedzielski and Kosek 2012).

Higher order semblance function reveals that addition of hydrology angular momentum to the sum of atmospheric and oceanic excitation functions of polar motion improves the phase agreement between the geodetic and fluid excitation functions in the annual frequency band. The common oscillations in the geodetic and fluid excitation functions of polar motion can be detected using wavelet based semblance filtering (Kosek et al., 2011).

At the University of Wroclaw in Poland the real time system and service for sea level prediction called PROGNOCEAN has been built (Niedzielski and Mizinski 2013). The aim of this system is computation of altimeter-derived sea level anomalies data prediction for 1 day, 1 week and 2 weeks in the future, together with the maps of the mean prediction errors. The predictions are computed in real time, so the users are available to evaluate the performance of the system and service. The forecasting strategies are based on a few time series methods: (1) extrapolation of the polynomial-harmonic model, (2) extrapolation of the polynomial-harmonic model with autoregressive prediction, (3) extrapolation of the polynomial-harmonic model with self-exciting threshold autoregressive model, (4) extrapolation of the polynomial-harmonic model with auto covariance prediction, (5) extrapolation of the polynomial-harmonic model with vector autoregressive prediction, (6) extrapolation of the polynomial-harmonic model with generalized space-time autoregressive model (Prognosean 2013).

A software package TSoft for the analysis of Time Series and Earth Tides has been created by Paul Vauterin in the Royal Observatory of Belgium. It allows the user to process the data in a fully interactive and graphical way and has a number of important advantages, particularly in the field of error correction of (strongly perturbed) data, and the detection and processing of special events (e.g. free oscillations after Earthquakes (ROB 2013)).

The influence of the hydrological noise on repeated gravity measurements has been investigated on the basis of the time series of 18 superconducting gravimeters (SGs) and on predictions inferred from the Land Dynamics (LaD) world Gascoyne land water energy balances model. It is shown that the PSDs of the hydrological effects flattens at low frequency and is characterized by a generalized Gauss Markov structure (Van Camp et al. 2010).

The new method of data processing was used for the absolute gravimeters (AGs) observations during intercomparison campaigns since 1980. A new criterion, based on the minimization of the L1 norm of the offsets, for fixing the constant of the ill-conditioned problem, was found to be statistically more precise than the one classically used (de Viron et al. 2011). Based on synthetic data representative of signals observed by superconducting gravimeters (SG) at various station locations, it was found that the addition of SG information mitigates the error in the estimation of gravity rates of change caused by the presence of long period, inter-annual, and annual signals in the AGs data. These results were discussed as a function of the sampling rate of the absolute gravity measurements, the duration of the observations, and the uncertainties of the AGs (Van Camp et al. 2013).

It was shown that 25 different climate indices associated with a great variety of climatic fields and geographic regions share a very substantial fraction of their variability. This common fraction can be captured and described by using no more than four leading modes of variability correlated with the sea surface temperature field. The preferred periodicities apparent in these modes reflect mainly the quasi-biennial and quasi-quadrennial periodicities of El Niño Southern Oscillation (de Viron et al. 2013).

## Meetings

Since 2011 at each European Geosciences Union General Assembly the sessions G1.2 "Mathematical methods in the analysis and interpretation of potential field data and other geodetic time series" were organized, by two members of the JSG 0.1 study group (EGU 2011, 2012, 2013).

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## Joint Study Group 0.2: Gravity Field Modelling in Support of Height System Realization

*Chair: Pavel Novák (Czech Republic)*

### Introduction and objectives

This report covers activities and scientific outputs of the Joint Study Group 0.2 (JSG0.2) for the period 2011–13. In its terms of reference, the group outlined several research topics (of a theoretical nature) that were closely related to gravity field modelling and its role for establishment of a world height system (WHS). It was emphasized that namely geometric properties of the Earth's gravity field were very significant in this respect as one particular equipotential surface of the Earth's gravity field served as a vertical datum in geodesy.

Theoretical issues include this (non-exhaustive) list:

- Combining heterogeneous gravity field observables by using spatial inversion, spherical radial functions, collocation and wavelets, etc. and by taking into account their sampling in time and space, spectral and stochastic properties.
- Studying stable, accurate and numerically efficient methods for continuation of gravity field parameters including satellite observables of type GRACE and GOCE.
- Advancing methods for gravity potential estimation based on its measured directional derivatives (gravity, gravity gradients) by exploiting advantages of simultaneous continuation and inversion of observations.
- Investigating gravity data specifications (stochastic properties, spatial and temporal sampling and spectral content) required by specific geodetic applications.
- Studying available Earth's gravitational models (EGM) in terms of their available resolution and accuracy for the purpose of WHS realization.
- Defining relations between an adopted conventional EGM and parameters of a geocentric reference ellipsoid of revolution approximating a time invariant equipotential surface of the adopted EGM aligned to reduced observables of mean sea level.

This study group (SG) is affiliated to IAG Commissions 1 (*Reference Frames*) and 2 (*Gravity Field*); co-operation with GGOS Theme 1 *Unified Global Height System* has been foreseen.

### Report on published/presented results of the study group

Main scientific outcomes of the study group include journal publications, oral and poster presentations at international conferences and meetings, and eventually progress reports and final reports delivered to scientific authorities. The following overview provides just samples of these products.

#### *Selected publications*

Čunderlík R, Mikula K, Špir R (2012) An oblique derivative in the direct BEM formulation of the fixed gravimetric BVP. In: *7th Hotine-Marussi Symposium on Mathematical Geodesy*. International Association of Geodesy Symposia 137, DOI: 10.1007/978-3-642-22078-4\_34.

Čunderlík R, Fašková Z, Mikula K (2012) Fixed gravimetric BVP for the vertical datum problem. In: *Geodesy for Planet Earth*. International Association of Geodesy Symposia 136, DOI: 10.1007/978-3-642-20338-1\_40.

Featherstone WE (2013) Deterministic, stochastic, hybrid and band-limited modifications of Hotine's integral. *Journal of Geodesy* 87(5): 487-500, DOI: 10.1007/s00190-013-0612-9.



Filmer MS, Hirt C, Featherstone WE (2013) Error sources and data limitations for the prediction of surface gravity: a case study using benchmarks. *Studia Geophysica et Geodaetica* 57(1): 47-66, DOI: 10.1007/s11200-012-1114-6.

Featherstone WE, Filmer MS (2012) The north-south tilt in the Australian Height Datum is explained by the ocean's mean dynamic topography. *Journal of Geophysical Research – Oceans* 117: C08035, DOI: 10.1029/2012JC007974.

Hirt C, Kuhn M, Featherstone WE (2012) Topographic/isostatic evaluation of new-generation GOCE gravity field models. *Journal of Geophysical Research – Solid Earth* 117: B05407, DOI: 10.1029/2011JB008878.

Heck B (2011) A Brovar-type solution of the fixed geodetic boundary-value problem. *Studia Geophysica et Geodaetica* 55(3): 441-454, DOI: 10.1007/s11200-011-0025-2.

Gruber C, Novák P, Sebera J (2011) FFT-based high-performance spherical harmonic transformation. *Studia Geophysica et Geodaetica* 55(3): 489-500.

Sjoberg LE, Eshagh M (2012) A theory on geoid modelling by spectral combination of data from satellite gravity gradiometry, terrestrial gravity and an earth gravitational model. *Studia Geophysica et Geodaetica* 47(1): 13-28, DOI: 10.1556/AGeod.47.2012.1.2.

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Tenzer R, Hamayan, Novák P, Gladkikh V, Vajda P (2012) Global crust-mantle density contrast estimated from EGM2008, DTM2008, CRUST2.0 and ICE-5G. *Pure and Applied Geophysics* 169(9): 1663-1678.

Tenzer R, Novák P, Gladkikh V (2012) The bathymetric stripping corrections to gravity field quantities for a depth-dependent model of seawater density. *Marine Geodesy* 35: 1-23.

### *Selected oral and poster presentations*

Abd-Elmotaal H, Kuehtreiber N (2012) Comparison between astro-gravimetric and astro-geodetic geoids for Austria. EGU2012-223.

Amjadiparvar B, Rangelova E, Sideris MG, Hayden TS (2013) The role of local gravity information in the unification of the North American vertical datums. EGU2013-6480.

Čunderlík R, Mikula K (2012) Realization of WHS based on the static gravity field observed by GOCE. International Symposium on Gravity, Geoid and Height Systems (GGHS2012). Venice, October 2012 (S5-179).

Elhabiby MM, Sideris MG, Keller W (2011) A combined multi-resolution multi-dimensional wavelet approach for the inversion of geodetic integrals. EGU2011-13775.

Fašková Z, Macák M, Čunderlík R, Mikula K (2012) Finite volume numerical scheme for high-resolution gravity field modelling and its parallel implementation. EGU2012-8827.

Gruber C, Novák P, Barthelmes F (2011) Derivation of topographic potential from global DEM models. EGU2011-10170.

Gruber C, Moon YJ, Flechtner F, Novák P, Daras I (2011) Submonthly GRACE solutions from localising integral equations and Kalman filtering. 25th General Assembly of IUGG, Melbourne, July 2011.

Heck B, Müßle M, Seitz K, Grombein T (2013) On the effect of planar approximation in the geodetic boundary value problem. EGU2013-8963.

Huang J, Véronneau M (2013) Contribution of the GRACE and GOCE models to a geopotential-based geodetic vertical datum in Canada. EGU2013-10164.

Novák P, Sebera J, Val'ko M (2012) On the downward continuation of gravitational gradients. International Symposium on Gravity, Geoid and Height Systems (GGHS2012). Venice, October 2012 (S2-201).

Roman D, Véronneau M, Avalos D, Li X, Holmes S, Huang J (2012) Integration of gravity data into a seamless transnational height model for North America. International Symposium on Gravity, Geoid and Height Systems (GGHS2012). Venice, October 2012 (S5-075).

Sideris MG, Rangelova E (2012) First results on height systems unification in North America using GOCE. International Symposium on Gravity, Geoid and Height Systems (GGHS2012). Venice, October 2012 (S5-092).

Sebera J, Novák P, Vařko M, Šprlák M, Bezděk A, Bouman J, Fuchs M (2013) Downward continuation of gridded and reprocessed GOCE gravitational gradients. EGU2013-8265.

Šprlák M, Novák P, Valko M, Sebera J (2013) Spherical integral formulas for upward/downward continuation of gravitational gradients onto gravitational gradients. 8th Hotine-Marussi Symposium, Rome, June 2013.

Wang YM, Li X, Holmes S, Roman D, Smith D (2013) Investigation of the use of deflections of vertical measured by DIADEM camera in the GSVS11 survey. EGU2013-12779.

### *Study group web page*

The webpage of the group is [http://icct.kma.zcu.cz/index.php/IC\\_SG2](http://icct.kma.zcu.cz/index.php/IC_SG2).

### **Report on activities of the study group**

During the 2011–13 period, there were no specific sessions organized during regular geodetic conferences but one at the Hotine-Marussi Symposium 2013 in Rome. At this event, organized by ICCT, the session on geopotential modelling, boundary-value problems and height systems co-convened by chairmen of the JSG0.2 and JSG0.3 has been organized with total 11 oral and 2 poster presentations. Other contributions of the group's members can be found on programs of geodetic and geophysical conferences and meetings (such as EGU, AGU, GGHS2012) organized during the period starting after the IUGG General Assembly in Melbourne 2011. This report lists only some of the presented contributions. Activities within the scope of the JSG partially overlapped with project activities of its members including two projects of the ESA'S Support to Science Element (STSE) program (GOCE data in support of WHS and for geophysical exploration). These international projects represent a platform for scientific co-operation of scientists including regular meetings and visits.

### **Outlook and plans**

To discuss activities of the JSG for the remaining two-year period (2013-15), there will be at hand two upcoming opportunities: VIII. Hotine-Marussi Symposium in Rome, June 2013, and the Scientific Assembly of the IAG in Potsdam, September 2013. Generally, the focus remains on the research areas specified above as the establishment of WHS remains one of the major scientific projects of IAG for the period until its next General Assembly in Prague in 2015.

## **Joint Study Group 0.3: Comparison of Current Methodologies in Regional Gravity Field Modelling**

*Chairs: Michael Schmidt, Christian Gerlach (Germany)*

### **Introduction**

The main objectives of JSG0.3 are:

- to collect information of available methodologies and strategies for regional modelling,
- to analyze the collected information in order to find specific properties of the different approaches and to find, why certain strategies have been chosen,
- to create a benchmark data set for comparative numerical studies,
- to carry out numerical comparisons between different solution strategies for estimating the model parameters and to validate the results with other approaches (spherical harmonic models, least-squares collocation, etc.),
- to quantify and interpret the differences of the comparisons with a focus on detection, explanation and treatment of inconsistencies and possible instabilities of the different approaches,
- to create guidelines for generating regional gravity solutions,
- to outline standards and conventions for future regional gravity products.

Since the focus is on the methodological foundations it is straightforward to compare different methodologies in regional gravity field modelling based on synthetic data.

A first initiative to motivate active contribution to this study was a workshop on regional potential field modelling (see next section). On the workshop it was agreed to prepare a set of simulated gravity field data which should be used for computing regional gravity field models by different groups employing different methodologies. This should facilitate a numerical comparison of the different approaches.

### **Workshop**

On February 23–24, 2012, an international “Workshop on Regional Gravity and Geomagnetic Field Modelling” was held at the Bavarian Academy of Sciences and Humanities (BAdW) in Munich, Germany. The workshop was jointly organized by the German Geodetic Research Institute (DGFI, Michael Schmidt), the Commission for Geodesy and Glaciology of BAdW (KEG, Christian Gerlach) and the Institute for Geodesy and Geoinformatics of the University of Bonn (IGG, Jürgen Kusche).

The active participants were asked to present their modelling approach with regard to their

- field of application (gravity field, geomagnetic field, static or time-variable, etc.),
- the type of input data used (terrestrial, airborne, satellite data or a combination of those),
- the type of modelling approach used including choice of base functions and point grids, properties of the mathematical and stochastic models and details on the mathematical solution and regularization techniques which are employed.
- In addition, open question and specific problem areas were presented.

After a general introduction by Michael Schmidt on general aspects of regional modelling and the scope of the workshop several modelling approaches were presented by several groups. Table 1 gives an overview of the modelling approaches presented during the two workshop days. Altogether there were 31 participants from 11 different countries. The participation was not limited to the original members of JSG 0.3 which reflects the study groups open policy that interested research groups can join at any time.

### Simulation Data

On the workshop it was agreed within the final discussion to generate a simulation data set to be used by all different groups in order to facilitate numerical comparison between the different methodologies. The data set was jointly prepared by DGFI and IGG Bonn; it is available from the web site of JGS 0.3 at <http://jsg03.dgfi.badw.de>. The data set is publicly available and all groups interested in testing their approach are invited to use the data set and share the results. First results of individual groups were presented during the VIII Hotine-Marussi Symposium in Rome, June 17-21, 2013. Comprehensive comparisons and evaluations of the individual results are planned for the beginning of 2014 and will be presented at the EGU General Assembly 2014 in Vienna at the end of April, so far results from the actively contributing groups are made available to JGS 0.3 by the end of 2013.

The data sets comprise terrestrial data on regular geographic coordinate grids, airborne data on synthetic flight tracks and satellite data along real orbits of GRACE and GOCE. They are provided for two test areas, namely in Europe and South America, both having an extension of  $20^\circ \times 30^\circ$ . The data is provided error-free along with time series of white noise errors. At a later stage the inclusion of coloured noise models is planned.

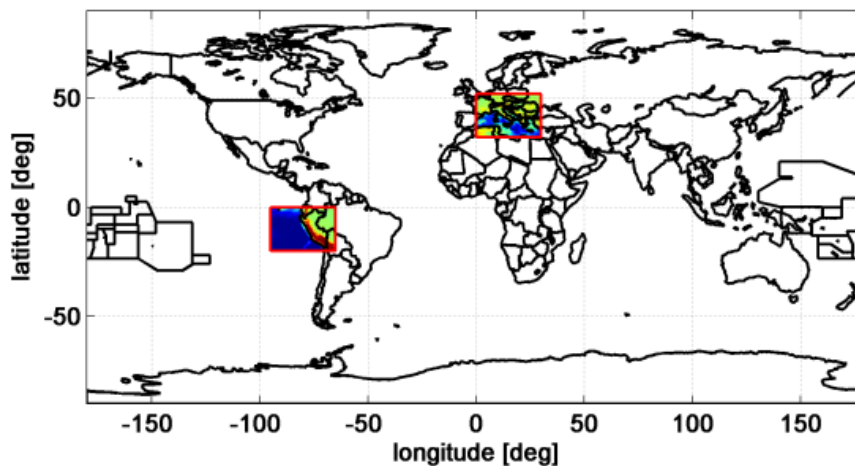


Figure 1: Global map with red boxes marking the test regions.

For validation of the computations from the data sets an additional data also on regular geographic surface grids is provided. In order to allow validation of gravity field approximation at independent locations, the validation grids are shifted with respect to the observation data grids.

Table 1: Overview of modelling approaches presented at the “Workshop on Regional Gravity and Geomagnetic Field Modelling”

Functional model (base function)	Field of Application	Research Group
Spherical splines	Static and time-variable gravity field from satellite data	IGG, Bonn (Eicker, Schall, Kusche )
Spherical radial basis functions	Time-variable gravity field from satellite data	University of Life Sciences Ås, Norway (Bentel, Gerlach)
Spherical radial basis functions	Multi resolution representation of static and time-variable gravity field and combination of all data types	DGFI, Munich (Lieb, Schmidt)
Poisson multipole wavelets	Regional static gravity field refinement by combination of satellite and terrestrial data	IGN / IPGP Paris (Panet)
Spherical radial basis functions	Regional static and time-variable gravity field from satellite data	University Hannover (Naemi)
Spherical radial basis functions	Regional gravity field modelling from satellite data	University Stuttgart (Antoni)
Slepian functions	Spatiospectral localization on the sphere	Princeton University (Harig, Simons)
Global directional wavelets	Sensitivity of satellite formations and geomagnetic data analysis	Danish National Space Institute (Einarsson)
Regional empirical orthonormal functions	Geomagnetic field modeling	GFZ Potsdam (Schachtschneider)
Poisson multipole wavelets	Time variable gravity field from satellite data	University Potsdam (Fuhrmann)
Harmonic splines	Regional geomagnetic field	GFZ Potsdam (Lesur)
Least-squares collocation	Regional static gravity field from combination of all various data sources	Technical University Munich (Pail)
Greens function	Regional time-variable gravity field from satellite data	GFZ Potsdam (Fagioligni, Gruber)
Isoparametric boundary elements	Regional gravity field from satellite data	University Stuttgart (Weigelt)
Point mass modelling	Regional gravity field and geoid models from all available data	BKG Frankfurt (Schäfer)

## Joint Study Group 0.4: Coordinate Systems in Numerical Weather Models

*Chair: Thomas Hobiger (Japan)*

Numerical weather models (NWM's) contain valuable information relevant for removing the environmental signal from geodetic data. Currently no clear documentation exists regarding how to deal with the height systems when carrying out the calculations in a geodetic reference frame. A "conventional" transformation model (available also as source code) would enable geodesists to handle such data easily and allow them to use data from different meteorological datasets. In addition, geodetic products such as GNSS-derived zenith total delays are being assimilated into NWMs. Thus, the transformations that convert the meteorological data into a geodetic reference frame should also support the use of geodetic data in meteorological models. This study group has been set up to 1) deal with the differences between geodetic and meteorological reference systems and 2) provide consistent models for transforming between the two systems.

### Vertical transformation

In order to decide on a consistent transformation to/from numerical weather models the study group has started to investigate vertical transformation first, before making a decision on how to deal with horizontal coordinates.

*Ellipsoidal heights ↔ geopotential heights*

Ellipsoidal heights ( $h$ ) can be obtained from orthometric heights ( $H$ ) when the geoid undulation ( $N$ ) is known.

$$h = H + N \quad (1)$$

Furthermore, orthometric heights relate to geopotential heights ( $Z$ ) by

$$H = Z g_n / g_0 \quad (2)$$

where  $g_n$  denotes the conventional gravity constant used throughout the numerical weather model.  $g_0$  is the mean gravity, defined as

$$g_0 = 1/\zeta \int g \, dz \quad (3)$$

where (vertical) integration has to be performed from the geoid surface to height  $\zeta$ .

*Error sources*

Although the transformation between numerical weather model heights and geodetic (ellipsoidal) heights can be described in a mathematically unique sense (equations 1-3) the choice of geophysical models, the selection of constants or the definition of the origin can lead to uncertainties of the transformation which can reach several meters. Thus, in the next sections the following effects on ellipsoidal heights are being studied:

- Impact of the gravity model and the way how the mean gravity ( $g_0$ ) is calculated
- Impact of the vertical direction w.r.t. the ellipsoid instead of the vertical w.r.t. a sphere (as used for numerical weather models)
- Uncertainty of the geoid (undulation)
- Using a different value for the conventional gravity constant.

In order to choose the mean gravity for the height transformation the study group has investigated how and to what extent the choice of the gravity model changes the obtained ellipsoidal height. In doing so, geopotential heights from a numerical weather model ( $g_n = 9.80665 \text{ m/s}^2$ ) had to be transformed to ellipsoidal heights (assuming a constant geoid undulation of  $N = 20 \text{ m}$ ). Calculations were performed on global 1x1 grids and it was assumed that geodetic latitude/longitude is identical to the one used in the numerical weather models. In total 8 contributions (from GFZ/Germany, GRGS/France, NICT/Japan, UNB/Canada(5 solutions) and VUT/Austria) were submitted. Fitting a linear function over all results, allows to derive a simple estimate for the uncertainty due to the choice of the mean gravity (see figure 0.4).

When the normal to the sphere is used instead of the normal to the ellipsoid, transformed heights are expected to be changed slightly as well. Similar to the study about the mean gravity model, GRGS evaluated data at various heights and grid points and computed the difference between two transformations, one using the normal to the ellipsoid and one using the normal w.r.t. a mean sphere.

Geoid undulations  $N$  need to be obtained from regional or global geoid models and applied to all grid points of the numerical weather model before obtaining ellipsoidal heights from orthometric heights (Equation 1). Thus, any error/uncertainty of these models directly propagates into the obtained ellipsoidal heights. Although regional geoid solutions can provide mm-accuracy such models don't cover the whole area of the numerical weather model. Thus, an error of 1 cm is taken as a (conservative) value for the uncertainty of geoid undulations on a global scale.

In case the gravity constant is inaccurate and not properly considered for the transformation, an additional error source for obtaining ellipsoidal heights results. However, most of the NWMs rely upon a value of  $g_n = 9.80665 \text{ m/s}^2$  or explicitly document the usage of another value. Thus, the impact from this error source can be assumed to be zero.

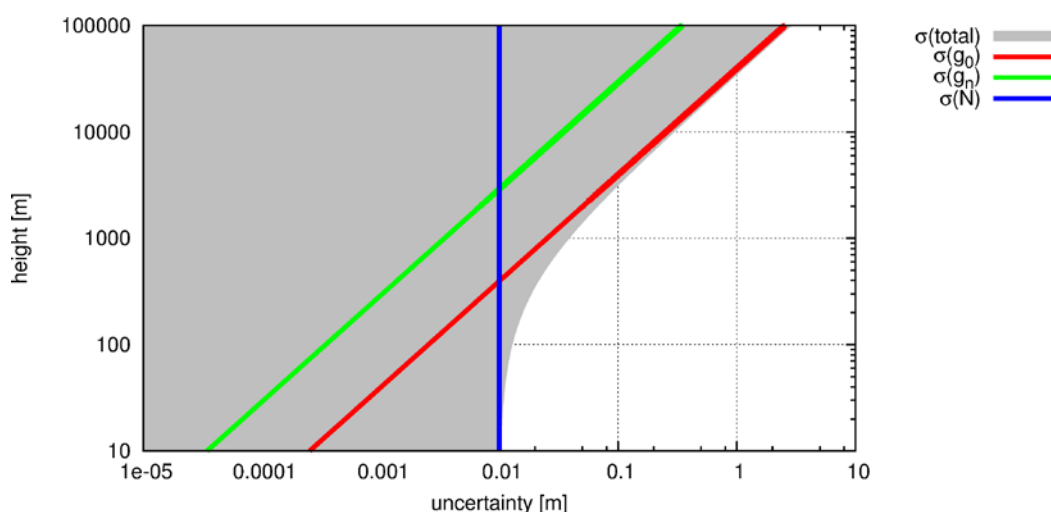


Figure 0.4: Uncertainties of  $\sigma(g)$ ,  $\sigma(g_0)$ ,  $\sigma(g_n)$  and  $\sigma(N)$

As shown in figure 0.4, the uncertainty of the geoid model, resulting mostly from the geoid undulation ( $N$ ) dominates the overall error budget in the lower height domains, i.e.  $<500 \text{ m}$ . Above that height, the choice of the gravity model and the way in which the mean gravity acceleration is computed becomes more important, and this error source starts to reduce the accuracy of the transformation. Thus, for a consistent and conventional height transformation

between geopotential heights from a numerical weather model and ellipsoidal heights it is important that

- geoid undulations are known with mm-accuracy on a global scale
- the gravity model provides both geoid undulations and gravity acceleration at a given location
- the proper direction of the normal w.r.t. the reference figure is properly considered for the highest accuracy.

Fortunately, most of the atmospheric parameters relevant for geodesy (mainly pressure) decrease exponentially with height, which reduces the impact of an imperfect height transformation when performing an integration/summation in vertical direction.

### **Next steps and horizontal transformation**

The study group has agreed that a conventional vertical transformation should be made available for users online and should be provided in three programming languages (FORTRAN, C/C++ and Matlab). Depending on the accuracy requirement and computational efforts, three different versions of the transformation will be provided.

1. A “conventional algorithm” based on EGM96 which transforms between the two systems. The model is expected to provide both, mean gravity as well as geoid undulations, and should be available in Fortran, Matlab and C/C++.
2. A “reduced algorithm” similar to (1) which uses a sub-set of the spherical harmonic coefficients. Source codes should be available in Fortran, Matlab and C/C++ and aims at high performance for reduced accuracy applications.
3. A “simple algorithm” which is also available in Fortran, Matlab and C/C++. This algorithm will use an (semi-) analytical expression for the gravity calculations and requires the user to input geoid undulations manually.

Routines should be made available around summer after the output from different programming languages has been checked for consistency, especially for model (1), which deals with high degree/order spherical harmonics.

Based on various discussions it appears that horizontal coordinates in numerical weather models are equivalent to geodetic (WGS84 based) latitude/longitude pairs. Meteorologists deal with geodetic coordinates directly, i.e. they apply them on the sphere without any transformation. Although this method is straightforward for operational use, it might lead to some inconsistencies since the total volume of the atmosphere is changed. Thus, the study group will draft and circulate a document that lists questions concerning horizontal coordinates, which need to be addressed to weather agencies. A draft version will be provided during the summer months with the goal to have a complete list of important questions for weather agencies before September 2013.



## Joint Study Group 0.5: Multi-Sensor Combination for the Separation of Integral Geodetic Signals

*Chair: Florian Seitz (Germany)*

### Introduction and Objectives

This document presents a status report of the work undertaken in the framework of the ICCT Joint Study Group JSG0.5 since its creation in 2011. Activities of the study group are focussed on the analysis and interpretation of observations from modern space-borne methods of Earth observation. A large part of the parameters derived from space geodetic observation techniques are integral quantities of the Earth system. Among the most prominent ones are parameters related to Earth rotation and the gravity field, whose variations reflect the superposed effect of a multitude of dynamical processes and interactions in various subsystems of the Earth. The integral geodetic quantities provide fundamental and unique information on different balances in the Earth system, in particular on the balances of mass and angular momentum that are directly related to (variations of) the gravity field and Earth rotation.

In respective balance equations, the geodetic parameters reflect the integrative effect of all mass- and angular momentum-related processes in the Earth system. For studies of suchlike processes, Geodesy provides important input in the form of highly accurate parameter time series covering many decades. Variations of Earth rotation have even been determined for more than one and a half century using continuously improved astrometric and space geodetic observation techniques. Thus geodesy provides an excellent data base for the analysis of long term changes in the Earth system and contributes fundamentally to an improved understanding of large-scale processes.

However, in general the integral parameter time series cannot be separated into contributions of specific processes without further information. Their separation and therewith their geophysical interpretation requires complementary data from observation techniques that are unequally sensitive for individual effects and/or from numerical models. Activities of the study group are focussed on the development of strategies for the separation of the integral geodetic signals on the basis of modern space-based Earth observation systems. A multitude of simultaneously operating satellite systems with different objectives is available today. They offer a broad spectrum of information on global and regional-scale processes at different temporal resolutions. Ongoing research within the study group deals with the question in which way the combination of heterogeneous data sets allows for the quantification of individual contributors to the balances of mass and angular momentum. The activities are coordinated between the participating scientists and conducted in interdisciplinary collaboration. The study group is primarily affiliated with the IAG commissions 2 (Gravity field) and 3 (Earth rotation and geodynamics).

### Report of Activities of the Study Group

#### *Publications of SG Members*

Singh, A., Seitz, F., Schwatke, C.: **Application of multi-sensor satellite data to observe water storage variations.** J. Selected Topics in Applied Earth Obs. and Remote Sens., 99, 1–7, 2013.

Abelen, S., Seitz, F.: Relating satellite gravimetry data to global soil moisture products via data harmonization and correlation analysis. Remote Sensing of Environ., 136, 89–98, 2013.

Schnitzer, S., Seitz, F., Eicker, A., Güntner, A., Wattenbach, W., Menzel, A.: Estimation of soil loss by water erosion in the Chinese Loess Plateau using Universal Soil Loss Equation and GRACE. *Geophysical J. International*, 193, Nr. 3, 1283-1290, 2013.

Seitz, F., Hedman, K., Meyer, F., Lee, H.: Multi-sensor space observation of heavy flood and drought conditions in the Amazon region. In: Rizos, C., Willis, P. (eds.) *Earth on the Edge: Science for a Sustainable Planet*, IAG Symposia, Vol. 139, 2013.

Singh, A., Seitz, F.: Water Storage Variations in the Aral Sea from Multi-sensor Satellite Data in comparison with Results from GRACE gravimetry. *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 3042-3045, 2012.

Schmeer, M., Schmidt, M., Bosch, W., Seitz, F.: Separation of mass signals within GRACE monthly gravity field models by means of empirical orthogonal functions. *J Geodynamics*, 59, 124-132, 2012.

Seitz, F., Kirschner, S., Neubersch, D.: Determination of the Earth's Pole Tide Love Number  $k_2$  from Observations of Polar Motion Using an Adaptive Kalman Filter Approach. *J. Geophysical Research*, Vol. 117, Nr. B09, EID B09403, 2012.

Singh, A., Seitz, F., Schwatke, C.: Inter-annual water storage changes in the Aral Sea from multi-mission satellite altimetry, optical remote sensing, and GRACE satellite gravimetry. *Remote Sensing of Environ.*, 123, 187-195, 2012.

Seitz, F., Thomas, M.: Simulation, prediction and analysis of Earth rotation parameters with a dynamic Earth system model. in: Schuh, H., et al. (eds.) *Proc. "Journées 2011 Systèmes de Référence Spatio-temporels"*, 109-112, TU Wien, 2012.

Abelen, S., Seitz, F., Schmidt, M., Güntner, A.: Analysis of regional variations in soil moisture by means of remote sensing, satellite gravimetry and hydrological modelling. In: Hafeez, M., et al. (eds.) *GRACE, Remote Sensing and Ground-based Methods in Multi-Scale Hydrology*, IAHS Red Book Series, Nr. 343, 9-15, 2011.

### *Conference Contributions of SG Members*

Seitz, F., Hedman, K., Spiridonova, S.: Intersection of SAR imagery with medium resolution DEM for the estimation of regional water storage changes. *German Geodetic Week*, Hannover, 10.10.2012.

Seitz, F., Kirschner, S.: Application of Earth rotation parameters in Earth system science. *IAU XXVIII GA*, Beijing, 30.08.2012.

Seitz, F.: Understanding Earth Rotation: Physical Foundations and Interpretation. *International Summer School on Space Geodesy and Earth System*, Shanghai, 23.08.2012.

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Abelen, S., Seitz, F., Güntner, A., Schmidt, M.: Signals of soil moisture variations in remote sensing and gravity field observations. IUGG XXV GA, Melbourne, 02.07.2011.

### *Study group web page*

The webpage of the group is [http://icct.kma.zcu.cz/index.php/IC\\_SG5](http://icct.kma.zcu.cz/index.php/IC_SG5)

### *Conference Sessions*

#### **EGU General Assembly, Vienna, 23 April 2012:**

Session G5.1: Observing and understanding Earth rotation variability and its geophysical excitation (Convenor: F. Seitz): 6 oral presentations, 18 posters.

#### **IAU General Assembly, Beijing, 29-30 August 2012:**

Science Meeting of IAU Commission 19 – Rotation of the Earth (Convenor: F. Seitz): 10 oral presentations.

#### **German Geodetic Week, Hannover, 11 October 2012:**

Session 5: GGOS – Global Geodetic Observing System (Co-Convenor: F. Seitz): 5 oral presentations.

#### **EGU General Assembly, Vienna, 4 April 2013:**

Session G3.3: Observing and understanding Earth rotation variability and its geophysical excitation (Convenor: F. Seitz): 6 oral presentations, 14 posters.

#### **German Geodetic Week, Essen, 8-10 October 2013:**

Session 5: GGOS – Global Geodetic Observing System (Co-Convenor: F. Seitz)

### *Joint third party funded projects*

The activities of the JSG also include the proposal of joint third-party funded projects in the thematic field of the JSG in order to raise funds for the employment of PhD students. In the context of the study group a common project with three positions for PhD students is ongoing in the frame of the International Graduate School of Science and Engineering (IGSSE) of the Technische Universität München (TUM). The project CLIVAR-Hydro (*Signals of Climate Variability in Continental Hydrology from Multi-Sensor Space and In-situ Observations and Hydro-logical Modeling*) has been initiated in 2010. A follow-up proposal for two additional PhD positions has been developed in collaboration between members of JSG0.5 and has been submitted in 2013.

Scientists perform mutual research visits at the institutions involved, where they work together for several months in the frame of the common project. The exchange of personnel between the institutions is financed through project funds. From March until November 2013 a PhD student of the Universidad de Concepción has been working at DGFI and the TUM. From November until December 2013 a PhD student from the TUM will join the group in Chile. This mobility significantly contributes to fostering the collaboration within JSG0.5.

## Joint Study Group 0.6: Applicability of Current GRACE Solution Strategies to the Next Generation of Inter-Satellite Range Observations

*Chairs: Matthias Weigelt (Germany), Adrian Jäggi (Switzerland)*

The main objective of this study group is the preparation and testing of existing solution strategies for their applicability to the upcoming GRACE-Follow On and future satellite missions. These missions will be equipped with improved instruments such as the laser interferometer (LRI). Existing solution strategies however make often use of linearization and/or depend on augmentation with other observed quantities, e.g. GPS. With the improved accuracy provided by the new instruments it needs to be tested if the existing solution strategies are still suitable. For example, despite the improvements in the inter-satellite observation, an improvement in the GPS-observations with the same order of magnitude may not be expected. Recognizing the need for these investigations, the proposal listed several objectives, among them identification of approximations and linearizations, the identification of limitations and the need for more accurate observations and the impact of errors in the tidal and non-tidal gravitational forces. In order to achieve these targets, first dedicated simulated observations and error information needed to be created.

### Simulation of observations:

The first step to allow for addressing the above mentioned important targets is the creation of simulated data sets which are applicable to theoretical questions but offer also a great deal of realism at the same time. Both are often contradicting aims as the increase of realism may obscure the impact of e.g. linearization errors. Therefore, the group opted for two data sets: one based on orbit integration with only a static gravity field and one with high degree of realism including various time variable signals.

For the first one, members of the group suggested to make use of the heritage of earlier investigations. The decision was made to use the SC7 data set which has been developed by a team led by the University of Bonn in 2003. This data set is based on an orbit integration of the gravity field EGM96 to degree and order 300 and provides noise-free data for 30 days with a 5 second sampling. The data set includes position and velocity for both satellites. Inter-satellite quantities need to be derived separately by the user.

The second data set was prepared by colleagues at the German Research Centre for Geoscience in Potsdam and is based on orbit integration of the static gravity field EIGEN-GL04C up to degree and order 90 but includes also astronomic and ocean tides, geophysical effects inducing a time variable gravity signal or non-gravitational forces. Details are listed in table 1.

Table 1: Models included in the preparation of the simulated data set with a high degree of realism

Source	Implementation
Static gravity field	EIGEN-GL04C up to 90x90
Planetary Ephemerides	JPL DE405 - only Sun and Moon
Ocean tides	EOT08a up to 50x50; only 8 waves: Q1, O1, P1, K1, N2, M2, S2, K2
Time variable gravity field	AOHIS ESA model up to 90x90
Non-gravitational accelerations	atmospheric drag, solar radiation pressure, Earth albedo and infra-red radiation (also provided separately)

The data set is again prepared for 30 days and with a five second sampling. Satellite-specific as well as inter-satellite quantities are provided including attitude information for both satellites. Currently, the data set is limited to one month only in order to minimize the amount of storage needed for the data but additional data sets may be prepared in the future in order to allow for investigations related to the time variable gravity field.

### **Simulation of noise**

The second important step is the preparation of realistic noise time series for the various simulated sensors, e.g. the inter-satellite K-Band and LRI observations. These noise time series are therefore only prepared for the second data set at the moment. Currently, two types of noise data sets are under development. The first one has been prepared in the framework of the “BMBF-Geotechnologien” program “Zukunftskonzepte für Schwerefeldmissionen” and is kindly made available to members of this study group. This data set is currently reformatted to allow for easy usage.

The second data set is prepared based on noise PSDs provided by Frank Flechtner from the German Research Centre for Geoscience. The PSDs are converted to noise time series by estimating filter coefficients and filtering white noise sequences. The resulting time series resemble noise time series with the same properties as the provided PSDs.

Both data sets will be released shortly to the group members.

### **Derivation of a variant of the differential gravimetry approach**

Additionally to the high effort to prepare the simulated data sets, first theoretical investigations also took place. The focus has been primarily on the differential gravimetry approach being one that needs augmentation with GPS-observations. The poorer accuracy of this type of observations prevents normally the full exploitation of the K-Band information. The standard approach circumvents this by reducing the observations to residual quantities using a priori information and estimating for corrections to the a priori gravity field. This approach demands a high computational effort and appears to be of limited use in the application to the more precise LRI observations. Therefore, alternatives have been investigated and one possibility was to replace the GPS-observations by observations of the rotation rate made by the star cameras. For this, the differential gravimetry approach needed to be reformulated in terms of rotational quantities. This has been successfully achieved and the new formulation allows for considerable insight into the nature of the satellite observation system. For example, an analytical explanation for the poor East-West observability of GRACE is at hand now. Also investigations are ongoing if the provided accuracy of the star cameras is sufficient. Both results will be presented at the VIII Hotine-Marussi symposium in Rome.

### **Organisational and other achievements**

Besides the technical progress also other activities have been successfully accomplished. The members of the group assigned themselves to various workgroups allowing for a structured approach to the various objectives of the study group. The exchange of information and knowledge has been fostered, e.g. a literature list with the most important and relevant publications for the investigated approaches has been compiled and made available to the members of the group. Group members are updated about the developments within the group by means of the internal newsletter “JSG0.6 Circular”.

## **Future plans**

The release of the aforementioned noise time series will be a major milestone for the activities of the group. The next steps will include a benchmark comparison which will allow identifying strength and weaknesses of the various approaches in a dedicated but common environment. One major point of concern for example is the numerical accuracy of the integration in the various approaches based on variational equations. The accumulation of errors may prevent the full exploitation of the LRI-observation.

Another important point for which activities has been triggered is the impact of the accelerometer data. This type of data often needs the co-estimation of instrument specific parameters which correlate with the gravity field and orbit parameters. The impact is still unclear but will be investigated in the upcoming activities.

At the same time, attention is paid to the impact of background models, e.g. the ocean tide models. Deficient ocean tide models yield aliasing of high frequency signal to the gravity field. The phenomenon has been observed but the underlying mechanism is still not well understood mostly due to the complex interaction of the sampling along the orbit with the spatial and temporal coverage of the Earth.

Last but not least, the interlink to the study group JSG0.3 will be fostered. Having a full set of (global) simulated data set available will allow the members of this study group to test their modelling tools with realistic GRACE-type of observations.

## **Joint Study Group 0.7: Computational Methods for High-Resolution Gravity Field Modelling and Nonlinear Diffusion Filtering**

*Chairs: Róbert Čunderlik, Karol Mikula (Slovakia)*

Recent activities of the JSG-0.7 have been mainly focused on development of new approaches for high-resolution gravity field modelling and nonlinear diffusion filtering using efficient numerical methods, namely the boundary element method (BEM), finite volume method (FVM) and method of fundamental solution (MFS). Some of the achieved results were presented in the GGHS-2012 symposium in Venice (October 2012) and EU-2013 in Wien (April 2013). Recent results will be presented in the VIII Hotine-Marussi Symposium in Roma (June 2013) where our JSG is organizing the session “Computational geodesy”. Some of the results have been already published in the journal papers or proceedings from conferences, or are preparing for submitting. Below is a more detail description of our activities.

### **High-resolution gravity field modelling**

#### *Boundary element method*

In case of the developed parallel approach by BEM, which considers real topography of the Earth's surface, the problem of oblique derivative has been investigated. There have been proposed and tested algorithms where the oblique derivative is decomposed to normal and tangential components. The numerical experiments have been applied for high-resolution global gravity field modelling as well as for precise local modelling using discrete terrestrial gravimetric measurements, e.g. in Slovakia and New Zealand.

#### *Finite volume method*

There have been proposed and developed new approach by FVM for global and local modelling. The parallel implementation using the MPI procedures and large-scale parallel computations on clusters with distributed memory has resulted in the global FVM solutions with the horizontal resolution corresponding to the spherical harmonics (SH) up to degree 2160 (EGM-2008). This approach has been successfully applied for local modelling as well. Nowadays the problem of oblique derivative is incorporating in the proposed numerical schemes.

#### *Method of fundamental solutions*

There has been developed new approach by MFS for global gravity field modelling. This approach has been proposed to process the direct GOCE measurements. So far, the developed algorithm is designed to derive the disturbing potential or its derivatives from the observed  $T_{zz}$  components. The numerical experiments have studied how a depth of the fictitious boundary, where the source points are located, influences accuracy of the achieved results. Ideas of the singular boundary method have been applied in case that source points are located directly on the Earth's surface. A parallel implementation of algorithms, iterative elimination of far zones' interactions and large-scale computations have resulted in the GOCE-based global gravity field models. Then they have been used to evaluate the geopotential on the mean sea surface models. It yields the  $W_0$  estimates that are fully independent from ones obtained by SH-based methods.

## **Nonlinear diffusion filtering**

There have been proposed and developed new approaches for linear and nonlinear diffusion filtering on a closed surface like a sphere, ellipsoid or the triangulated approximation of the real Earth's surface. The surface FVM have been used to derive an implicit numerical scheme for the linear diffusion and semi-implicit numerical schemes for the nonlinear diffusion equations on such closed surfaces. Two nonlinear models have been considered. In case of the Perona-Malik model, which is suitable for reducing an additive noise, the developed method has been applied for filtering various data, e.g., the satellite-only mean dynamic topography or the direct GOCE measurements. This model as well as numerical experiments has been recently published in *Journal of Geodesy* (2013, Vol. 87). Another nonlinear filtering model based on the geodesic mean curvature flow, which is suitable for reducing noise of the type "salt & pepper", has been already proposed and now is in process of development. The first testing numerical experiments have been successfully accomplished.



## Joint Study Group 0.8: Earth System Interaction from Space Geodesy

*Chair: Shuanggen Jin (China)*

### Activities

- **18-21 August 2012**, Shuanggen Jin organized International Symposium on Space Geodesy and Earth System (SGES2012) as Chair of Symposium, Shanghai, China.

The International Symposium on Space Geodesy and Earth System (SGES2012) was held in Shanghai, China, August 18-21, 2012, which was hosted by the Shanghai Astronomical Observatory, Chinese Academy of Sciences. Prof. Shuanggen Jin was the chair of the symposium. About 180 participants from over 15 countries or districts attended the SGES2012. Topics include data retrieval of space geodetic techniques, reference frame, atmospheric-ionospheric sounding and disturbance, gravity field, crustal deformation and earthquake geodesy, GIA, Earth rotation, hydrological cycle, ocean circulation, sea level change, and ice sheet mass balance as well as their coupling in the Earth system. This SGES symposium was sponsored by the International Association of Geodesy (IAG) and Global Geodetic Observing System (GGOS).

The SGES2012 provided a forum for assessing current technological capabilities and presenting recent results of space geodetic observations and understanding the physical processes and coupling in the Earth system, and future impacts on climate. More information can be found at <http://www.shao.ac.cn/meetings>

- **21-25 August 2012**, Shuanggen Jin organized International Summer School on Space Geodesy and Earth System.

Over 100 participants attended the International Summer School on Space Geodesy and Earth System, including 4<sup>th</sup> undergraduates, graduates, post-docs and young scientists. Lectures are Zuheir Altamimi (IGN, France), Richard Gross (JPL, NASA, USA), Manabu Hashimoto (Kyoto Univ., Japan), Shuanggen Jin (SHAO, CAS, China), Roland Klees (Delft Uni. Tech., Netherlands), Harald Schuh (Vienna Uni. Tech., Austria), Florian Seitz (Tech. Uni. Munich, Germany), Shimon Wdowinski (University of Miami, USA), Jens Wickert (GFZ, Potsdam, Germany) and Jeffrey T. Freymueller (Uni. of Alaska, USA). This Summer School introduced the space geodetic techniques and capabilities of measuring the Earth's shape, gravity field and rotation, e.g., GNSS, VLBI, Altimetry, InSAR, Gravimetry, which provided the opportunity to discuss and exchange experiences and ideas for researchers to understand the physical processes and coupling in the Earth system, and future impacts on climate.

- **10-18 November 2011**, Shuanggen Jin was invited to visit and give several talks at Taiwan National Chiao Tung University, National Cheng Kung University, National Central University and Institute of Earth Sciences, Academia Sinica, Taiwan
- **25-31 March 2012**, Shuanggen Jin was invited to give a talk at Universiti Teknologi Malaysia (UTM), Johor, Malaysia and Chaired one Session with one talk at Progress In Electromagnetics Research Symposium (PIERS), Kuala Lumpur, Malaysia.

### Publications

Jin, S.G., and G. Feng (2013), Global groundwater cycles and extreme events responses observed by satellite gravimetry, in U. Marti et al. (Eds.), IAG Symposia Book Series: Gravity, Geoid and Height Systems (GGHS2012), Venice, Italy, 9-12 October 2012, Springer Verlag, Heidelberg, Germany

Jin, S.G., T. van Dam, and S. Wdowinski (Eds.) (2013), Earth System Observing and Modelling from Space Geodesy, Special Issue in Journal of Geodynamics, Elsevier, ISSN: 0264-3707

- Jin, S.G. (2013), *Satellite Gravimetry: Mass Transport and Redistribution in the Earth System*, in S.G. Jin (Ed.), *Geodetic Sciences: Observations, Modeling and Applications*, InTech-Publisher, Rijeka, Croatia, ISBN: 980-953-307-595-7
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## **Communication and Outreach Branch (COB)**

<http://www.iag-aig.org>

*President: József Ádám (Hungary)*

*Secretary: Szabolcs Rózsa (Hungary)*

*IAG Newsletter Editor: Gyula Tóth (Hungary)*

### **Activity Report**

#### **1. Introduction**

The period of 2011-2015 is the third term in the operation of the Communication and Outreach Branch (COB) hosted at the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BME).

The Communication and Outreach Branch is one of the components of the Association.

According to the new Statutes (§5) of the IAG, the COB is the office responsible for the promotional activities of the IAG and the communication with its members.

The Terms of Reference and program of activities of the COB, and a short report on the IAG website ("IAG on the Internet"), were published in The Geodesist's Handbook 2012 (Ádám and Rózsa, 2012; Rózsa, 2012), respectively.

In the past period of the third term (since the 2011 IUGG General Assembly in Melbourne till July, 2013) the COB's President attended the EC meeting in two cases (Singapore, August 15, 2012 and Vienna, April 7, 2013), while COB's Secretary represented COB on the EC meeting in San Francisco, December 5th, 2011. A joint meeting of the IAG Office (H. Drewes and H. Hornik) and the COB (J. Ádám, Sz. Rózsa and Gy. Tóth) was organized in Budapest in November, 2012, where the following topics were discussed:

- the structure and operation of the website;
- IAG gifts/merchandising during the anniversary year at the SA in Potsdam.

#### **2. The IAG Website**

The Communication and Outreach Branch maintained the IAG Website. The website has been operational, no significant downtime has been experienced in the service. A regular update of the content has been carried out using the material provided by Association and Commission leaders, conference organizers and other members of the Association.

In the second half of the period the website has been redesigned after a consultation with the IAG Office and the Steering Committee members.

A new section has been introduced, where the actual topics in Geodesy can be highlighted ("Hot topics"). The website is currently redesigned according to the decision of the joint meeting of COB and the IAG Office. The updated website will be available for the SA in Potsdam.

Since the submission of the last report the following features have been added to the website:

- Facebook integration: all the pages of the website can be 'liked' on FB,
- Regenerating forgotten passwords automatically for the IAG Forum and the Members' Area.

The IAG Website is visited by 30 to 50 users per day.

All organizers of the IAG meetings were asked to send the announcements for meetings as well as summarising reports on these events to the COB in order to put these texts into the IAG Website and IAG Newsletter informing the whole community.



Weekly visitors from January to July, 2013.

### 3. The IAG Newsletters

Altogether 30 IAG Newsletters have been published from January 2011 till June 2013 and can be accessed on the IAG new website in HTML, HTML print version and in PDF formats. Each issue of the IAG Newsletter in 2012 and 2013 contains a special IAG logo designed for the 150th anniversary of the IAG. We strive to publish only relevant information by keeping the Newsletter updated on a per-monthly basis. IAG Individual Members, IUGG and JB GIS Presidents and Secretaries as well as interested persons mainly in developing countries received it in PDF and/or text attachments, with a link in the e-mail message to access the actual HTML Newsletter on the IAG website. As of June 2013 the IAG Newsletter is sent to 872 subscribers by e-mail. Selected content of the electronic Newsletters were compiled and have been sent regularly to Springer for publication for 32 issues of the Journal of Geodesy (Vol 85/1 – 87/8).

### 4. Outreach Activities

The COB has been active in the publishing of information material in the reporting period. A new version of the IAG brochure has been published (16 coloured pages), which targets the wider public and decision makers by introducing Geodesy in general as well as the role of the Association to the readers (Ádám and Rózsa, 2013). It has a chapter on the Global Geodetic Observing System, and provides information on the IAG components (Commissions, Inter-Commission Committee, Services, etc.).

The brochure can be downloaded from the opening page of the IAG website, together with the updated IAG leaflet (Ádám and Rózsa, 2013).

J. Ádám and H. Drewes (2012) prepared a summary on “The International Association of Geodesy (IAG) – Historical Overview”.

Various examples for badges, tokens, stickers, tags, key rings etc were prepared to be distributed before and during IAG Scientific Assembly/150 Years Celebration. The EC and the IAG Office selected several of them to be produced in a sufficient number for the event. A number of these objects will be sent to the IAG National Delegates.

## 5. Summary

In sum, the following activities were done:

- a) the IAG website was updated, improved and continuously maintained;
- b) the IAG Newsletter was regularly issued monthly and distributed electronically, and selected parts of them were prepared to publish in the Journal of Geodesy as IAG News;
- c) new version of the IAG Leaflet was prepared, printed and distributed at different IAG meetings;
- d) the large IAG Brochure was reprinted;
- f) some works were made in preparation and for finalizing The Geodesist's Handbook 2012 (Drewes et al., 2012),
- g) various examples for IAG presents (badges, key rings, caps, wooden pencils, scarfs, etc) were prepared to be distributed before, during and after IAG Scientific Assembly/150 Years Celebration, and
- h) many e-mail correspondences to the community as part of the outreach activities.

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## **Global Geodetic Observing System (GGOS)**

<http://www.ggos.org>

*Chair: Hansjörg Kutterer (Germany)*

*Vice Chair: Ruth Neilan (USA)*

### **Structure**

Working Group 0.1: Satellite missions

Working Group 0.2: Earth system modelling

Working Group 0.3: Data and information systems

Working Group 0.4: User linkage and outreach

Working Group 0.5: ITRS standard

Bureau for standards and conventions

Bureau of networks and communication

Theme 1: Unified height system

Working Group 0.1.1: Vertical datum standardisation

Theme 2: Geohazards monitoring

Working Group 0.2.1: New technologies for disaster monitoring and management

Theme 3: Sea-level change, variability and forecasting

### **Overview**

#### **New structure and elections**

During the IUGG General Assembly 2011 in Melbourne the IAG Executive Committee had decided about the new structure of GGOS and had approved the respective Terms of Reference (ToR). In order to implement the new structure, various nominations and elections became necessary.

#### *GGOS Consortium*

First, the GGOS Consortium as the large steering committee and collective voice of GGOS had to be composed according to the GGOS ToR. Each GGOS entity had to nominate two representatives. The present members of the GGOS Consortium as result of this nomination procedure are compiled in the following list. The presiding chair of GGOS is also the chair of the GGOS Consortium. As the GGOS Consortium is supposed to meet annually, the first meeting took place during the weekend before the AGU meeting in San Francisco 2012.

Table 1: Members of the GGOS Consortium – July 2013

Services	Name	Title
GGOS	Hansjörg Kutterer	GGOS Chair
Int'l Gravimetric Bureau (BGI)	Sylvain Bonvalot	Director
Bureau International des Poids et Mesures (BIPM) - Time Section	Elisa Felicitas Arias	Director
International Altimetry Services (IAS)	Wolfgang Bosch Cheinway Hwang	Chair
International Center for Earth Tides (ICET)	Jean-Pierre Barriot	Chair
International Centre for Global Earth Models (ICGEM)	Franz Barthelmes	Director
International Digital Elevation Model Service (IDEMS)	Philippa Berry R.G. Smith	Director
International Doris Service (IDS)	Laurent Soudarin Pascal Willis	Director Chair
International Earth Rotation and Reference Systems Service (IERS)	Bernd Richter Chopo Ma	Director of the Central Bureau Chair of the Directing Board
International Geoid Service (IGeS)	Fernando Sansò Riccardo Barzaghi	President Director
International Gravity Field Service (IGFS)	Rene Forsberg Steve Kenyon	Chair Director of the Central Bureau
International GNSS Service (IGS)	Ruth Neilan Urs Hugentobler	Director Chair
The International Laser Ranging Service (ILRS)	Graham Appleby Erricos Pavlis	Chair of Governing Board Analysis Coordinator
International VLBI Service for Geodesy and Astrometry (IVS)	Dirk Behrend Axel Nothnagel	Director IVS Analysis Coordinator
Permanent Service for Mean Sea Level (PSMSL)	Lesley J. Rickards Mark Tamisiea	Director

### *GGOS Coordinating Board*

After finalizing the composition of the GGOS Consortium the members of the GGOS Coordinating Board (CB) were elected. The GGOS acts as the decision-making body of GGOS. The present members of the GGOS CB are indicated in the following table. The GGOS CB meets twice a year on the occasion of the EGU meeting in Vienna and the AGU meeting in San Francisco with the fourth meeting held during the weekend before the EGU 2013.

Table 2: Members of the GGOS Coordinating Board – July 2013

Position	Rights	Name
GGOS Chair	1 (voting)	Hansjörg Kutterer
Vice-Chair	1 (voting)	Ruth Neilan
Chair of GGOS Science Panel	1 (voting)	Richard Gross
Head, Coordinating Office	1 (ex-officio, voting)	Giuseppe Bianco
Directors of GGOS Bureaus	2 (ex-officio, voting)	
Bureau of Networks and Communication		Michael Pearlman
Bureau of Standards and Conventions		Detlef Angermann
IAG President or design. representative	1 (ex-officio, voting)	Chris Rizos
Service Representatives	4 (elected by the Consortium, voting)	Pascal Willis, Ruth Neilan, Erricos Pavlis, Chopo Ma
IAG Commissions Representatives	2 (elected by the Consortium, voting)	Srinivas Bettadpur, Tonie van Dam
Members-at-Large	3 (elected by the CB, voting)	Yamin Dang, Yoichi Fukuda, Maria Cristina Pacino
<i>Chairs of GGOS Working Groups</i>	1 or more (ex-officio, non-voting)	
Satellite Missions		Isabelle Panet
Data and Information Systems		Bernd Richter
Earth System Modelling		Maik Thomas
Outreach and User Linkage		Giuseppe Bianco
ITRS Standard		Claude Boucher
<i>Theme Leads</i>	3 (ex-officio, non-voting)	
Theme 1		Michael G. Sideris
Theme 2		Tim Dixon
Theme 3		Tilo Schöne
GGOS Portal Manager	1 (ex-officio, non- voting)	Bernd Richter
Immediate Past Chair of the CB	1 (ex-officio, non- voting)	Markus Rothacher
Representative of the GIAC/GIC	1 (ex-officio, non- voting)	Gary Johnston

### *GGOS Executive Committee*

Based on the members of the GGOS CB the members of the GGOS Executive Committee (EC) were nominated by the GGOS chair and approved by the GGOS CB. The present members of the GGOS EC are compiled in the following list. The role of the GGOS EC is to serve at the direction of the CB to accomplish day-to-day activities of GGOS tasks. The GGOS EC has had regular telecons on a more or less monthly basis since July 2011 continuing the sequence of telecons under the previous structure.



Table 3: Members of the GGOS Executive Committee – July 2013

Name	Role
Hansjörg Kutterer	GGOS Chair
Ruth Neilan	GGOS Vice-Chair
Pascal Willis	Voting member of the GGOS CB
Srinivas Bettadpur	Voting member of the GGOS CB
Detlef Angermann	Voting member of the GGOS CB
Markus Rothacher	Immediate past chair of GGOS
Giuseppe Bianco	Director of the GGOS Coordinating Office
Harald Schuh	IAG Vice-President
Richard Gross	Chair GGOS Science Panel
GGOS CO	Coordinating Office
Mike Pearlman	Observer
Chopo Ma	Observer

### *GGOS Science Panel*

Finally, the members of the GGOS Science Panel (SP) as well as the chair of the Science Panel were approved; see the following list. The role of the SP is to advise the CB and to represent the geodetic and geoscience community.

- Jonathan Bamber (U Bristol)
- Alexander Brzezinski (SRC)
- Jim Davis (LDEO)
- Athanasios Dermanis (Aristotle U)
- Andrea Donnellan (JPL)
- Richard Gross (JPL) – Chair
- Roger Haagmans (ESA)
- Sylvie Malardel (ECMWF)
- Rui Ponte (AER)
- Matt Rodell (GSFC)
- Seth Stein (Northwestern U)
- Tonie van Dam (U Luxembourg)

The GGOS Science Panel is an independent and multi-disciplinary advisory board that provides scientific support to the GGOS steering and coordination entities. With the approval of the GGOS SP, the new structure of GGOS was finalized in Spring 2012.

### *GGOS Retreat in Frankfurt 2012*

During the IUGG General Assembly 2011 in Melbourne the GGOS Terms of Reference as well as the Vision, Mission and Goals paper of GGOS were approved by the IAG Executive Committee. After the finalization of the new structure the GGOS CB met for a retreat in Frankfurt in 2012, June 27-29, mainly to work on the GGOS strategy and to discuss the further implementation of GGOS as an observing system. The main activities were concerned with the review of the action plan, the documentation of user requirements, the improvement of interaction and communication amongst GGOS, the IAG services and the commissions.

Other aspects were the relationship to the GIAC, the GGOS inter-agency committee, the better integration of experts for gravity and the formulation of standardized GGOS review processes.

The main outcomes of the Frankfurt 2012 retreat were integrated in tabular form as the so-called Frankfurt matrix. It was decided to further elaborate the matrix with distinction of two ways to proceed: strategic activities on the one hand aiming at the development and application of a strategic plan and GGOS 2020 project activities aiming at the implementation and operationalization of GGOS as an observing system – or to be more precise as a system of systems. Both parts dominate the ongoing work of the GGOS CB and the GGOS EC.

#### *Contribution of the IAG and GGOS to UN GGIM*

The initiative of the United Nations (UN) in the field of Global Geospatial Information Management (GGIM) is concerned with several fields of work. The Statistics Division of the UN is in charge of this initiative. Until now two so-called High-Level Forums took place in Seoul (Nov. 2011) and Doha (Feb. 2013). In July 2013 the third Committee of Experts meeting will take place in Cambridge, U.K., after a first meeting in Seoul (Nov. 2011) and New York (Aug. 2012).

Global geodetic reference systems and frames as well as global geodetic infrastructure are considered besides geo-topography and land tenure within this initiative. As the activities under the umbrella of the UN refer to the member states, the IAG participates in this initiative as an observer. A stronger link between UN GGIM and the IAG was established through a joint effort of the GGOS chair and colleagues from Australia, France and other countries. The involvement of the IAG aims at the formulation of a UN mandate for geodetic infrastructure. More information on UN GGIM (including all material concerning the meetings) is available through the UN GGIM website ([un.ggim.org](http://un.ggim.org)).

Present outcomes are indicated in the so-called Doha declaration from February 2013:

“We, therefore resolve, to commit ourselves to working together as an international community, under the coordination of the United Nations, to work with all stakeholders to improve a sustained operational global geodetic reference frame and infrastructure, to support the increasing demand for positioning and monitoring applications with associated societal and economic benefits; ...

The Forum addressed the need for a sound and sustainable global geodetic reference frame and noted the significant contributions made by the International Association for Geodesy (IAG) over the past 150 years. It was noted that the current International Terrestrial Reference Frame (ITRF) and other products developed and maintained by IAG were endorsed and used by many countries. The role of the private sector in providing location-based positioning services was also discussed.

The Forum noted that the increasing need for the global geodetic system to track changes such as terrestrial adjustments and sea level rise would require significant refinement to the current systems and need for further precision. Expansion in the current geodetic observing infrastructure such as the receiving stations, combined with greater interoperability, willingness to share of data, and coherence to standards would be required.

The Forum agreed that while the science of establishing a sound geodetic reference frame is available, it was essential to have the governments accept the responsibility of establishing and maintaining a sound national geodetic reference frame which could serve as the foundation for a global system. Some countries had expanded their national system on account of economic benefits through better located-based positioning services. It was agreed that the UN-GGIM has an important role to play and that a resolution at the General Assembly of the United Nations urging the governments to support a global geodetic frame would provide a strong mandate for further development of the frame.”

As the chairs of GGOS and of GIAC (Gary Johnston, Australia) are the national representatives within UN GGIM the geodetic activities are strongly aligned with the interests and efforts of the IAG.

#### *Progress of the GGOS Bureaus*

The GGOS Bureau on Networks and Communications continued soliciting for the GGOS Network under the GGOS Call for Participation (see: [http://space-geodesy.gsfc.nasa.gov/docs/2012/GGOS\\_CfP\\_Response\\_Summary\\_20121219.pdf](http://space-geodesy.gsfc.nasa.gov/docs/2012/GGOS_CfP_Response_Summary_20121219.pdf)). The Network Characterization Model for the Space Geodesy Co-location Network was completed, including projections five and ten years into the future (see: [http://space-geodesy.gsfc.nasa.gov/docs/2013/candidatesites\\_130122.pdf](http://space-geodesy.gsfc.nasa.gov/docs/2013/candidatesites_130122.pdf)). The critical elements of the GGOS Infrastructure Implementation Plan were completed as well as the site evaluations on GSFC, Haystack, Monument Peak, McDonald, Kokee Park, Haleakala, Gilmore Creek, and several other US West Coast Sites. In addition, international core site development was monitored: three Russian Sites in operation at Svetloe, Zelenchukskaya, and Badary; Korean Core Site in testing. Discussions with several agencies regarding partnership sites for the GGOS Core Network continued.

The major activities of the Bureau of Standards and Conventions were dedicated to the compilation of an inventory of standards and conventions used for the generation of the IAG/GGOS products. This includes the celestial and terrestrial reference frames, the Earth Orientation Parameter (EOP), orbits for GNSS satellites, global and regional gravity fields as well as vertical reference frames. Therefore, the standards and conventions currently in use in the geodetic community were evaluated, such as the Geodetic Reference System 1980, the IERS Conventions 2010 and the standards for gravity missions (e. g., CHAMP, GOCE). Resolutions of IUGG, IAG and IAU as well as standards and fundamental physical constants adopted by external bodies (e.g., ISO, BIPM, CODATA) were also considered. A publication of such a product-based inventory is under preparation. A major outcome are recommendations to resolve existing inconsistencies, which shall be distributed among the relevant IAG Components until the end of 2013.

#### *Progress of the GGOS Working Groups*

The WG on Satellite Missions performed an analysis of existing infrastructure. On the one hand all relevant missions were compiled referring to gravity field, SLR, LLR, GNSS, SAR, and altimetry, as well as missions with DORIS receiver. On the other hand the missions were assessed regarding their current contributions to GGOS 2020 goals.

One of the most important tasks of the WG on Earth System Modelling was the development of a strategy for establishing a physically consistent system model for near-surface dynamics. Activities focused on the question, how global mass conservation can be realized in a

passively coupled forward system model consisting of sub-models with different grid characteristics, parameterizations and spatiotemporal resolutions. Significant mass imbalances still result from application of inconsistent boundary conditions in individual sub-models, such as different land-ocean masks and forcing fields. However, users superimposing results from various models for further analyses are often not aware of these inconsistencies. Hence, meaningful meta-data have to be provided.

The work of the WG on Outreach and User Linkage was on the one hand concerned with the preparation and provision of information material such as a GGOS leaflet and on the other hand on the revision of the GGOS strategic plan together with the group of the GGOS vice-chair at JPL.

### *Progress of the GGOS Themes*

The action plan of Theme 1 “Unified Height System” was revised. In addition, contributions to Theme 1 were derived through the ESA project STSE – GOCE+: Height System Unification with GOCE. This project works on the unification of North American, European and North Atlantic Datum. In addition, studies of regional  $W_o$  determination, datum offsets estimation, GOCE and other contributions to the European Geoid Model (EGM) are performed. Effects of local data/omission errors, data biases and noise, ocean models and EGM truncation as well as benchmark/tide gauge spacing and distribution are considered. Within this scope, the JWG 0.1.1 “Vertical Datum Standardization” provided complementary work: Global  $W_o$  computations by four different groups delivered very close results (around 62 636 854  $\text{m}^2\text{s}^{-2}$ ), but there are still differences of about 0.5  $\text{m}^2\text{s}^{-2}$  (~ 5 cm). It is necessary to start defining the standards and conventions for a formal recommendation on  $W_o$ .

The thematic scope of Theme 2 “Geohazards Monitoring” is still under discussion in order to better align it with geodetic competences.

Theme 3 “Sea-Level Change, Variability and Forecasting” concentrated its work on organizational issues. Besides some work on the proper understanding of global and regional/local sea-level rise and its variability especially in so far as they relate to geodetic monitoring provided by the GGOS infrastructure, organizations or individuals should be identified who can act as points of contact for regarding GGOS. Thus, a set of practical pilot projects should be identified which demonstrate the viability, and the importance of geodetic measurements to mitigation of sea-level rise at a local or regional level. This identification will be followed by construction of proposals for pilot projects. The respective Call for Participation was issued in 2012. One project was already selected, other projects are under discussion.

## Working Group 0.1: Satellite Missions

*Chair: Isabelle Panet (France)*

*Co-chair: Roland Pail (Germany)*

### Summary and objectives

The working group objectives for the 2011-2015 time frame can be summarized as follows:

- To fully set-up the working group organization: update of the charter and terms of reference, members and working group interfaces with GGOS/IAG, space agencies and CEOS.
- To set-up a plan of actions, and then start realizing this plan, for facilitating the use of satellite products by users. To assess the satellite infrastructure relevant for achieving the goals of GGOS and make recommendations for needed missions.
- To support proposed missions by providing inputs on their scientific and societal relevance in the context of GGOS goals, focussing on particular types of missions to be identified.
- To provide outreach on satellite missions via the GGOS portal.
- To reconsider the possible establishment of a Bureau.

### Present status (July 2013)

The working group is presently constituted of 23 members:

- Bettadpur Srinivas, CSR, Univ. Texas, US
- Biancale Richard, CNES/GRGS, France
- Chao Benjamin, National Central University, Taiwan
- Cho Sungki, Korea Astronomy and Space Science Institute, Korea
- Flechtner Frank, GFZ Potsdam, Germany
- Fotopoulos Georgia, University Toronto, Canada
- Fukuda Yoichi, Kyoto University, Japan
- Hwang ,Cheinwey, National Chiao Tung University, Taiwan
- Knudsen Per, DTU, Denmark
- Matsumoto Koji, Japan
- Müller Jürgen, Universität Hannover, Germany
- Nerem R. Steve, University Colorado, US
- Pail Roland, IAPG, TU München, Germany (co-chair)
- Panet Isabelle, Institut Géographique National, France (chair)
- Ping Jinsong, Shanghai Observatory, China
- Shum C.K., Ohio State University, US
- Sideris M., Univ. Calgary, Canada
- Sneeuw Nico, Universität Stuttgart, Germany
- Joong-Sun Won, Yonsei University
- Min Zhong, Inst. of Geodesy & Geophysics, CAS, Wuhan, China
- Virendra Tiwari, National Geophysical Research Institute, Hyderabad, India
- Haagmans Roger, ESA
- LaBrecque John, NASA

### **Actions done (2011-mid 2013)**

During the last two years, we carried out the following actions:

- We have updated the WG charter and terms of reference, and selected new members. In particular, a few members allow to make a link with a few space agencies.
- Outreach: the WG contributed to the GGOS portal, for satellite missions webpages,
- Discussions regarding the access to satellite products lead to the conclusion that this topic relates to that of the GGOS products,
- Analysis of satellite infrastructure: the WG has compiled an inventory of the characteristics of the past, existing and currently planned satellite missions. This inventory comprises gravity field missions, satellite laser ranging, lunar laser ranging, satellites equipped with a retro-reflector, GNSS satellites, SAR missions, altimetry missions and missions with a DORIS receiver. The WG then started a gap analysis, based on an evaluation of how these missions contribute to measuring the geodetic parameters relevant to GGOS (in the categories reference frames and Earth change monitoring), and thus to fulfil the GGOS 2020 goals.
- Providing inputs on the scientific relevance of proposed missions in the context of GGOS goals: the WG contributed to the preparation of a letter from the IUGG addressed to ESA, in support of future gravity missions (June 2012). A joint workshop with IAG subcommissions 2.3 (dedicated satellite gravity missions), 2.6 (gravity and mass displacements), and with IUGG as organizing partners is proposed, in order to provide a consolidated view on the science requirements for such a future mission.
- Finally, the WG serves as a forum where to inform and exchange on questions related to satellite missions.

### **Topics of attention for 2013 - 2015**

Topics of attention that have been identified are:

- to keep the assessment of the satellite infrastructure and needs up to date,
- gather and propose new concepts for future missions,
- advocate the previously identified needed missions,
- interface to CEOS should be discussed – a possibility is to provide technical support regarding satellite missions in the participation of GGOS to CEOS,
- rationalize the possible establishment of a Bureau of Satellite Missions.

## **Working Group 0.2: Contributions to Earth System Modelling**

*Chair: Maik Thomas (Germany)*

The GGOS Working Group (WG) on “Contributions to Earth System Modeling” has been established in 2011. Its major goal is the preparation of a physically consistent unconstrained numerical Earth system model focussing on near-surface fluid dynamics. This modular model is expected to allow a homogeneous processing, interpretation, and prediction of geodetic parameters, i.e., Earth rotation, gravity field and deformation, and, thus, to finally contribute to a deeper understanding of dynamical processes in the Earth system reflected in geodetic observables. According to the planned multi-disciplinary activities, the members represent a broad field of expertise, covering system dynamics from the atmosphere to the Earth’s deep interior.

Traditionally, various independent models tailored to specific spatial and temporal scales and to specific dynamical processes in individual sub-systems of the Earth are applied in order to estimate particular contributions to observed variations of geodetic parameters. Although it is well known that the individual sub-systems are coupled via fluxes of mass, energy and momentum, these interactions are generally not adequately considered or even neglected, and the total amount of geophysical excitation is mostly described by a simple linear addition of the individual contributions. Another deficiency results from the fact that the various estimates are based on different standards and parameters and use diverse analysis strategies and formats. Thus, in order to ensure physical consistency, in particular mass conservation, and to consider feedbacks a modular model approach with individual modules representing sub-systems or components interacting through boundary conditions is mandatory.

In the initial phase, one of the most important tasks of the WG was the development of a strategy for establishing a physically consistent system model for near-surface dynamics. Since model based analyses and predictions of geodetic parameters are, in particular, sensitive to the representation of mass transport and redistribution, activities focused on the question, how global mass conservation can be realized in a passively coupled forward system model consisting of sub-models with different grid characteristics, parameterizations and spatio-temporal resolutions. This issue has also been discussed within the WG during the IERS workshop held in Vienna on April 20, 2012. Significant mass imbalances still result from application of inconsistent boundary conditions in individual sub-models, such as different land-ocean masks and forcing fields. However, users superimposing results from various models for further analyses are often not aware of these inconsistencies. Hence, the preparation and provision of meaningful meta data is an essential task of modelers and data centres that should be taken more seriously. Although significant causes of mass imbalances could be identified, the WG itself will not be able to overcome all these difficulties. It is rather a challenge to motivate source code developers from other Earth science disciplines to pay attention to these model deficiencies, e.g., by demonstrating mutual benefits. This is especially important in the case of atmospheric modeling, since data from numerical weather models or re-analysis projects are used to force cryospheric, oceanic, and hydrological models. Hence, the WG will, in particular, try to strengthen the cooperation with the meteorological community.

Apart from the further development of a strategy to ensure physical consistency, planned actions will focus on i) the selection of appropriate models for the representation of dynamics of the individual near-surface sub-systems, such as atmosphere, oceans, continental hydrosphere, cryosphere, and lithosphere; ii) the identification of relevant interactions among sub-

systems as well as of appropriate parameterizations for their numerical consideration; iii) the definition of common standards, parameters, and formats in order to promote multi-model validations and cross comparisons of model based estimates of variations of geodetic parameters. In this context, the usefulness of standard analysis tools will be discussed, too. According to the requirements of the geodetic community, the WG will also pay attention to the question, to what extent the preparation of error estimates of model based predictions of geodetic quantities might be possible and reasonable.



### **Working Group 0.3: Data and Information Systems**

*Chairs: Bernd Richter (Germany) and Carey Noll (USA)*

The GGOS Working Group on Data and Information Systems established in 2009 will support GGOS in all data management aspects of the design, coordination, and implementation of the GGOS data and information system for the interdisciplinary scientific and non-scientific user community by:

- evolving the data information systems based upon user requirements,
- developing and proposing a common technology and frame work to provide a uniform access to the data of all IAG services,
- developing and proposing uniform access to heterogeneous space geodetic and in-situ data and information systems, and
- offering a single point of entry (GGOS Portal).

The GGOS Portal provides a unique access point to all geodetic products ([http://www.ggos-portal.org/lang\\_en/GGOS-Portal/EN/Home/homepageLink.html](http://www.ggos-portal.org/lang_en/GGOS-Portal/EN/Home/homepageLink.html)). Thus, the Portal will emphasize Geodesy's contribution to Earth Observation for assessing geohazards and reducing disaster. The Portal consists of information to GGOS Themes, GGOS topics, a metadata catalogue including a search engine and an editor, a map viewer, and a list of GGOS products.

The area "GGOS Themes" provides an overview but also detailed information about the three GGOS themes: Unified Height Systems, Natural Hazards, Understanding and Forecasting Sea-Level Rise and Variability. Up to now information about theme 3 are presented and a call is launched for proposals to demonstrate the value of geodetic techniques to Sea level science and applications. Theme 1 needs some the standards and conventions for a formal recommendation whereas theme 2 is still under discussion (see section GGOS themes above). Information will be added as soon as available.

GGOS integrates different geodetic techniques, different models and different approaches in order to ensure a long-term, precise monitoring of the geodetic observables. An overview of science and geodetic applications, satellite missions, techniques and services involved in these subjects could be found in the "Topics" areas and their sub-areas.

"Discovery" or "search" is still under construction. It is linked to GeoNetworks, an open source to search data. A limited set of geodetic data (all IERS products) are specified by meta-data (ISO 19115) and thus open the possibilities for search. The missing key element for these actions is a generalized meta-data catalogues for all geodetic applications and products. In consideration of the fact that high level scientific as well as political documents demand and support an Open Data policy the working group will renew the discussion on that subject.

The "Viewer and Application" areas provide basic functions, mainly derived from IERS applications, and are open for community inputs. "GGOS products" lists an overview of GGOS products and infrastructure. The latest section documents the activities of the GGOS Inter-Agency Committee to support GGOS.

## Working Group 0.4: Outreach and User Linkage

*Chair: Guiseppe Bianco (Italy)*

### Summary and scope

The GGOS Component “Outreach” [OR] is chaired by the GGOS Coordinating Office (CO) and managed by the Working Group on Outreach and Education (WG on O&E), approved during the GGOS Steering Committee meeting held in San Francisco on December 11th, 2010; its scope and duties have been discussed during the GGOS Retreat held in Zurich, February 2-4, 2011.

The scope of this Working Group derives mainly from the GGOS 2020 Recommendation 1.3 (Outreach and Education): recognizing that society to a large extent is not aware of the vital role played by geodesy for realizing a sustainable development, and that educational aspects are extremely important (because they have the greatest implication on societal behaviour) in order to prepare future generations to make use of the full benefits of geodesy, it is recommended that IAG and GGOS make dedicated outreach efforts to science and society at large with the goal to promote geodesy’s role in reaching sustainable development and to integrate this role of geodesy appropriately into education.

### Current status

The WG 0.4 currently consists of the following people

- Chair:
  - Giuseppe Bianco (Agenzia Spaziale Italiana, Italy)
- Members
  - Allison Craddock (NASA Jet Propulsion Laboratory, USA)
  - Doreen Hagemeister (Agenzia Spaziale Italiana, Italy)
  - Cinzia Luceri (e-Geos, Italy)
  - Stephen Merkowitz (NASA Goddard Space Flight Center, USA)
  - Ruth Neilan (NASA Jet Propulsion Laboratory, USA)
  - Carey Noll (NASA Goddard Space Flight Center, USA)
  - Mike Pearlman (Center for Astrophysics, USA)
  - Chris Rizos (University of New South Wales, Australia)
  - Phil Woodworth (National Oceanography Centre, UK)
  - Susanna Zerbini (University of Bologna, Italy)

The first accomplishment of the Outreach component has been the new GGOS web site ([www.ggos.org](http://www.ggos.org)), managed by the GGOS CO, put on line in summer 2010, and maintained since then.

Work has started on the GGOS Outreach Document. This activity has proven longer and more difficult than originally foreseen, possibly due to the lack of specific professional outreach skills within GGOS.

### **Short Term objectives**

- GGOS Outreach Document
- GGOS Monographs
- GGOS Web site improvement

GGOS Monographs are short yet complete documents, targeted to non specialized public, designed to clearly describe the role of geodesy in reaching sustainable development. Monographs may be devoted to specific earth science fields, such as oceanography, crustal deformations, and so on, or to societal issues such as hazard mitigation, water scarcity, global warming, and so on.

### **Mid-term objectives**

- Design and implementation of multimedial outreach material
- Collaboration with national/international media to promote geodesy

Those objectives are a bit fuzzy at this time, since it is not easy to identify a clear path to improve awareness of the role of geodesy.

## Working Group 0.5: ITRS Standard

*Chair: Claude Boucher (France)*

Referring to the activity report for 2012, the 2013 activities have occurred within the ISO TC211/Project 19161 on geodetic references, including:

- Geodetic datums
- Terrestrial reference systems and frames
- Geodetic ellipsoids
- Coordinate systems used for geo-referencing
- Map projections
- Gravity and geoid (gravity models, geoidal models..)
- Vertical reference systems
- Geodetic networks (classical triangulations or leveling, space geodesy, gravity stations ...) and related metadata (such as station identifiers, ...)
- .....

The main objectives of this project are:

- to investigate and formulate requirements related to standardization on geodetic references
- to recommend standards to be developed within ISO TC 211

The final report of the project is expected for end of 2014.

Zuheir Altamimi has been recently appointed as IAG liaison representative in the project.

Concerning the issue of an ITRS standard, the proposed strategy is to draft a preliminary version of such a document, with the help of an international panel of experts, in parallel to the project activity. Anticipating that the project will recommend such a standard, this draft will be then formally submitted to ISO TC 211 for approval.

It is therefore recommended to GGOS to upgrade the initial charter of this GGOS WG, with the following items:

- to provide IAG expertise to the work of the ISO project, driven by the IAG representative
- to provide expertise to the drafting of the ITRS document
- to contribute to the proposal of other subjects of standardization, such as vertical references
- to coordinate the overall IAG activities in the field of standardization

## **Bureau for Standards and Conventions**

*Chair: Detlef Angermann (Germany)*

The Bureau for Standards and Conventions (BSC) was established as a GGOS component in 2009. The BSC is hosted and supported by the Deutsches Geodätisches Forschungsinstitut (DGFI) and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of Technische Universität München, under the umbrella of the Forschungsgruppe Satellitengeodäsie (FGS). Initially, U. Hugentobler acted as director of the Bureau. In April 2011, D. Angermann was nominated as his successor. The present members of the BSC are D. Angermann (director), T. Gruber (deputy director), M. Gerstl, U. Hugentobler, L. Sánchez, P. Steigenberger.

### **Purpose**

The work of the BSC is primarily built on the IAG Services (IGS, ILRS, IVS, IDS, IERS, IGFS, etc.) and the products they derive on an operational basis for Earth monitoring making use of various space geodetic observation techniques such as VLBI, SLR/LLR, GNSS, DORIS, altimetry, gravity satellite missions, gravimetry, etc. The purpose and major goal of the BSC is to ensure that common standards and conventions are adopted and implemented by the IAG components as a fundamental basis for the generation of consistent IAG/GGOS products. The use of identical standards and conventions is crucial for the adequate modelling and processing of the different geodetic observations as well as for a reliable parameter estimation and representation in all fields of geodesy, in order to ensure consistent results for the geometry, the rotation and gravity field of the Earth along with its variations in time.

### **Objectives**

The implementation of common standards and conventions for the generation of geometric and gravimetric products is of crucial importance for GGOS. The BSC supports GGOS in its goal to obtain products of highest accuracy, consistency, temporal and spatial resolutions, and referring to a unique reference frame stable over decades.

According to the Terms of References the objectives of the BSC are:

- To keep track of the strict observance of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in the generation of IAG/GGOS products.
- To review, examine and evaluate all standards, constants, resolutions and conventions adopted by IAG or its components and recommend their use or propose the necessary updates.
- To identify gaps, inconsistencies and deficiencies in standards and conventions and to initiate steps to remove them.
- To propose the adoption of new standards where necessary.
- To propagate standards and conventions to the wider scientific community and promote their use.

### **Activities**

The major activities of the BSC have been focussed on the compilation of an inventory of standards and conventions used for the generation of the IAG/GGOS products, such as the celestial and terrestrial reference frames, the Earth Orientation Parameter (EOP), orbits for

GNSS satellites, global and regional gravity fields as well as vertical reference frames. This includes an evaluation of the standards and conventions currently in use in the geodetic community, such as the Geodetic Reference System 1980, the IERS Conventions 2010 and the standards for gravity missions (e.g. CHAMP, GOCE). Relevant are also resolutions of IUGG, IAG and IAU as well as standards and fundamental physical constants adopted by external bodies (e.g., ISO, BIPM, CODATA). The BSC evaluates the status regarding standards and conventions for the mentioned IAG/GGOS products, identifies gaps and inconsistencies as well as interactions between different products. A publication of such a product-based inventory is in progress, which is entitled: “*GGOS Bureau for Standards and Conventions: Inventory of standards and conventions used for the generation of IAG/GGOS products*”. A major outcome are recommendations to resolve existing inconsistencies, which shall be distributed among the relevant IAG Components until the end of this year.

As an example, Table 1 shows a comparison of numerical standards obtained from various sources, such as the Geodetic Reference System 1980 (Moritz 2000), fundamental parameters and current (2004) best estimates of the parameters of common relevance to astronomy, geodesy, and geodynamics (Groten 2004), and the IERS Conventions 2010 (Petit and Luzum 2010). The different definitions for some of the quantities are a source for errors and inconsistencies in the analysis and combination of space geodetic observations and product generation. A potential source of confusion concerns also the time and tide system as used by the different geodetic communities.

Table 1: Comparison of numerical standards

Quantity	IERS2010 (Petit and Luzum, 2010)	GRS80 (Moritz 2000)	Fundamental Parameters (Groten 2004)	Unit
Geocentric gravitational constant (GM)	398.6004118	398.6005	398.6004118	$[10^{-12} \text{ m}^3 \text{ s}^{-2}]$
Equatorial radius (a)				[m]
- zero-tide value	6 378136.6	6378137	637836.62	
- mean-tide value			637836.72	
- tide-free value			637836.59	
Flattening factor (1/f)				[ ]
- zero-tide value	298.25642	298.25722	298.25642	
- mean-tide value			298.25231	
- tide-free value			298.25765	
Dyn. form factor ( $J_2$ )	1082.6359	1082.63	1082.6359	$[10^{-6}]$
Ang. Rot. velocity ( $\omega$ )	7.292115	7.292115	7.292115	$[\text{rad s}^{-1}]$
Potential geoid ( $W_0$ )	62636856.0	62636860.85	62636856.4	$[\text{m}^2 \text{ s}^{-2}]$

### Interactions between the BSC and the IAG Components and IAU

The interaction with the IAG Services, which is fundamental for the compilation of the inventory of standards and conventions applied for the generation of the IAG/GGOS products, is organized by nominating a representative of each Service as an Associated Member of the BSC.

At present (status: June 2013) the following IAG Services are represented in the BSC:

- International Earth Rotation and Reference Systems Service (IERS): G. Petit, France
- International GNSS Service (IGS): U. Hugentobler (in personal union for the IGS)
- International Laser Ranging Service (ILRS): E. Pavlis, U.S.A.
- International VLBI Service for Geodesy and Astrometry (IVS), J. Gibson, U.S.A.
- International DORIS Service (IDS), Frank Lemoine, John Ries, both U.S.A.
- Intern. Center for Global Gravity Field Models (ICGEM): F. Barthelmes, Germany
- International Geoid Service (IGeS): R. Barzaghi, Italy
- International Gravimetric Bureau (BGI), Sylvain Bonvalot, France

The link of the BSC to IAU has been established by nominating R. Heinkelmann (GFZ) as a representative. He is a member of the IAU Working Group “Numerical Standards for Fundamental Astrometry”.

In addition, the following associated members have been nominated to the BSC:

- M. Craymer, Canada: Chair of Control Body for the ISO Geodetic Registry Network
- J. Ádám, Hungary: Chair of the IAG Communication and Outreach Branch
- J. Ihde, Germany: IAG representative to ISO/TC211
- J. Kusche, Germany: Representative of gravity community

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## Bureau of Networks and Communication

*Chair: Mike Pearlman (USA)*

The Bureau is focused on working with the GGOS Coordinating Office and the IAG Services to facilitate the implementation of a global network of ground-based multi-technique space geodetic core sites, i.e. observatories with co-located SLR, VLBI, GNSS and DORIS systems. This GGOS network will support the development of future ITRFs with an accuracy of 1 mm and a stability of 0.1mm/year, to satisfy the GGOS Scientific Objectives (GGOS 2020 document). The main driver for this requirement is the application of the reference frame in sea level monitoring and forecasting, but measurement requirements for many other phenomena require similar level of accuracy as well. The network will evolve over time with new technologies replacing legacy technologies and new sites being established. The quality of GGOS data products will improve as the network progresses. The goal is very challenging and all fully operational sites will continue to play a crucial role as this evolution proceeds.

Network simulations at the University of Maryland have estimated that ~30 globally distributed, well positioned, core sites (including SLR, VLBI, GNSS and DORIS where available) with modern technology and proper operating conditions will satisfy the GGOS 2020 requirement. Figure 1 is a conceptual layout of stations by region. In addition, the simulations show that ~16 of these core sites must be tracking GNSS satellites with SLR to calibrate the GNSS orbits and make the reference frame available to users around the world, at all times. Simulations continue with studies of sensitivity to intersystem vector accuracy, phased deployment/evolution of the data products, impact of errors and outages, additional space objects, tracking scenarios, etc. The simulations are also being expanded to include the added strength provided by all of the co-located sites with less than the full complement of systems.

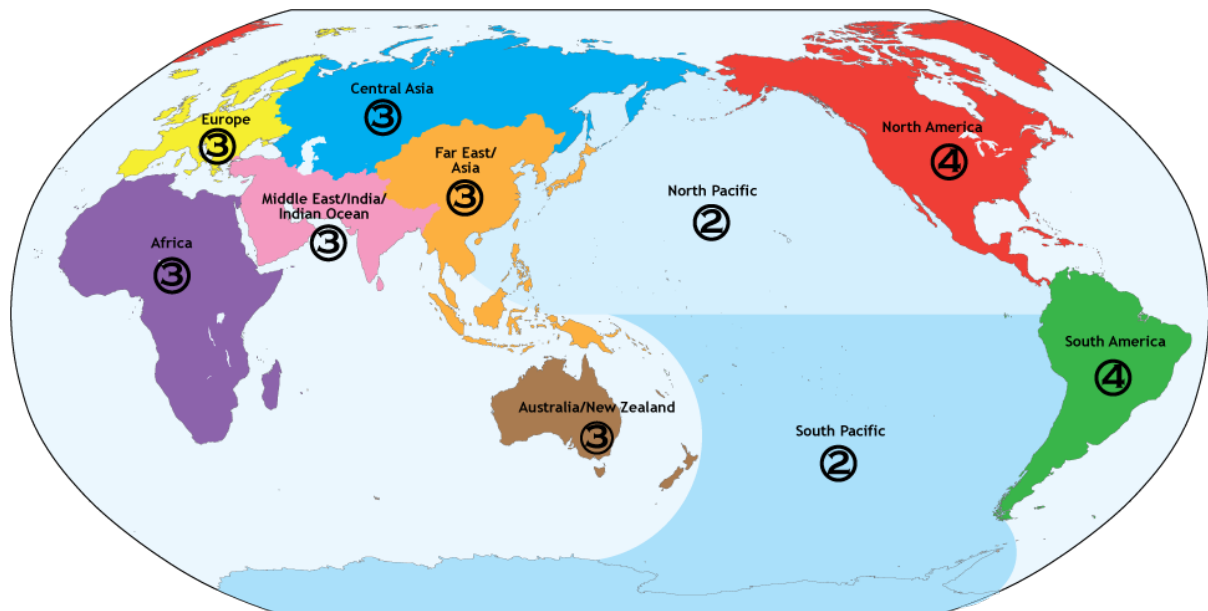


Fig. 1: Network simulations for about 30 globally distributed GGOS core stations



The Bureau continued soliciting contributions for the GGOS Network through the GGOS Call for Participation. With the recent addition of three new core stations in Russia and stations underway or in the planning stage, eighteen organizations have submitted 40 sites for inclusion in that GGOS Network, ranging from established core sites, co-location sites, single technology sites, sites underway and being planned, and sites being offered. In addition, the GGOS network has been greatly enhanced with the recent addition of the full DORIS network maintained by CNES. The Networks and Bureau Section of the GGOS website (<http://www.ggos.org> provides additional details on the CfP and its responses). Discussions are also underway with several other groups that have expressed interest in participating and whose contribution could fill large geographic gaps in the present network. There are currently 12 core sites in the global network with several more in process. Presently, the operational systems at these field stations range from legacy to modern technologies, presenting the community with a challenging mix of technologies, however, the potential exists for greatly enhanced performance as systems are upgraded and new ones are deployed.



Fig. 2: Core sites established, in progress, and proposed

A network characterization model has been developed to tabulate the critical conditions and level of technology at each of the current, planned, and proposed space geodesy sites (with either VLBI or SLR); projections have been made to forecast site capabilities 5 and 10 years into the future to allow us to forecast network performance. This model is now being used to forecast network performance under various options and scenarios. It is being used to examine placement options for new systems. See Networks and Bureau Section at <http://www.ggos.org>.

A first draft elements or tasks of the GGOS network plan has been developed, see Networks and Bureau Section at <http://www.ggos.org>. The goal of the plan is to define the process by which we determine the extent of the needed infrastructure, including the scope and

specification of the network, conditioned on the existing or plausible technology available. The plan will assess the capability of the available or plausible technology and use performance based on analyzed data and projected capability in simulations to scope and specify the network. In developing the plan, we recognize the network will be a balance among the ideal network based on our requirements, the resources that our participants are willing to contribute, cooperation and partnerships that participants are willing to undertake; geographic, political and other practical realities, and the influence that GGOS community can exert. The plan relies on the simulation and modeling activity above.

Table 1: Summary of Responses to the CfP

Agency (Country)	Sites
BKG/FESG (Germany)	Wetzell
NERC (UK)	Herstmonceux
IRA (Italy)	Medicina, Noto, Sardinia
OSO (Sweden)	Onsala
FGI (Finland)	Metsahovi
IGN Spain)	Yebes
SPC (Poland)	Borowiec
SHAO (China)	Shanghai, Beijing, Changchun, Wuhan, Kunming, Urumuqi, Sanyo, (San Juan)
GA (Australia)	Yarragadee, Mt. Stromlo, Katherine, Hobart
NASRDA (Nigeria)	Toro
NASA (US)	GSFC, Westford, Kokee Park, Monument Peak, Fortaleza, McDonald, Mt. Haleakala, Hartebeesthoek, Papeete, Arequipa
RIG (Czech Republic)	Pecný
NRF (South Africa)	Hartebeesthoek,
ASI (Italy)	Matera
KACST (Saudi Arabia)	Riyadh (SALRO)
NMA (Norway)	Ny-Ålesund
RAS (Russian Federation)	Svetloe, Zelenchukskaya, Badary
CNES	DORIS Network

As a means of evaluating current sites and in preparation for selecting new core sites, the Bureau compiled a Core Site Requirements Document ([http://cddis.gsfc.nasa.gov/docs/GGOS\\_SiteReqDoc.pdf](http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)). The document discusses the conditions that are important to the success of a core site including: geographic location, ground stability, weather and sky conditions, radio frequency and optical interference, horizon conditions, air traffic and aircraft protection, power and communications, security, local infrastructure, etc.

The success of the network depends on the progress made in the development of the new technologies. All of the techniques are making progress at present:

- Satellite Laser Ranging: Several systems are now working in the KHz regime demonstrating mm normal point precision, increased data yield and daylight ranging on the GNSS satellites; new high performance arrays are being placed on new GNSS satellites;

- VLBI: the prototype VLBI 2010 is in testing at GSFC; several new VLBI 2010 compatible systems are in process;
- GNSS: multiple constellations with additional frequencies are being deployed as well as multi-constellation-capable ground receivers
- DORIS: the network is nearly complete, additional satellites are being launched that enhance DORIS coverage.

In the fall of 2011, NASA embarked on a two-year “Space Geodesy Project” to establish and operate a prototype next generation core site with SLR, VLBI, GNSS, and DORIS systems, along with a system that provides for accurate vector ties between them. The project was undertaken to develop a model for new stations to help fill out the global network for space geodesy applications, with primary stress on the improvement of the reference frame as required by GGOS 2020. Testing of the systems is underway and the full core site is on schedule to be operational in the fall of 2013.

The Bureau held its semi-annual meetings in conjunction with AGU and EGU; the presentations from meetings along with updates on the Bureau status are given in the Networks and Bureau Section at <http://www.ggos.org>. The Bureau also gives frequent talks at EGU, AGU, APGS and other meetings on development of the network capability.

**Global Geodetic Observing System (GGOS)**

**Site Requirements  
for  
GGOS Core Sites**

**August 1, 2011**

**Contributors:**

Howard Donovan	HTSI
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## Theme 1: Unified Height System

Chair: Michael G. Sideris (Canada)

### Present Status and Progress

- **Joint Working Group 0.1.1: Vertical Datum Standardisation**
  - Global  $W_o$  computations by four different groups delivered very close results (around  $62\,636\,854\text{ m}^2\text{s}^{-2}$ ), but there are still differences of about  $0.5\text{ m}^2\text{s}^{-2}$  ( $\sim 5\text{ cm}$ ). It is necessary to start defining the standards and conventions for a formal recommendation on  $W_o$
  - Web site: <http://whs.dgfi.badw.de>
- **ESA project STSE – GOCE+: Height System Unification with GOCE**
  - Unification of North American, European and North Atlantic Datum
  - Studies of regional  $W_o$  determination, datum offsets estimation, GOCE and other EGM contributions, effects of: local data/omission errors, data biases and noise, ocean models, EGM truncation, benchmark/tide gauge spacing and distribution
  - Results published online in Special Issue on Regional and Global Geoid-based Vertical Datums of the *Journal of Geodetic Science*, Issue 4 (Dec. 2012), pp. 246 - 376, <http://www.degruyter.com/view/j/jogs.2012.2.issue-4/issue-files/jogs.2012.2.issue-4.xml>
  - Web site: [www.goceplushsu.eu](http://www.goceplushsu.eu)
- **Canada (GSD), Mexico (INEGI), USA (NGS) - NA vertical datum unification plans**
  - Selected the  $W_o$  in the ERS Conventions (based on tide gauge fit in NA)
  - Implementation:
    - Canada: will adopt geoid-based datum this November
    - USA: will adopt geoid-based datum in 2022
  - Web sites: [www.ngs.noaa.gov/heightmod/](http://www.ngs.noaa.gov/heightmod/) & [www.nrcan.gc.ca/earth-sciences/geography-boundary/spatial-referencing/height-reference-system/modernization/5664](http://www.nrcan.gc.ca/earth-sciences/geography-boundary/spatial-referencing/height-reference-system/modernization/5664)

### Planned Actions and Milestones

- **Joint Working Group 0.1.1: Vertical Datum Standardisation**
  - Formal recommendation of adoption of a new global  $W_o$  value by the IAG based on additional studies of
    - Combination of a “geodetic” sea surface model and an “oceanographic” DOT model to reproduce a sea surface closer to an equipotential surface (geoid)
    - Integration of polar regions on the Earth’s surface representation
    - Differences between  $W_o$  values obtained from a long-term mean sea surface model and yearly mean sea surface models
  - A formal procedure for proper error propagation
- **ESA project STSE – GOCE+: Height System Unification with GOCE**
  - Completion of the assessment of GOCE’s contributions to HSU
  - Recommendation of HSU procedures
    - for well surveyed (large and small) regions
    - for poorly surveyed areas
    - across the ocean
  - Production of a roadmap for regional and global height datum unification

## Open problems

- **Data, procedures, standards, policies**

- Lack of standards and conventions for physical heights
- Inconsistencies between physical and geometric heights (e.g., tide systems) – Insufficient collaboration between “geometric” and “gravimetric” Services
- Uncertainties with respect to data biases, accuracies, gross errors, reference epochs, reference surfaces, temporal changes
- Acceptable global realization of the surface of potential  $W_0$
- Governments unready to accept new height datums (and thus new elevation values), especially where social issues may arise (e.g., in coastal regions, flood-prone regions)

- **Difficulty in attracting broad international participation in the work of Theme 1**

- Groups work in this area only if (a) they have either their own individual research funding or (b) are jointly funded by government or other sources (such as ESA)
- Though very difficult, GGOS should maybe consider the possibility of supporting its Themes in attracting funding for their work, through its connections with GIAC, National Geodetic Surveys, Space agencies

## Joint Working Group 0.1.1: Vertical Datum Standardisation

*Chair: Laura Sánchez (Germany)*

### Introduction

The main purpose of the joint working group on Vertical Datum Standardization (JWG 0.1.1) is to provide a reliable  $W_0$  value to be introduced as the conventional reference level for the realization of a Unified Global Height System. Although any  $W_0$  value can arbitrarily be chosen, it is expected that this value be consistent with other defining parameters of geometric and physical models of the Earth. In this way, activities developed by JWG 0.1.1 shall be based on the state-of-the-art data and methodologies, especially on the newest available representations of the Earth's surface and gravity field. Computations carried out by JWG 0.1.1 are to be documented in detail in order to guarantee the repeatability and reliability of the results. This documentation shall support the adoption of the obtained  $W_0$  value as an official IAG/GGOS convention. An additional product will be dedicated to provide guidance on the usage of  $W_0$  in practice, in particular for the vertical datum unification.

### The global vertical reference level $W_0$

At present, there are four groups working on the  $W_0$  determination: the Prague Group (Vatrt et al., former Burša et al.), the Munich Group (Sánchez et al.), the Bratislava Group (Čunderlik et al.), and the Newcastle/Latakia Group (Dayoub et al.). When the JWG 0.1.1 was created (during the IUGG General Assembly in Melbourne, August 2011), the  $W_0$  estimations of Čunderlik et al., Dayoub et al., Sánchez et al. were very close to each other (largest discrepancy  $\sim 0,2 \text{ m}^2\text{s}^{-2}$ ); while the estimation of Burša et al. was a little far away (about  $\sim 2 \text{ m}^2\text{s}^{-2}$ ). According to this, these four groups were invited to participate in the JWG 0.1.1 and they agreed on joining efforts to refine and compare their computations in order to

- evaluate their individual methodologies,
- establish inconsistencies between the input data,
- ensure redundancy between the different computations,
- identify possible discrepancies between the individual results,
- clarify and solve remaining disagreements between the individually computed  $W_0$  values.

During these two years, each group repeated its computations using its own methodology but the same input data, explicitly the same mean sea surface models (CLS11, DUT10) and global gravity models (EGM2008, GOCO03S, EIGEN6C). An exception is the Burša Group, who applied its own mean sea surface model derived from recent satellite altimetry measurements. The new results were presented during the GGHS2012 symposium (International Symposium on Gravity, Geoid and Height Systems, San Servolo Island, Venice, October 2012), being the main conclusion that all the computations are now delivering very close values (including the computation of Burša et al.) and the remaining differences ( $\sim 0,5 \text{ m}^2\text{s}^{-2}$ ) can be solved by outlining specific standards and conventions.

According to these new results, the JWG 0.1.1 members agreed on the following:

- The  $W_0$  value included in the IERS Conventions (and used by the IAU for the definition of the  $L_G$  constant) presents a discrepancy of about  $\sim 2 \text{ m}^2\text{s}^{-2}$  with respect to the recent computations.

- A formal IAG recommendation regarding the best present  $W_0$  estimate shall be outlined to replace the value included in the IERS Conventions and to be introduced as the reference level in the GGOS Unified Height System.
- The outlined recommendation shall be supported by four individual papers describing methodology and input data applied by each group. Based on these four papers, a further common summary paper shall be produced to provide an overview and the main characteristics of the  $W_0$  estimation recommended.
- The next activities to be carried out by the individual groups to refine their estimations and to advance in the definition of required standards and conventions shall include:
  - Combination of a “geodetic” sea surface model and an “oceanographic” mean dynamic topography model to reproduce a sea surface closer to an equipotential surface (geoid);
  - Integration of polar regions on the Earth’s surface representation;
  - Differences between  $W_0$  values obtained from a long-term mean sea surface model and yearly mean sea surface models;
- A formal procedure for the error propagation analysis.

### **Local/regional realisation of the global vertical reference level**

One of the main objectives of the JWG 0.1.1 is to provide guidance in the practical realisation of the global  $W_0$  at regional/local level. One possibility is the combination of geometrical and physical heights with (quasi)geoid models of high resolution, i.e.  $h=H-N$ . Although this combination is at present widely used for several purposes, it is clear that there are still too many inconsistencies between the different heights and their combination is not reliable enough for the precise realisation of any reference level. To face this inconvenience, it was asked whether the JWG 0.1.1 could try to outline the basic standards to be followed by the three coordinates ( $h, H, N$ ) to guarantee a consistent combination and, as a consequence, to design an appropriate realisation strategy of the global  $W_0$ . This proposal produced many pro and contra comments and it was decided to take up this discussion again once the recommendation on  $W_0$  is ready.

**Website:** <http://whs.dgfi.badw.de>

The chair of the JWG 0.1.1 tries to keep a web site about these activities updated. This web site was initially established for the IAG Inter-Commission Project 1.2 (Vertical Reference Frames) and at present contains:

- Terms of reference of the JWG 0.1.1 (objectives, plan of activities, members, etc.)
- The ICP1.2 documents (Conventions, presentations, reports, meeting summaries, etc.)
- The terms of reference of GGOS-Theme 1 (because they are missing in the GGOS portal)
- A list of references with recent “vertical datum”-related publications
- Meeting presentations of the JWG 0.1.1 members, when they agree to publish their contributions in the web site.

### **Members**

L. Sánchez (Germany), J. Ågren (Sweden), R. Cunderlík (Slovakia), N. Dayoub (Syria), J. Huang (Canada), R. Klees (The Netherlands), J. Mäkinen (Finland), K. Mikula (Slovakia), Z. Minarechová (Slovakia), P. Moore (United Kingdom), D. Roman (USA), Z. Šima (Czech Republic), C. Tocho (Argentina), V. Vatr (Czech Republic), M. Vojtiskova (Czech Republic), Y. Wang (USA).

## Publications and presentations

Ågren J., Engberg L.E., Alm L., Dahlström F., Engfeldt A., Lidberg M.: Improving the Swedish quasigeoid by gravity observations on the ice of Lake Vänern. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012

Ågren J., Sjöberg L.E.: Investigations of the requirements for a future 5 mm quasigeoid model over Sweden. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012

Burša M., Kouba J., Šima Z., Vatrt V., Vojtiškova M.: Wo improved by EGM08 / GRACE geopotential models and Jason 1, 2 altimetry. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

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Dayoub N., Edwards S.J., Moore P. (2012). The Gauss-Listing potential value  $W_0$  and its rate from altimetric mean sea level and GRACE. *J Geod* 86: 681 - 694.

Huang J., Véronneau M.: A Stokes approach for the comparative analysis of satellite gravity models and terrestrial gravity data. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

Macak M., Mikula M.: On solving oblique derivative boundary-value problem by the finite volume method. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012

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Roman D., Véronneau M., Avalos D., Li X., Holmes S., Huang J.: Integration of gravity data into a seamless transnational height model for North America. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

Santos M.C., Avalos D., Peet T., Huang J., Vaníček P.: Assessment of GOCE models over Mexico and Canada. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012

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Sánchez L.: Towards a vertical datum standardisation under the umbrella of Global Geodetic Observing System. *Journal of Geodetic Science*, 2(4): 325 – 342, 2012.

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Sánchez L., Ågren J., Čunderlík R., Dayoub N., Faskova Z., Huang J., Mikula K., Moore P., Roman D., Šima Z., Vatrt V., Vojtiškova M., Wang Y.M.: Report on the activities of the working group "Vertical Datum Standardisation". In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

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Spir R., Čunderlík R., Mikula K.: Impact of the oblique derivative on precise local quasigeoid modelling in mountainous regions. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

Wang Y.M., Li X.: Data fusion for geoid computation - numerical tests in Texas area. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012.

Sinem Ince E., Sideris M.G., Huang J., Véronneau M.: Assessment of GOCE gravity field models for the new geoid-based vertical datum in Canada. In: GGHS2012 Symposium, Venice, Italy, October 9 -12, 2012



## Theme 2: Geohazards Monitoring

*Chair: Tim Dixon (USA)*

Mitigating the impact on human life and property of natural hazards such as earthquakes, volcanic eruptions, debris flows, landslides, land subsidence, tsunamis, floods, storm surges, hurricanes and extreme weather is an important scientific task to which GGOS can make fundamental contributions.<sup>8</sup> GNSS and InSAR can be used to monitor the pre-eruptive deformation of volcanoes and the pre-seismic deformation of earthquake fault zones, aiding in the issuance of volcanic eruption and earthquake warnings. GNSS can also be used to rapidly estimate earthquake fault motion, aiding in the modeling of tsunami genesis and the issuance of tsunami warnings. Gravity measurements can be used to track mass motion within volcanic conduits; and gravity and altimetric measurements can be used to track floodwaters in river basins.

Geodetic observations are essential for understanding the processes causing the hazard, for assessing the risks of the hazard, for monitoring the development of the hazard, for deciding whether or not to issue an early warning, and to support rescue and damage assessment activities.

The objective of Theme 2 is to improve the effectiveness of the geodetic community in supporting natural hazard identification, assessment, prioritization, prediction, and early warning. As an international organization, GGOS can be very effective as an advocate for the role of geodesy in understanding and mitigating natural hazards. GGOS can be an effective advocate for improving the geodetic data needed for natural hazards research including better spatial coverage, higher sampling rate, lower latency, and wider data availability, particularly of SAR and GNSS data. Finally, improved public outreach is needed to better educate and inform the public about the benefits of geodesy for geohazards monitoring.

An important international activity related to the objective of Theme 2 is the development of geohazard supersites, a GEO initiative to provide access to spaceborne and in-situ geophysical data of selected sites prone to earthquake, volcano or other natural hazards.<sup>9</sup> These supersites represent a global partnership of scientists, satellite providers, and in-situ data providers yielding extensive data sets. A major focus of the Geohazard Supersites Initiative is to improve access to this data, particularly to InSAR data. Much of the InSAR data that is needed for geohazards studies is proprietary and largely unavailable to scientists, even in the aftermath of natural disasters when it could aid in rescue activities and damage assessment. Improving access to this data can support national authorities and policy makers in risk assessment and mitigation strategies.

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<sup>8</sup> Dixon, T., and F. Amelung, "Theme 2: Geohazards" <http://192.106.234.28/Meetings/GGOS%20Consortium/1st%20GGOS%20Consortium/Theme2.pdf>

<sup>9</sup> Geohazard Supersites and Natural Laboratories, Group on Earth Observations, <http://supersites.earthobservations.org/>

## **Joint Working Group 0.2.1: New Technologies for Disaster Monitoring and Management**

*Chair: Ioannis Doukas (Greece)*

*Co-chair: Guenther Retscher (Austria)*

The Study Group 4.1 has been active in the past period and consists of 14 members. The website can be found at [http://doukas.civil.auth.gr/iag\\_sc41\\_sg41/Introduction.html](http://doukas.civil.auth.gr/iag_sc41_sg41/Introduction.html)

The international financial strong anomalies, however, did not allow for great member activities in relation to the group's targets, especially in the last eight months. By taking into account these financial disturbances, after a long period of personal negotiations with each member, there is a light at the end of the tunnel. Some co-operations are being planned to start within the next four to five months, aiming at the creation of the 'critical mass' which will intensify the expansion of cooperation among the group's members. As a preliminary result of these co-operations, the group managed to start negotiations with the Central European Journal of Engineering (see <http://versita.com/serial/ceje/>). A Special Issue including publications concerning our Study Group is planned. The publisher has agreed to allocate this special issue for the second half of 2014. The study group members are encouraged to publish their research results in this journal issue.

### **Recent publications of Study Group members**

1. Doukas, I.D. and Retscher, G. (2011): Where to with Earthquake Risk Management: The Resultant of Sensor-Web and Web-GIS Could Show the Way. International Conference on Indoor Positioning and Indoor Navigation (IPIN), Guimarães, Portugal, 21-23 September 2011.
2. Doukas, I.D. and Retscher, G. (2011): The Contribution of Contemporary Sensors to the Management of Natural and Manmade Disasters – The Present and the Future. Joint International Symposium on Deformation Monitoring (JISDM), Hong Kong, China, 2-4 November 2011.
3. Doukas, I.D. and Rossikopoulos, D. (2012): Geodetic Control of Deformations. The Case of Monuments and Technical Works. 4th National Congress on Metrology "Metrologia 2012", National Technical University of Athens, Αθήνα, 3-4 February 2012 (in Greek).
4. Doukas, I.D. (2012): The Contribution of Geodetic Instruments and Methods to Construction Automation. 4th National Congress on Metrology "Metrologia 2012", National Technical University of Athens, Αθήνα, 3-4 February 2012 (in Greek).
5. Demoula, S.D., Doukas, I.D. and Savvaidis, P.D. (2012): Spatiotemporal Approach of the Distribution of Jews Professionals in Thessaloniki During the Years 1908-1915, with the Use of a Geo-information System. Interdisciplinary Symposium: "Thessaloniki on the Eve of 1912", History Centre of Thessaloniki, 21-23 September 2012 (in Greek).
6. Demoula, S.D., Doukas, I.D. and Savvaidis, P.D. (2012): Spatiotemporal Study of the Accommodation and Entertainment in Thessaloniki During the Years 1908-1915, with the Use of a Geo-information System. Interdisciplinary Symposium: "Thessaloniki on the Eve of 1912", History Centre of Thessaloniki, 21-23 September 2012 (in Greek).
7. Voulgaroudis, A.X. and Doukas, I.D. (2012): Use of Mobile Devices with 3G/4G Networks and/or Wifi for Data Collection Related to Post-seismic Control of Buildings. Cooperation with a Geoinformation System. 3rd National Conference of Urban Planning and Regional Development, Volos, September 27-30, 2012 (in Greek).
8. Demoula, S.D. and Doukas, I.D. (2012): On the Business Activities of Ethnicities on Venizelou Street in Thessaloniki: Studying their Temporal Variations (1908-1938) with the use of a Geographic Information System. International Conference: "Thessaloniki: A City in Transition, 1912-2012", Thessaloniki, 18-21 October, 2012 (in Greek).
9. Tziavos, I.N., Alexandridis, T.K., Alexandrov, B., Andrianopoulos, A., Cernisencu I., Dimova S., Doukas, I.D., Georgiadis, P., Grigoras, I., Grigoriadis, V.N., Karapetsas, N., Michailides, C., Papadopoulou, I.D., Repa, E., Savvaidis, P., Stancheva, M., Stergioudis, A., Stila, K., Teodorof, L., Vergos, G.S., Vorobyova, L. and Zalidis, G.C. (2013): Development of a WebGIS-based Monitoring and Environmental Protection and Preservation System for the Black Sea: The ECO-Satellite project. EGU General Assembly, Vienna, Austria, April 07-12, 2013.

## **Theme 3: Sea-Level Change, Variability and Forecasting**

*Chairs: Tilo Schöne (Germany), CK Shum (USA), Mark Tamisiea (UK), Phil Woodworth (UK)*

### **Introduction**

Sea level rise and its impact on human habitats and economic well being have received considerable attention in recent years by the general public, engineers, and policy makers. A GGOS retreat in 2010 has identified sea level change as one of the cross-cutting themes for geodesy. Sea Level is also a major aspect in other observing systems, e.g. GEO or GCOS. The primary focus of GGOS Theme 3 is to demonstrate the value of geodetic techniques, which are under the umbrella of GGOS, to the mitigation of sea level rise including studies of the impacts of its change over the world's coastal regions and islands, and to support practical applications such as sustainability. One major topic is the identification of gaps in geodetic observing techniques and to advocate additions in the GGOS monitoring network and Services where necessary.

### **Activities**

Theme 3 has identified major actions to be undertaken to advance geodetic techniques and technologies applied in sea level research. These are

- Identification or (re)-definition of the requirements for a proper understanding of global and regional/local sea-level rise and its variability especially in so far as they relate to geodetic monitoring provided by the GGOS infrastructure, and their current links to external organizations (e.g., GEO, CEOS, and other observing systems).
- Identification of organizations or individuals who can take forward each requirement, or act as points of contact for each requirement where they are primarily the responsibility of bodies not related to GGOS.
- Identification of a preliminary set of practical (as opposed to scientific) pilot projects, which will demonstrate the viability, and the importance of geodetic measurements to mitigation of sea-level rise at a local or regional level. This identification will be followed by construction of proposals for pilot projects and their undertaking.

In the long-term, the aim is to support forecasting of global and regional sea level for the 21<sup>st</sup> century with an expected forecast period of 20 to 30 years.

The Call for Participation ([http://www.ggos-portal.org/lang\\_en/nn\\_261554/GGOS-Portal/EN/Themes/SeaLevel/seaLevel.html?\\_\\_nnn=true](http://www.ggos-portal.org/lang_en/nn_261554/GGOS-Portal/EN/Themes/SeaLevel/seaLevel.html?__nnn=true)) was issued in 2012. Special emphasis is given to local and regional projects which are relevant to coastal communities, and which depend on the global perspective of GGOS. The first selected project addresses major aspects of the sea level research in Britain (lead: R. Bingley, University of Nottingham). Other projects under discussion to become Theme 3 landmark projects are addressing subsidence monitoring in Bangkok (Thailand) and Jakarta and Semarang (Indonesia). All projects have a major focus on the combination of sea level and geodetic monitoring in an integrative approach.

Also in the reporting period, Theme 3 established communications with organizations, dealing with other than geodetic aspects of sea level monitoring. These are the UNESCO International Oceanographic Commission Group of Experts (UNESCO/IOC GE) and the World Glacier Monitoring Service (WGMS). Also cooperation with the IGS Tide Gauge Benchmark Monitoring Working Group and European Space Agency - ESRIN Earth Observation Science & Applications group is established.

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## **Bureau International des Poids et Mesures (BIPM) – Time Department –**

<http://www.bipm.org/en/scientific/tfg/>

*Director of Department: Elisa Felicitas Arias*

### **Overview**

The international time scales TAI and UTC have been regularly computed during the period of the report. Results have been published in monthly *BIPM Circular T*, which represents the key comparison CCTF-K001.UTC. The frequency stability of TAI, expressed in terms of an Allan deviation, is estimated to  $3 \times 10^{-16}$  for averaging times of one month.

Eight primary frequency standards contributed during the period to improve the accuracy of TAI, all are caesium fountains developed and maintained in metrology institutes in France, Germany, Japan, the United Kingdom and the USA. The scale unit of TAI has been estimated to match the SI second to about  $5 \times 10^{-16}$ .

Routine clock comparison for TAI is undertaken using different techniques and methods of time transfer. All laboratories contributing to the calculation of UTC at the BIPM are equipped for GNSS reception. GPS C/A observations from time and geodetic-type receivers are used with different methods, depending on the characteristics of the receivers. Dual-frequency receivers allow performing iono-free solutions. Also observations of GLONASS are used for the computation of TAI. Thanks to this evolution, the statistical uncertainty of time comparisons is at the sub-nanosecond level for the best GNSS time links. Some laboratories are equipped of two-way satellite time and frequency transfer (TWSTFT) devices allowing time comparisons independent from GNSS through geostationary communication satellites. Combination of time links (TWSTFT/GPS PPP and GPS/GLONASS) is routinely used in the computation of TAI since 2011. The uncertainty of time comparison by GNSS is still limited by the hardware to 5 ns for the calibrated links whilst in the case of TWSTFT it is at the nanosecond order.

Extensive comparisons of the different techniques and methods for clock comparisons are computed regularly and published on the ftp server of the section, as well as complete information on data and results (<http://www.bipm.org/jsp/en/TimeFtp.jsp>).

The section organizes and runs GNSS receiver round trips with the aim of characterizing the relative delays of time transfer equipment in contributing laboratories.

The algorithm used for the calculation of TAI has been significantly improved during the period covered by this report. The model for clock frequency prediction was revised, and a new model is in use since August 2011. As a consequence of this modification, the drift observed in the atomic free scale (EAL) with respect to the primary standards has completely disappeared. The procedure for establishing the clock weight is under revision.

Radiations other than the caesium 133, most in the optical wavelengths, have been recommended by the International Committee of Weights and Measures (CIPM) as secondary representations of the second. These frequency standards are at least one order of magnitude more accurate than the caesium. Their use for time metrology is still limited by the state of the art of frequency transfer. Experiments using optical fibres on baselines up to 1000 km confirmed

the capabilities of the method. It remains, however, limited to continental time and frequency transfer. New techniques are under study for extending the transfer onto intercontinental scale. This is part of the collective effort of the time metrology community aiming at a possible redefinition of the SI second.

Research work is also dedicated to space-time reference systems. The BIPM provides, in partnership with the US Naval Observatory, the Conventions Product Centre of the International Earth Rotation and Reference Systems Service (IERS). IERS activities in cooperation with the Paris Observatory on the realization of reference frames for astrogeodynamics, contribute to the maintenance of the international celestial reference frame in the scope of the IAU activities.

Following the decision of the CIPM in October 2009, the BIPM stopped the activities in gravimetry, but the Consultative Committee for the Mass and Related Quantities (CCM) continues organizing the Working Group on Gravimetry (WGG), and thus cooperating with the IAG in providing support to the future International Comparisons of Absolute Gravimeters (ICAG). In the new scheme, the comparisons are organized in different regions, with a national metrology institute acting as the pilot laboratory.

The last campaign (ICAG 2009) at the BIPM gave the opportunity to make the first absolute measurements in the room prepared for the operation of the BIPM watt balance. Based on measurements, the value for  $g$  and its uncertainty have been evaluated.

In January 2012 the Time Department started a pilot experiment for the implementation of a rapid UTC (UTC<sub>r</sub>). The aim of this project was to study the feasibility of providing some link to UTC on a more frequent basis than that of monthly *Circular T*. This experiment proved the capacities at the BIPM and at the contributing laboratories for assuring this rapid provision and after approval by the Consultative Committee for Time and Frequency (CCTF), UTC<sub>r</sub> will become a routine weekly publication.

A considerable amount of effort has been put in contributing to the discussions on a redefinition of UTC without leap seconds at the International Telecommunication Union (ITU). The BIPM Time Department is contributing to the preparation of a workshop on the future of the international time scale jointly organized by the ITU and the BIPM. The event will take place in Geneva, on 19-20 September 2013.

The total number of publications of the Time Department staff during the period is around 50.

## Activities

### International Atomic Time (TAI) and Coordinated Universal Time (UTC)

The reference time scales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), are computed from data reported regularly to the BIPM by the various timing centres that maintain a local UTC; monthly results are published in *Circular T*. The *BIPM Annual Report on Time Activities for 2011* and *for 2012* have been published in electronic version and are available on the BIPM website (<http://www.bipm.org>).

## *Algorithms*

The algorithm used for the calculation of time scales is an iterative process that starts by producing a free atomic scale (*Échelle atomique libre* or EAL) from which TAI and UTC are derived.

EAL is optimized in frequency stability, but nothing is done for matching its unit interval to the second of the International System of Units (SI second). In a second step, the frequency of EAL is compared to that of the primary frequency standards, and frequency accuracy is improved by applying whenever necessary a correction to the frequency of EAL. The resulting scale is TAI. Finally, UTC is obtained by adding an integral number of seconds (leap seconds). Research into time scale algorithms is conducted in the Time Department with the aim of improving the long-term stability of EAL and the accuracy of TAI/UTC.

Since August 2011 the clock frequency prediction model in the algorithm of calculation of TAI has been improved. The new algorithm uses the same quadratic model for predicting the frequency of all clocks (caesium and hydrogen-maser clocks). This model takes into account the drift of the hydrogen-masers frequency and the effects coming from the ageing of the caesium clocks. In consequence, the drift that had been observed in the frequency of EAL with respect to the primary frequency standards, amounting  $-1.3 \times 10^{-17}/\text{day}$  has been completely removed.

The old frequency prediction model (linear) did not take into account the drift of the hydrogen-masers frequency, and consequently these clocks were not properly used. After the change in the prediction model, it was clearly necessary to make a revision of the clock weighting procedure so that all clocks could contribute in function of their quality. The studies on the weighting algorithm progressed. A new method has been developed based on the criteria that a good clock is a predictable one, instead of using the frequency stability as indicator of its quality. Tests on this new procedure are still on-going, and they prove that the procedure is efficient in increasing the weight of the hydrogen-masers in the clock ensemble. It is foreseen to implement the new procedure in the algorithm before the end of 2013.

## *Stability of TAI*

About 420 clocks contribute as in April 2013 to the construction of TAI at the BIPM. Some 87 % of these clocks are either commercial caesium clocks or active, auto-tuned hydrogen masers. To improve the stability of EAL, a weighting procedure is applied to clocks where the maximum relative weight each month depends on the number of participating clocks. About 14 % of the participating clocks have been at the maximum weight, on average, per year. This procedure generates a time scale which relies upon the best clocks.

The stability of EAL, expressed in terms of an Allan deviation, has been about  $3 \times 10^{-16}$  for averaging times of one month.

## *Accuracy of TAI*

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from the SI second, as produced on the rotating geoid, by primary frequency standards. In the period of this report individual measurements of the TAI frequency have been provided by eight caesium fountains. Reports

on the operation of the primary frequency standards are regularly published in the *BIPM Annual Report on Time Activities* and on the BIPM website.

A monthly steering correction of maximum  $0.5 \times 10^{-15}$  has been applied as deemed necessary to put the frequency of TAI as close as possible as that of the primary frequency standards until October 2012. As a consequence of the implementation of the quadratic frequency prediction model no steering corrections have been applied since November 2012. In the period of this report, the global treatment of individual measurements has led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging from  $+5.9 \times 10^{-15}$  in July 2011 to  $-0.7 \times 10^{-15}$  in March 2013 with a standard uncertainty of less than  $0.5 \times 10^{-15}$ .

#### *BIPM realization of terrestrial time TT(BIPM)*

Because TAI is computed in “real-time” and has operational constraints, it does not provide an optimal realization of Terrestrial Time (TT), the time coordinate of the geocentric reference system. The BIPM therefore computes an additional realization TT(BIPM) in post-processing, which is based on a weighted average of the evaluation of the TAI frequency by the primary frequency standards. The last updated computation of TT(BIPM), named TT(BIPM12), valid until December 2012, has an estimated accuracy of order  $3 \times 10^{-16}$ . Extensions of TT(BIPM12) over 2013 are provided and are updated each month after the publication of *Circular T*.

#### *Primary frequency standards and secondary representations of the second*

Members of the BIPM Time Department are actively participating in the work of the CCL/CCTF Frequency Standards Working Group created jointly at the Consultative Committee for Length (CCL) and the CCTF, seeking to encourage knowledge sharing between laboratories, the creation of better documentation, comparisons, and the use of highly accurate primary frequency standards (Cs fountains) for TAI. A mission of this working group is to maintain a list of frequencies recommended for applications including the practical realization of the metre and secondary representations of the second. Updates of this list are proposed to the CCL and CCTF, and are finally recommended by the International Committee for Weights and Measures (CIPM).

Other microwave and optical atomic transitions have been approved and are recommended by the CIPM as secondary representations of the second. The list containing frequency values and uncertainties for transitions in Rb, and various atom and single ion species have been included in the list of recommended frequencies as secondary representations of the second at its last update in September 2012. BIPM staff continues to participate in the rapidly evolving field of optical frequency standards, addressing, for example, the issue of their comparison at the  $10^{-17}$  uncertainty level or below.

Reports of frequency measurements of the Rb transition at the French national metrology institute are being regularly submitted to the Time Department. Based on these reports, results of the comparison of the secondary standard with TAI are published in *Circular T* since the beginning of 2012. It is expected to use the Rb measurements in the current of 2013 for improving the accuracy of TAI.



### *Clock comparison for TAI*

TAI relies at present on 72 participating time laboratories equipped with GNSS receivers and/or operating TWSTFT stations.

The GPS all-in-view method has currently been used taking advantage of the increasing quality of the International GNSS Service (IGS) products (clocks and IGS time). Clock comparisons are possible with C/A code measurements from GPS/GLONASS single-frequency receivers (only 3% of the time links in TAI); with dual-frequency, multi-channel GPS geodetic type receivers (P3, 14%); with code and phase measurements (GPS PPP, 27%); and with two-way satellite time and frequency transfer through geostationary telecommunications satellites (TWSTFT, 18%). Single-frequency, multi-channel receivers still provide the majority of time links in TAI (30%).

Links calculated from a combination of individual techniques are regularly used in the computation of TAI and their number is increasing. At present, 7% of the links are from a combination of GPS and GLONASS observations, and 14% are obtained combining TWSTFT and GPS PPP.

All GNSS links are corrected for satellite positions using IGS and ESA post-processed, precise satellite ephemerides, and those links made with single-frequency receivers are corrected also for ionospheric delays using IGS maps.

Results of time links and link comparison using GNSS and TW observations are published monthly on the ftp server of the Time Department (<http://www.bipm.org/jsp/en/TimeFtp.jsp>).

### *Characterization of delays of time transfer equipment*

The BIPM continuously organizes and runs campaigns for measuring the relative delays of GNSS (GPS and GLONASS) time equipment in laboratories which contribute to TAI. The BIPM is also taking part in the organization of TWSTFT calibration trips; these trips are supported with a GNSS receiver from our time laboratory. Collaboration of the regional metrology organizations is under implementation for supporting the campaigns.

In the frame of a PhD successfully concluded in 2011 in cooperation with the CNES, a facility for absolute calibration of GNSS equipment has been developed.

### *Other activities in the field of time and frequency*

Collaboration continues with the Observatoire Midi-Pyrénées (OMP), Toulouse (France), and other radio-astronomy groups observing pulsars and analyzing pulsar data to study the potential capability of using millisecond pulsars as a means of sensing the very long-term stability of atomic time. The Time Department provides these groups with its post-processed realization of Terrestrial Time TT(BIPM). The IAU Division A created in 2012 a working group on Pulsar-based timescales, to which staff of the Time Department contributes.

The BIPM shares with the US Naval Observatory the responsibility for providing the IERS Conventions Centre. Updates to the IERS Conventions (2010) are published since May 2011 at <http://tai.bipm.org/iers/conv2010/conv2010.html>. The text of the conventions, in IERS Technical Note N°36 is also available at ([http://www.iers.org/nn\\_11216/IERS/EN/Publications/TechnicalNotes/tn36.html](http://www.iers.org/nn_11216/IERS/EN/Publications/TechnicalNotes/tn36.html)).

Activities related to the realization of reference frames for astronomy and geodesy are developing in cooperation with the IERS. In these domains, improvements in accuracy will enhance the need for a full relativistic treatment and it is essential to continue participating in international working groups on these matters; e.g. through the new IAU Commission “Relativity in Fundamental Astronomy”. Cooperation continues for the maintenance of the international celestial reference system. The IAU Division A established a working group for realizing the 3<sup>rd</sup> version of the international celestial reference frame, ICRF3. Staff of the Time Department contributes to this working group.

A change in the definition of UTC is under discussion at the ITU since year 2000, and the BIPM has permanently contributed as a Member of the ITU Radiocommunication Sector. Final decision on the adoption of a proposed recommendation of implementing a continuous time scale, namely stopping the insertion of leap seconds in UTC, will be taken at the World Radioconference in 2015. Technical documents for providing complete information to administrations member of the ITU are under preparation with the contribution of the BIPM. For complementing the effort of disseminating this information, a joint ITU/BIPM Workshop will take place in Geneva on 19-20 September 2013. Information on this event is provided at <http://www.itu.int/ITU-R/index.asp?category=conferences&rlink=itu-bipm-workshop-13&lang=en>.

## **Activities in Frequency**

### *Frequency comb, calibration and measurement service*

The frequency comb activities are limited to the comb maintenance for BIPM internal applications. The combs are passively kept in running conditions and used when needs appear. The Department has provided calibration and measurement service for combs and reference lasers for internal needs only. This includes the periodic absolute frequency determination of our reference lasers, both at 633 nm and 532 nm, used for iodine cell quality testing lasers and for the calculable capacitor project at the BIPM.

### *Iodine cells*

The service for filling and testing iodine cells has been discontinued in 2009. The BIPM maintains a list of suppliers of this service that can be provided on request to the Department Director.

## **Gravimetry**

The International Campaign of Absolute Gravimeters ICAG has been re-organized during the period of the present report.

Starting by ICAG 2013, the comparisons will be piloted by national metrology (and/or designated) institutes at the usual four-year frequency. The Working Group on Gravimetry (WGG) of the Consultative Committee for Mass and Related Quantities (CCM) keeps the responsibility for the general coordination of the campaigns.

ICAG 2013 will take place in Walferdange, under the auspices of the University of Luxembourg. The Federal Institute of Metrology (*METAS, Switzerland*) will act as the pilot laboratory.

### *Gravimetry for the BIPM watt balance project*

At the ICAG 2009 at the BIPM, the first measurements for determining the free-fall acceleration in the watt balance room were made with three absolute gravimeters participating to the comparison. The CCM has required a total relative standard uncertainty of  $2 \times 10^{-8}$  (corresponding to 20  $\mu\text{Gal}$ ) for the determination of the Planck constant  $h$  as a condition for the redefinition of the kilogram. Taking into account all effects that can be sources of uncertainty, the demonstrated uncertainty of the determination of the free-fall acceleration at the test mass centre is of 4.5  $\mu\text{Gal}$ . These studies and results have been submitted for publication.

### **Staff of the Department**

Dr Elisa Felicitas Arias, Principal Research Physicist, Director  
Ms Aurélie Harmegnies, Assistant  
Dr Zhiheng Jiang, Principal Physicist  
Mrs Hawaiï Konaté, Principal Technician  
Dr Włodzimierz Lewandowski, Principal Physicist  
Dr Gianna Panfilo, Physicist  
Dr Gérard Petit, Principal Physicist  
Dr Lennart Robertsson, Principal Physicist  
Mr Laurent Tisserand, Principal Technician

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1. BIPM Annual Report on Time Activities for 2010, 2011, **5**
2. BIPM Annual Report on Time Activities for 2011, 2012, **6**
3. BIPM Annual Report on Time Activities for 2012, 2013, **7**
4. *BIPM Circular T* (monthly)
5. Bauch A., Piester D., Fujieda M., Lewandowski W., Directive for operational use and data handling in two-way satellite time and frequency transfer (TWSTFT), *Rapport BIPM-2011/01*.
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## **International Altimetry Service (IAS)**

<http://ias.dgfi.badw.de>

*Chair: Wolfgang Bosch (Germany)*

### **Overview**

Following endorsements by GLOSS, IAPSO and IAG the **International Altimetry Service** was established as IAG initiative. IAS recognizes that there are already many organisations providing altimeter data and value-added products of geophysical and geodetic relevance. The IAS initiative is meant to be non-competitive, but open to identify and pool together all efforts which contribute to geodetic applications of satellite altimetry. Moreover, IAS will try to initiate projects completing or gradually improving existing services for the benefit of geodetic and geophysical applications at large.

### **Activities**

#### **GGOS 2012 Retreat**

On the occasion of the GGOS 2012 Retreat the chair reported on status and future of the International Altimeter Service (IAS):

There is a general agreement in the geodetic research community, that satellite altimetry has to be a core element of the Global Geodetic Observing System (GGOS). For satellite altimetry there are also important applications to other geosciences, like oceanography, marine geophysics, hydrology, meteorology, and glaciology. Naturally, altimetry is also understood as a core element of the ocean and climate observing systems GOOS and GCOS respectively. However, there are specific geodetic needs to altimeter data and products. As the ocean surface is nearly coinciding with an equipotential surface of the Earth gravity field satellite altimetry contributes to essential improvements of the Earth gravity field. Even with the dedicated gravity field missions GRACE and GOCE, satellite altimetry will remain the basic source for the determination of the high resolution marine gravity field. The sampling of short-term tidal variations is possible by sufficient long altimetry time series and allows to empirically estimating ocean tide models which in turn are required to correct any geodetic space techniques. Mapping and monitoring of seasonal and secular changes of the mean sea level helps to understand fundamental processes of the System Earth: the ocean water mass redistribution, one component of the global hydrological cycle, has impact to the Earth centre-of-gravity, to Earth rotation by the ocean angular momentum functions, the temporal variations of the Earth gravity field, as well as to studies on regional sea level changes and the global sea level rise. Finally the discrimination between the ocean surface and the geoid leads to improved knowledge on the dynamic ocean topography which does not only allow to infer mass and heat transfer in the ocean but also helps to globally unify height reference systems.

Many of the geodetic issues are already covered by the scientific community formed by the Topex and Jason Science Teams. The Ocean Surface Topography Science Team (OSTST) is one of the most efficient interdisciplinary scientific teams with annual meetings and dedicated splinter groups for calibration and validation, precise orbit computation, mean sea level modelling, estimation of the dynamic ocean topography and ocean tide modelling. Findings and recommendations of OSTST are adapted by space agencies, raw data providers and

product centres. IAS is not going to supersede any of the existing services and is not competing with the OST Science Teams.

Following themes have been identified as possible focus of IAS activities:

- **Terrestrial Reference System** investigating long-term stability (in particular wrt scale), robust geocentric realisation of satellite orbits, consistency between different tracking systems (DORIS, Laser, GPS) and the link between ITRF and tide gauges and altimeter calibration sites.
- **GNSS and Tide Gauges:** Extend the activities of the IGS Project TIGA (as requested by the OST at the last Venice conference); combine and consolidate the solutions of TIGA Processing Centres; make TIGA products (i.e. vertical tectonic rates) more visible and easy to use; promote continuous GPS operation at all tide gauges of the GLOS core network.
- **Precise Orbit Computation and Comparison** has been already performed by dedicated projects like IGS-LEO, REAPER, or ESAs Climate Change Initiative, but should be a permanent activity of all POD centres (AIUB, ASI, CSR, DEOS, ESOC, GFZ, GRGS, GSFC, JPL, NCL, ...); study impact of different processing standards e.g. time variable gravity fields, ocean tides; provide a tool to merge new orbits into altimeter data; study geographically correlated errors of new orbit computations.
- **Mean Sea Surface and Marine Gravity** are key objectives of geodesy. Systematic comparison of MSS models (e.g. CLS11, DTU10) and of marine gravity (SSv20.1, DTU10); absolute MSS calibration by means of GPS and tide gauges; validation in coastal zones; comparison and combination with satellite-only gravity fields (GRACE, GOCE) and with ship-born data.
- **Dynamic Ocean Topography (DOT)** is relevant for unification of height systems, another key objective of geodesy; compilation of different DOT estimates; comparison of geodetic and oceanography estimates; validation by drifter and ARGO floats, coastal HF-radar, ships, INSAR and other techniques; investigation on resolution and accuracy of geodetic DOT estimates.
- **Comparison of Ocean Tide Models:** validation by tide gauges is currently an initiative of D. Stammer aiming at a review paper; However, compilation and comparison of global ocean tide models (FES2004, GOT4.8, EOT11a, HAMTIDE, TPXO7.2, FES2012, ...) should become a permanent activity; nesting regional models into global ones; toolbox to evaluate ocean tide models and to merge tidal height to altimeter records; transform tide models to spherical harmonics for orbit computation and gravity field processing.

As IAS representatives to the GGOS Executive Committee two members of the IAS Steering Committee were nominated, namely Cheinway Hwang and Wolfgang Bosch.

### **Relaunch of the IAS Website**

The IAS web site has been relaunched and is now strictly following the intentionally limited strategy to provide links to mission descriptions, data and product providers and as far as available documents describing the raw mission data. There is no intention to set up IAS data holdings.

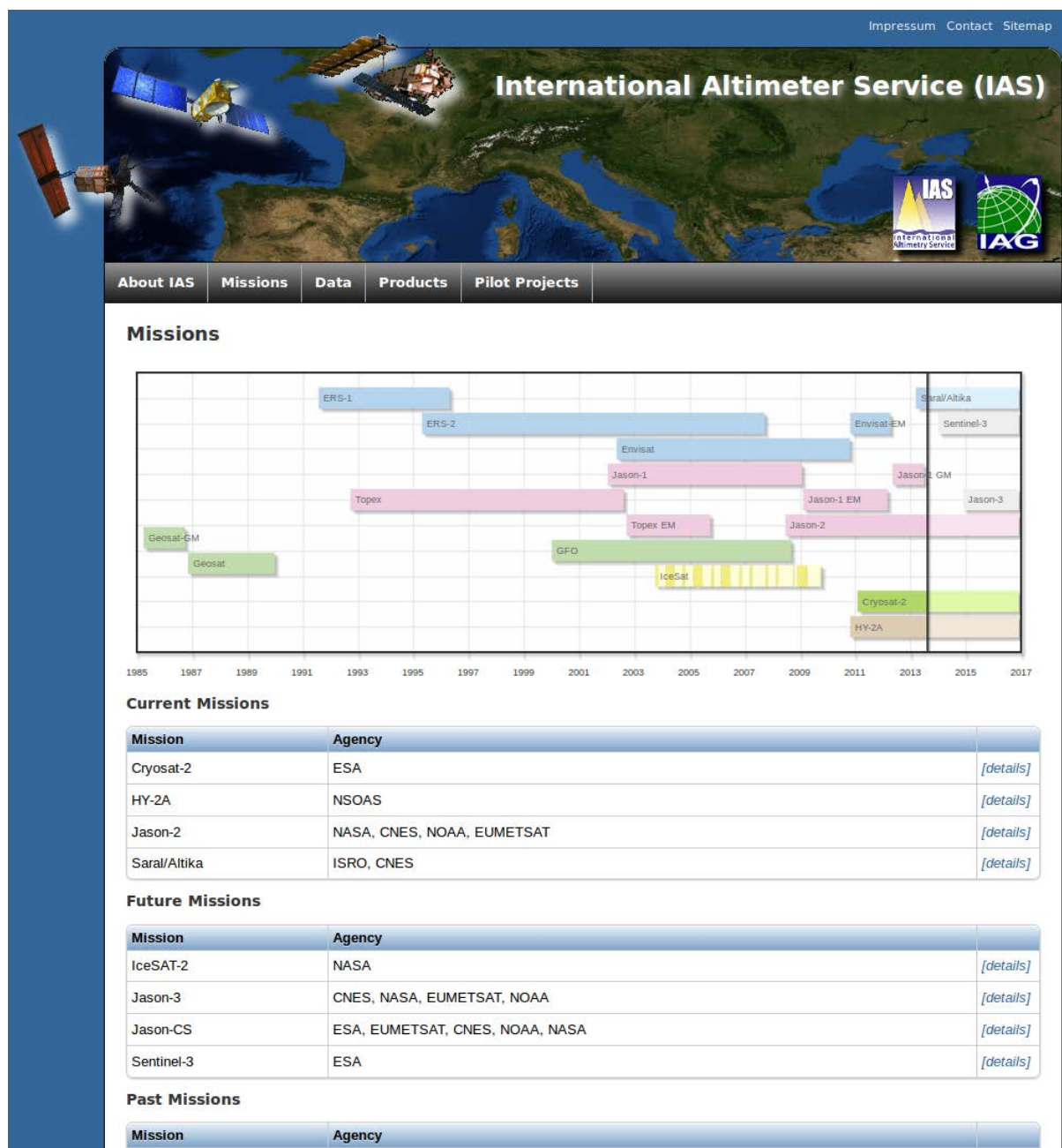


Figure 2: Snapshot of the 'Missions'-page of the IAS web site

## Preparation of an IAS Pilot Project on Ocean Tide Models

Prediction of ocean tides is crucial for the coastal environment and the protection of its ecosystem. But knowledge of ocean tides is also needed for the proper treatment of space observations used to compute satellite orbits, to determine the Earth gravity field or to map and monitor the ocean surface. Satellite altimetry, for example, is corrected for ocean tides in order to allow studying smaller, non-tidal signals, like seasonal variations or the sea level rise. The effect of ocean tides has to be removed from GRACE and GOCE observations in order to obtain gravity field models describing exclusively the Earth gravity. In both examples, aliasing of high frequency signals by a low frequency sampling is a potential source of errors.



To be able to compare similar investigations of the Earth system it is essential to ensure that the same (ocean tide) correction models are applied. Otherwise there is the risk to interpret differences of correction models as signal of the phenomena under investigation. Thus, it would be desirable to have internationally acknowledged recommendations or conventions, or to be at least able to assess the implications of different ocean tide models that were applied in similar investigations. On the other hand, sufficient flexibility is needed to change conventions as soon as improved models become available. The measures for the currently best model, however, is by no way clear. There is no common statistic for a comparison of state-of-the-art ocean tide models. Comparisons are in fact difficult, because global ocean tide models have different spatial resolution and different sets of tidal constituents. The data sets available for model evaluation are spread among various centres and investigators. There is no common software to evaluate ocean tide models, to perform the interpolation and to treat smaller or compound tides.

The International Altimeter Service (IAS) is going to launch a Pilot Projects on Ocean Tides, IAS-PP-OTM, as one of the focal points mentioned above. IAS-PP-OTM will be open to all relevant groups, agencies, and individuals. The objective is to organize and coordinate efforts to achieve a common understanding of the performance of ocean tide models for application in geodetic space techniques. IAS-PP-OTM is seeking proposals of groups, agencies, or individuals to contribute to one or more of the following initial, non-exclusive focal points:

- Compile global ocean tide models (OTMs), their error estimates (if available) and their documentation; put them to a common, self-standing format; provide interfaces to other formats or back-transformations to original formats.
- Analyse and compare how OTMs affect the treatment of geodetic space techniques, document and visualize differences.
- Provide software to evaluate OTMs for ocean areas, at individual observations sites or along the sub-satellite tracks of altimeter satellites; document the interpolation technique and the treatment of admittances.
- Provide software to transform OTMs to a spherical harmonic representation used for orbit and gravity field determination and other computations in Earth system sciences.
- Evaluate the impact of different OTMs on orbit computation (of LEO's) and gravity field determination by altimeter data (crossover statistics) and the analysis of residuals of space gravimetry or gradiometry observations (de-aliasing of GRACE and GOCE).

## International Centre for Earth Tides (ICET)

<http://www.bim-icet.org>

*Director: Jean-Pierre Barriot (France, French Polynesia)*

### Status of GGP data processing at ICET<sup>10</sup>

GGP raw minute data (GGP-SG-MIN) are preprocessed and validated at ICET in order to provide reliable hourly data sets for tidal analysis. In a first step, gaps and spikes in the monthly raw data files are corrected using the T-soft software. The corrected minute data (GGP-SG-CORMIN) are then uploaded on the Information System and Data Center (ISDC at [isdc.gdz-postdam.de](http://isdc.gdz-postdam.de)) with repair codes 12 or 22. The corrected minute data are decimated to one hour sampling and submitted to tidal analysis. The hourly data are also uploaded as one-year blocks (GGP-SG-HOUR, code h2) on the same site. We summarize the current status of our processing for all the GGP station.

We want to summarize in Table 1 the preprocessing and analysis work performed at ICET in the framework of the Global Geodynamics Program (GGP). In most of the 17 regularly co-operating stations we processed 18 months of additional data since the presentation at the IUGG General Assembly in 2011. Twenty superconducting gravimeters (SGs) and 325 monthly files are concerned. Additional raw data have been uploaded since our last processing as the data base is permanently in evolution. The instruments or stations marked with a star are no more operating. Two stations (AP and CO) are operating on a regular basis since 2009 and 2007 respectively but raw minute data are not yet available from ISDC, although the hourly data have been provided to ICET. Table 1 (column N) and Figure 1 provide also a global overview of the SG data available at GGP and ICET, including records previous to the beginning of the official GGP cooperation (1997/07/01). In some stations the end of the data had to be rejected from the global analysis due to degraded signal to noise ratio (last column of Table 1). Seventeen SG individual series reach a length of 8 years (3000 days), twelve 4000 days and five 5000 days. In stations where several instruments operated sequentially the total length reach 4000 days for BH and SU and 5000 days for WE. If the signal to noise ratio is good enough it is easy to separate the waves deriving from  $W_3^1$  and  $W_3^2$  potential with a data length of 3000 days (Ducarme 2012). For the nodal waves 4000 days is normally sufficient (Ducarme, 2011).

The standard deviation STD computed with ETERNA (ANALYZE) are given in Table 1 and Figure 2. As the stability of the sensitivity of the superconducting gravimeters is better than 0.1%, the STD is a measure of the signal to noise ratio in the station. For 22 series the STD is lower than  $1\text{nm/s}^2$ . When the STD is larger than  $2\text{nm/s}^2$  the data set is not suitable for a precise determination of the fine tidal spectrum.

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<sup>10</sup> Jean-Pierre Barriot, Youri Verschelle, Observatoire Géodésique de Tahiti, Université de la Polynésie française & Bernard Ducarme, Catholic University of Louvain, Georges Lemaître Centre for Earth and Climate Research

Table 1: Status of preprocessed and analyzed GGP data on April 2013

n: number of preprocessed months since 2011

N: number of days effectively used in the global tidal analysis

STD: standard deviation of the global analysis (ETERNA)

Code	Location	SG Instr.	ICET Code	RAW	Corrected	n (months)	N (days)	STD (nm/s <sup>2</sup> )	Rem arks
AP	Apache Point, USA	SG046	00466090	120900	051122	41	1195	1.200	
BA*	Bandung, Indonesia	T008	00084100	030600	030622		1104	2.938	
BE*	Brussels, Belgium	T003	07790200	000900	000901		¶16692	1.641	
BF	Black Forest, Germany	CD056_L CD056_H	01560716 02560716	121200 121200	120522 120522	27 27	693 693	0.598 0.657	
BH	Bad Homburg, Germany	(T001) CD030_L CD030_U SG044	01300734 02300734 00440734	070400 070400 121200	070422* 070422* 120422	15	¶1005 2222 2218 1874	0.950 0.783 0.835 0.599	
BO*	Boulder, USA	C024	00246085	031000	031022		1850	1.109	
BR*	Brasimone, Italy	T015	00150515	991200	991222		1428	2.954	
CA	Cantley, Canada	T012	00126824	121100	120222	14	5006 ¶6572	1.259 1.268	
CB	Canberra, Australia	C031	00314204	120100	110722	16	4933	0.762	
CO	Conrad	C025	00250699				1877	0.565	
ES	Esashi, Japan	T007	00072849	081200	081222?		2274	1.491	→2004 0225
HS	Hsinchu, Taiwan	T048	00482695	120800	081222		898	2.249	
KA	Kamioka, Japan	T016	00162828	120100	110722	16	2356	1.271	
KY*	Kyoto, Japan	T009	00092823	030600	030622		1533	3.691	→2002 0731
MA*	Matsushiro, Japan	T011	00112834	080600	080622		3954	1.008	
MB	Membach, Belgium	C021	00210243	120900	111222	19	5907	0.705	
MC	Medicina, Italy	C023	00230506	121200	120122	12	5047	0.871	
ME	Metsahovi, Finland	T020	00200892	120700	120722	19	5199 ¶5744	1.183 1.159	
MO	Moxa, Germany	CD034_L CD034_U	01340770 02340770	121200 121200	120622 120622	14 14	4357 4423	0.599 0.549	
NY	Ny Alesund, Norway	C039	00390005	120100	120122	22	3776	2.687	
PE	Pecny, CZ	OSG050	00500930	121100	120622	22	1860	0.540	
PO*	Potsdam, Germany	T018	00180765	980900	980912		2250	0.856	
ST	Strasbourg, France	(T005) C026	00230306	120500	120522	13	¶3272 5342	2.265 0.773	
SU	Sutherland, South Africa	CD037_L CD037_U SG052	01373806 02373806 00523806	121200 121200 121200	120622 120622 120622	18 18 18	3561 3398 1375	0.821 0.748 0.831	
SY	Syowa, Antarctic	T016	00169960	030100	030122*		1279	1.387	→2000 1231
TC	TIGO, Concepcion, Chile	RT038	00387621	121200	120922	21	2692	1.108	
VI*	Vienna, Austria	C025	00250698	061200	061222		3402 4278	0.525 0.463	
WE	Wetzell, Germany	(SG103) CD029_L CD029_U CD030_L CD030_U	01030731 01290731 02290731 01300731 02300731	980900 101000 101000 120900 120900	980921* 101022* 101022* 120922 120922	27 27	726 4264 4226 811 814	2.639 0.579 0.597 0.608 0.581	
WU	Wuhan, China	T004	00322647	120700	120712●		3722	0.937	
					TOTAL	420			

 \* instrument stopped  
 ( ) not included in GGP

 ? status unknown  
 ¶ with data before 1997/07

 ● preprocessed by data owner  
 → end of the global analysis

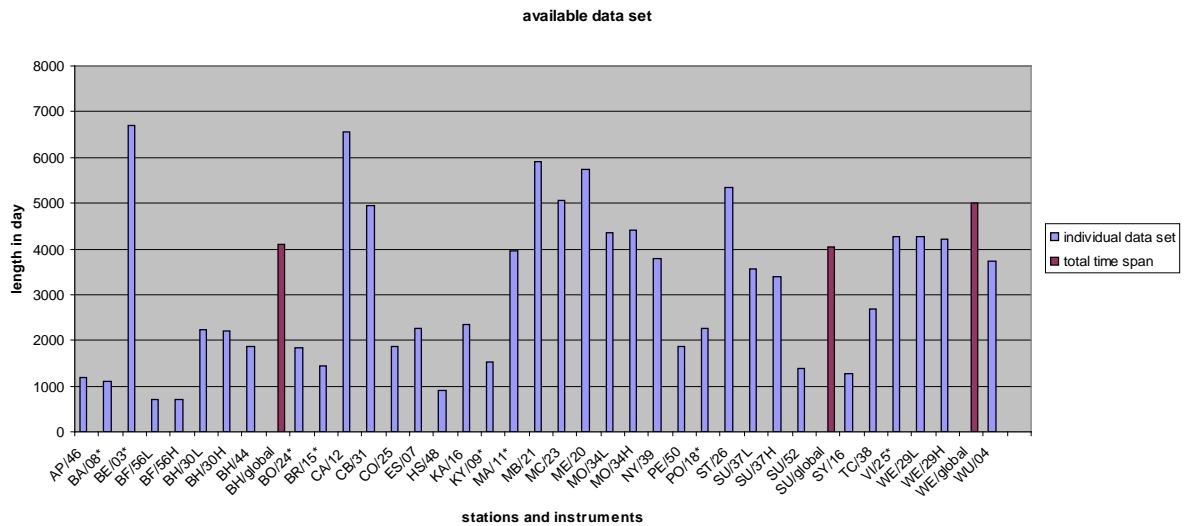


Figure 1: Length of the different data set

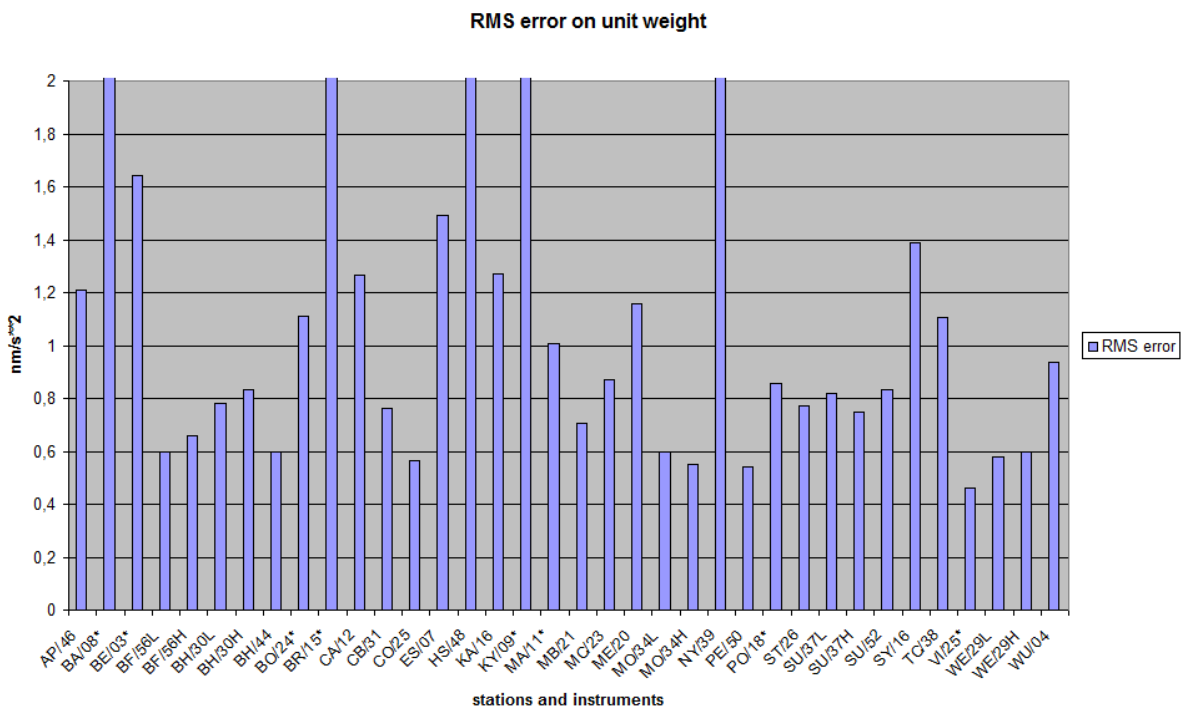


Figure 2: RMS error on the unit weight of the different data set

## References

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## **International Centre for Global Earth Models (ICGEM)**

<http://icgem.gfz-potsdam.de>

*Director: Franz Barthelmes (Germany)*

### **Overview**

The International Centre for Global Earth Models was established in 2003 and this year is its 10<sup>th</sup> anniversary.

It is mainly a web based service and comprehends:

- collecting and long-term archiving of existing global gravity field models; solutions from dedicated time periods (e.g. monthly GRACE models) are included
- making them available on the web in a standardised format (self-explanatory)
- interactive visualisation of the models (geoid undulations and gravity anomalies)
- animated visualization of monthly GRACE models
- web-interface to calculate gravity functionals from the spherical harmonic models on freely selectable grids (filtering included)
- theory and formulas of the calculation service in STR09/02 (downloadable)
- the ICGEM web-based discussion forum (answering questions)
- evaluation of the models
- visualisation of surface spherical harmonics as tutorial

Thanks to the availability of the new release of the 10-years monthly model series from GRACE, the static models from the recent GOCE mission, and their combined models of high spatial resolution, the importance of gravity field functionals for nearly all geosciences is rising permanently. In addition to its use for educational purposes, ICGEM helps researchers from different geoscientific fields to overcome the first obstacles in using these models and to get acquainted with the mathematical representation of gravity field in terms of spherical harmonic series. In this way ICGEM enables and stimulates the research based on these products, which are primarily the result of rapid and fruitful development of the satellite based geodetic gravity field determination methods in the past decades.

### **Services**

#### **The Models**

Currently, 135 models are listed with their references and 121 of them are available in form of spherical harmonic coefficients. If available, the link to the original model web site has been added. Models from dedicated time periods (e.g. monthly solutions from GRACE) of CSR, JPL, CNES/GRGS and GFZ are also available.

#### **The Format**

The spherical harmonic coefficients are available in a standardised self-explanatory format which has been accepted by ESA as the official format for the GOCE project.

## The Visualisation

An online interactive visualisation of the models (height anomalies and gravity anomalies) as illuminated projection on a freely rotatable sphere is available (fig. 1). Differences of two models, arbitrary degree windows, zooming in and out, are possible. To get an impression of the time variations there is an animation of the monthly solutions (fig. 2). The visualisation of single spherical harmonics is possible for tutorial purposes.

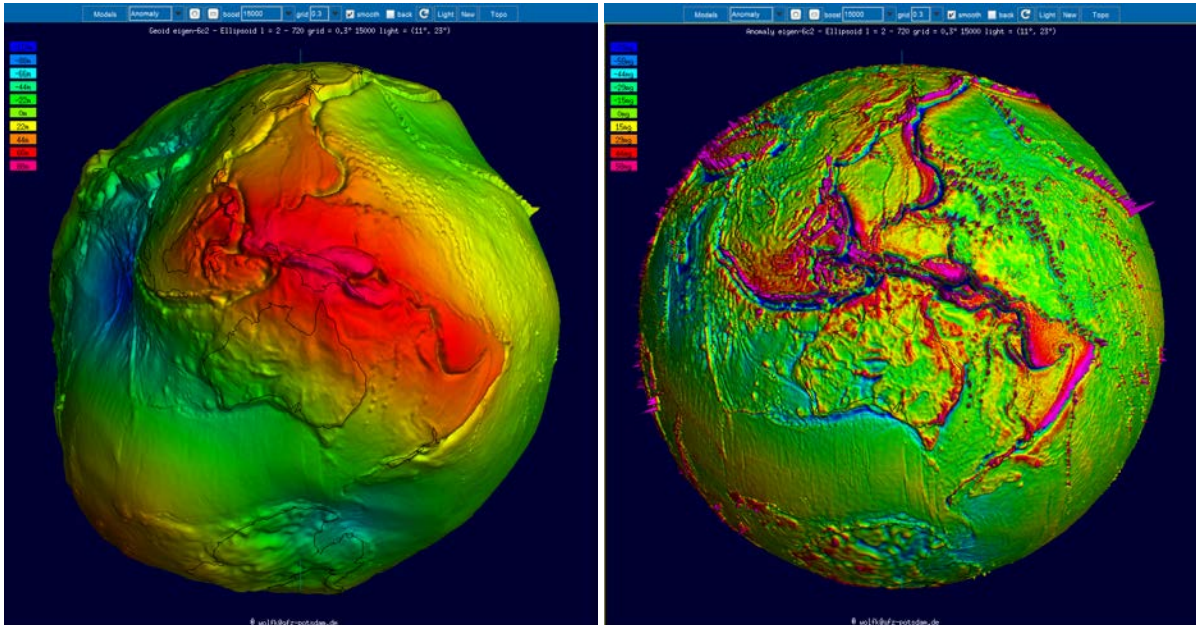


Fig. 1: Visualisation of a global gravity field model, geoid undulations (left) and gravity anomalies (right)

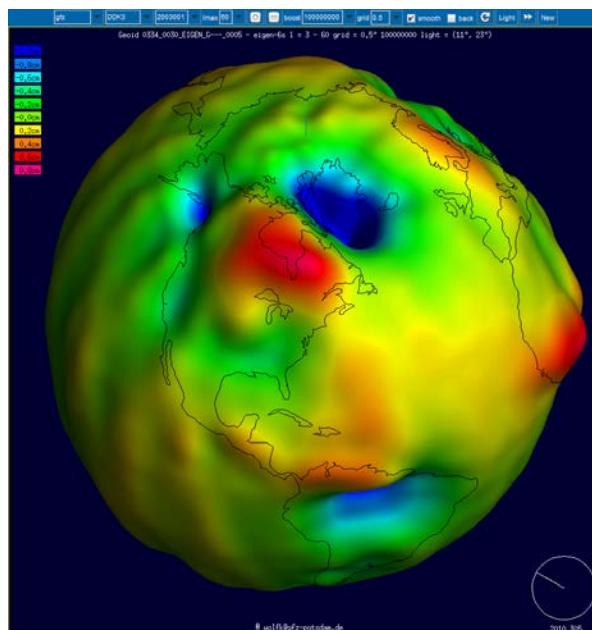


Fig. 2: Snapshot from the animation of the monthly models: geoid differences of the model for November 2010 to the mean model EIGEN-6S. Visible are the effect of mass loss (blue) due to deglaciation during the last years in Greenland and Alaska (eyes ☺), as well as the snapshot of the annual hydrological mass variations in the basin of the Amazon (mouth ☺), and the effect of increasing mass (red) due to postglacial uplift in North America (nose ☺).

## The Calculation Service

A web-interface to calculate gravity functionals from the spherical harmonic models on freely selectable grids, with respect to a reference system of the user's choice, is provided. The following functionals are available:

- pseudo height anomaly on the ellipsoid (or at arbitrary height over the ellipsoid)
- height anomaly (on the Earth's surface as defined)
- geoid height (height anomaly plus spherical shell approximation of the topography)
- gravity disturbance
- gravity disturbance in spherical approximation (at arbitrary height over the ellipsoid)
- gravity anomaly (classical and modern definition)
- gravity anomaly (in spherical approximation, at arbitrary height over the ellipsoid)
- simple Bouguer gravity anomaly
- gravity on the Earth's surface (including the centrifugal acceleration)
- gravity on the ellipsoid (or at arbitrary height over the ellipsoid, including the centrifugal acceleration)
- gravitation on the ellipsoid (or at arbitrary height over the ellipsoid, without centrifugal acceleration)
- potential on the ellipsoid (or at arbitrary height over the ellipsoid, without centrifugal potential)
- second derivative in spherical radius direction of the potential (at arbitrary height over the ellipsoid)
- equivalent water height (water column)

model and reference selection	
refsys	WGS84
radiusrefpot	6378137.0
flatrefpot	298.257223563
gmrefpot	3.986004418d+14
omegarefpot	7.292115d-5
model directory	longtime models
modelfile	go_cons_gcf_2_dir_r2
functional	gravity_anomaly_bg
tide_system	use unmodified model
zero_degree_term	yes

grid selection	
gridstep	0.075
longlimit_west	70
longlimit_east	110
latlimit_south	20
latlimit_north	50
height_over_ell	0

truncation	
max_used_degree	** max degree of model **
startgentlecut	** unused **

Gaussian filtering	
flength_definition	** unused **
filterlength_degree	5
filterlength_meter	556597

filterlength in meter	
start computation	<input type="button" value="start computation"/>
show directory	<input type="button" value="show directory"/>
get gridfile	<input type="button" value="get gridfile"/>
PS-file	<input checked="" type="checkbox"/> <input type="button" value="PS-file"/>
illumination	<input checked="" type="checkbox"/> <input type="button" value="illumination"/>
get PS-file	<input type="button" value="get PS-file"/>
reset defaults	<input type="button" value="reset defaults"/>

psfile 'go\_cons\_gcf\_2\_dir\_r2-87560.ps' computed successfully

Fig. 3: Input mask of the calculation service

Filtering is possible by selecting the maximum degree of the used coefficients or the filter length of a Gaussian averaging filter. The models from dedicated time periods (e.g. coefficients of monthly solutions from GRACE) are also available after non-isotropic smoothing (decorrelation). The calculated grids (self-explanatory format) and corresponding plots (postscript) are available for download after a few seconds or a few minutes depending on the functional, the maximum degree and the number of grid points.

Figure 3 shows the input mask of the calculation service and figures 4 to 6 show examples of plots (of grids) generated by the calculation service.

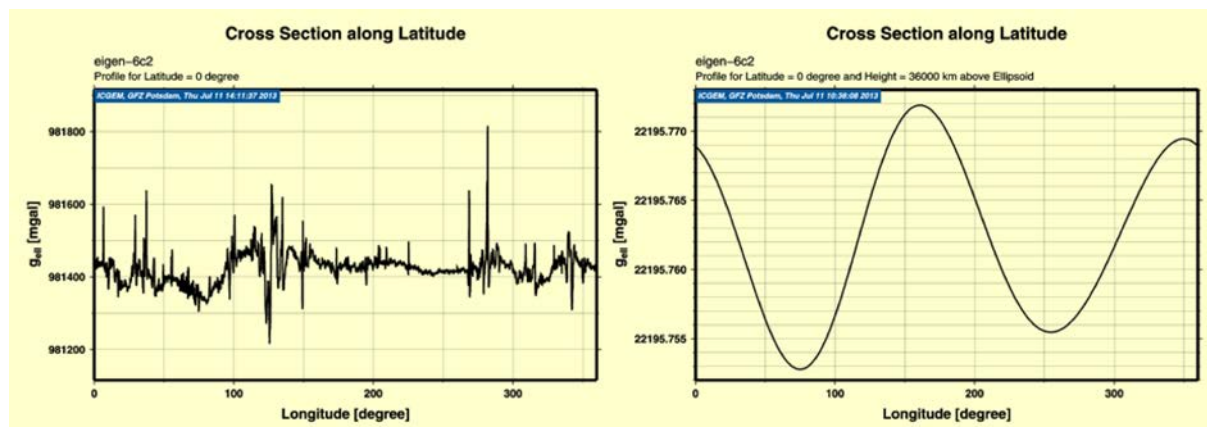


Fig. 4: Example of grid and plot generation by the calculation service: gravitation along the equatorial cross section on the ellipsoid (left), and 36000 km above the ellipsoid (right) from the model EIGEN-6C2

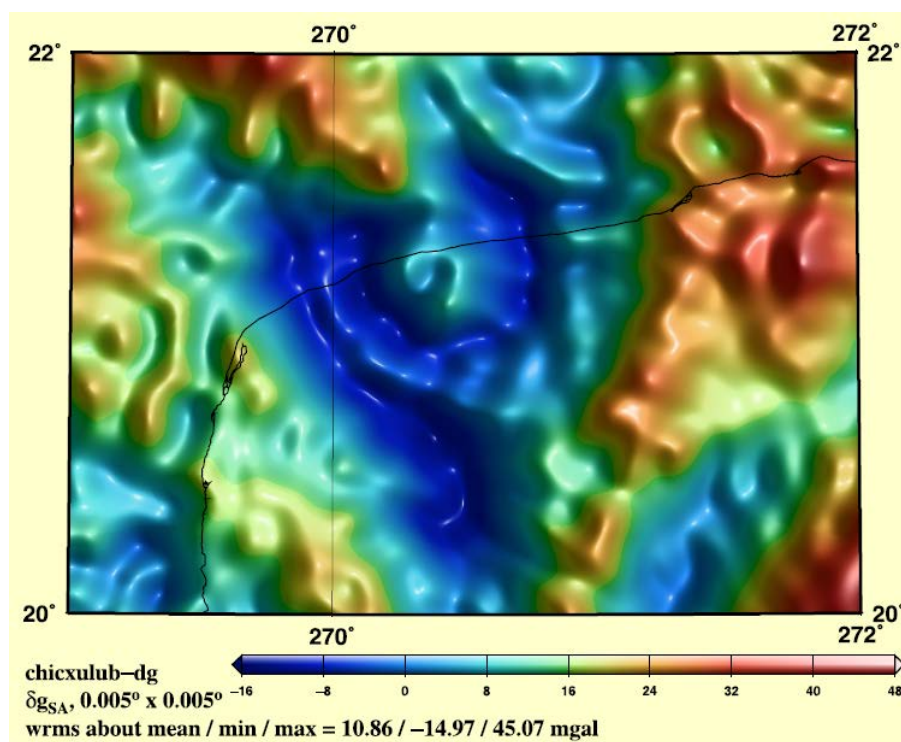


Fig. 5: Example of grid and plot generation by the calculation service: gravity disturbances of the Chicxulub crater region from the model EGM2008



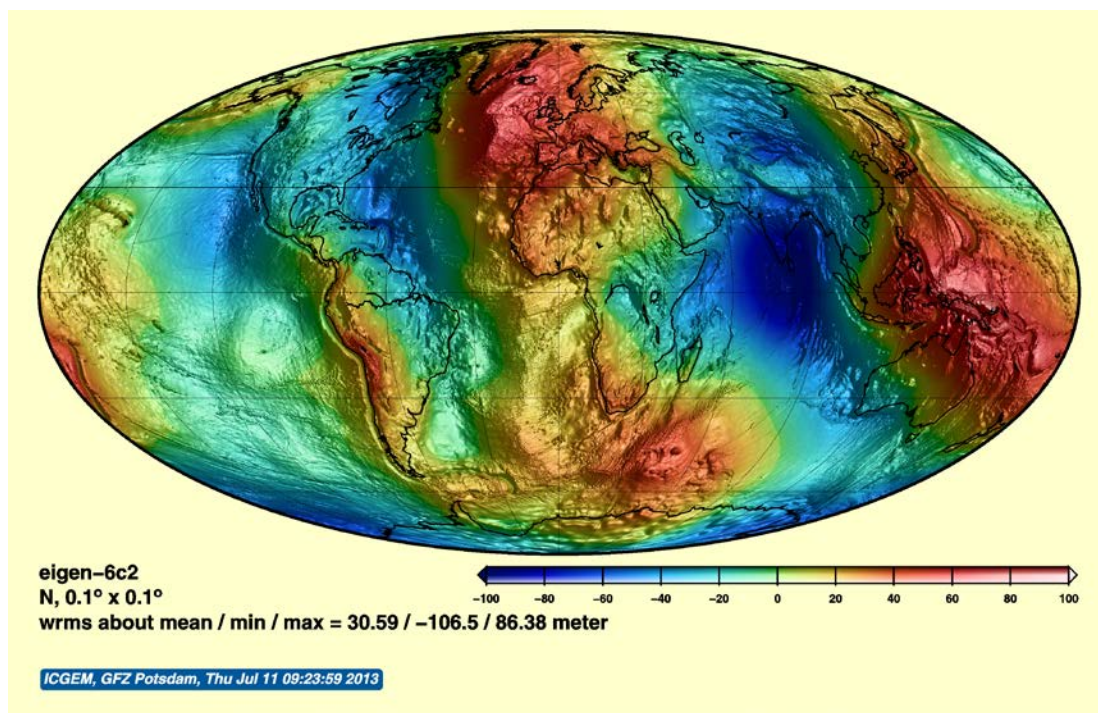


Fig. 6: Example of grid and plot generation by the calculation service: global geoid undulations from the model EIGEN-6C2 (with respect to WGS84)

## Evaluation

For a concise evaluation of the models, comparisons with GPS-levelling data and with the most recent combination model in the spectral domain are provided (see figures 7 and 8). A visualisation of the improvement of the satellite-only models over the past decades is also provided (fig. 9).

Model	Nmax	USA 6169 points	Canada 1930 points	Europe 1235 points	Australia 201 points	Japan 816 points
EIGEN-6C2	1949	0.249 m	0.127 m	0.212 m	0.214 m	0.080 m
DGM-1S	250	0.441 m	0.352 m	0.430 m	0.366 m	0.513 m
GOCO03S	250	0.428 m	0.340 m	0.418 m	0.355 m	0.500 m
GO_CONS_GCF_2_DIR_R3	240	0.431 m	0.347 m	0.423 m	0.355 m	0.506 m
GO_CONS_GCF_2_TIM_R3	250	0.430 m	0.343 m	0.417 m	0.357 m	0.496 m
EIGEN-6C	1420	0.247 m	0.135 m	0.214 m	0.219 m	0.082 m
GIF48	360	0.319 m	0.230 m	0.275 m	0.236 m	0.275 m
EIGEN-6S	240	0.446 m	0.373 m	0.449 m	0.397 m	0.520 m
GOCO02S	250	0.435 m	0.352 m	0.434 m	0.371 m	0.516 m
AIUB-GRACE03S	160	0.650 m	0.514 m	0.713 m	0.486 m	0.835 m
GO_CONS_GCF_2_DIR_R2	240	0.443 m	0.374 m	0.449 m	0.391 m	0.519 m
GO_CONS_GCF_2_TIM_R2	250	0.436 m	0.355 m	0.434 m	0.375 m	0.515 m
GO_CONS_GCF_2_SPW_R2	240	0.457 m	0.376 m	0.473 m	0.376 m	0.553 m
GO_CONS_GCF_2_DIR_R1	240	0.407 m	0.319 m	0.402 m	0.319 m	0.489 m
GO_CONS_GCF_2_TIM_R1	224	0.455 m	0.378 m	0.474 m	0.371 m	0.578 m
GO_CONS_GCF_2_SPW_R1	210	0.471 m	0.399 m	0.498 m	0.384 m	0.569 m

Fig. 7: Table (truncated) of comparison of the models with GPS-levelling: Root mean square (rms) about mean of GPS / levelling minus gravity field model derived geoid heights [m]

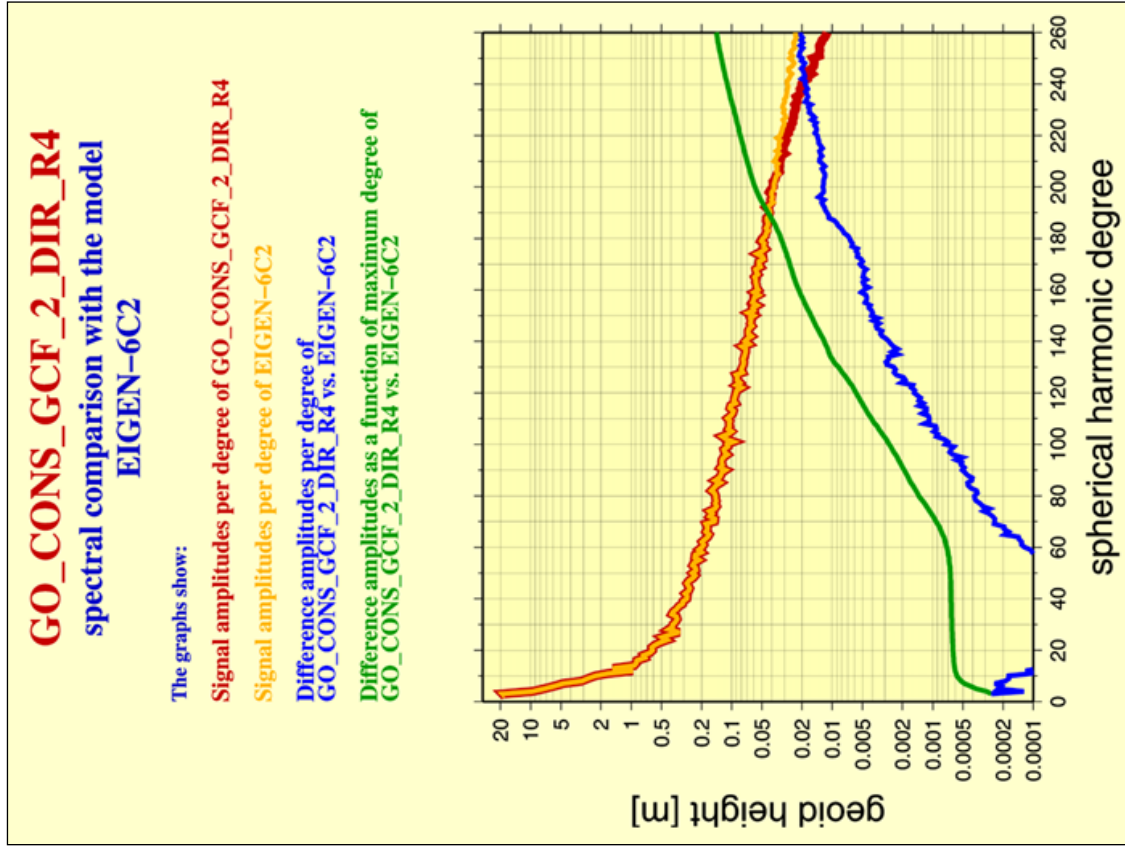


Fig. 8: Comparison of the models in the spectral domain (e.g.: GO\_CONS\_GCF\_2\_DIR\_R4) with one of the most recent combination models (e.g. EIGEN-6C2)

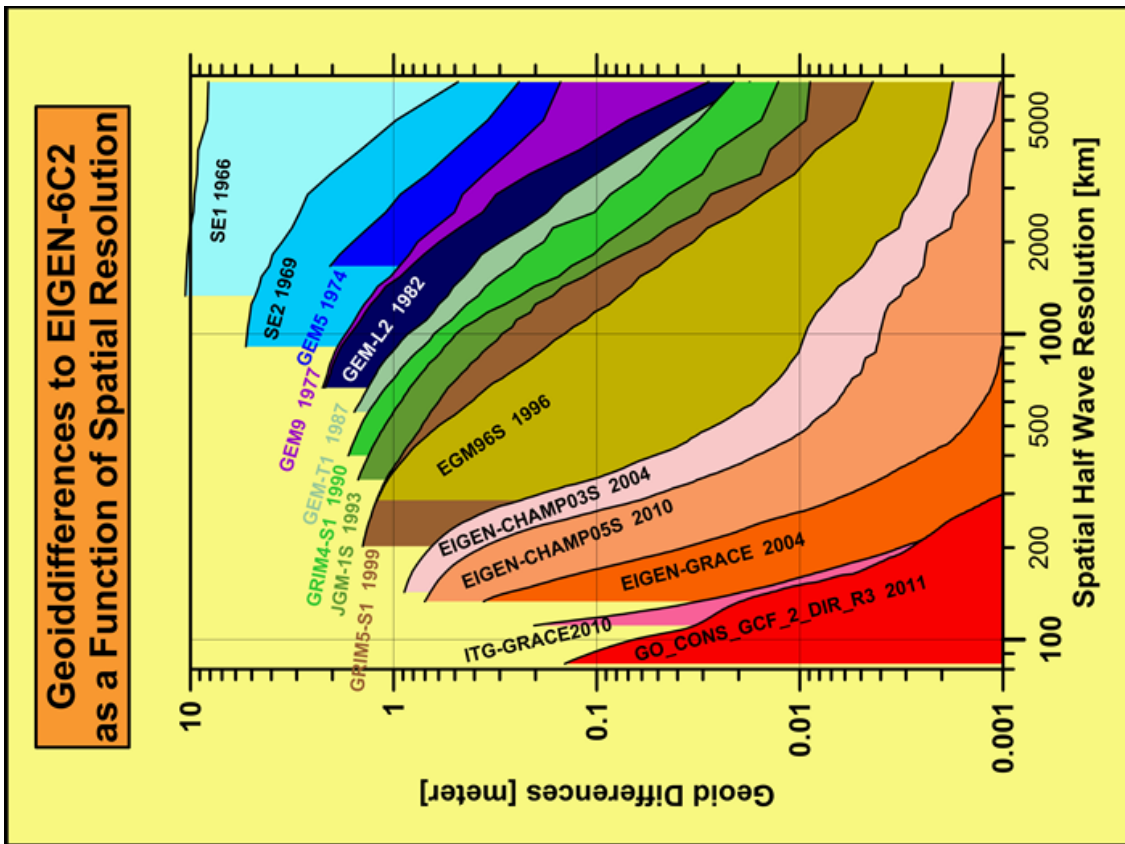


Fig. 9: Visualisation of the improvement of satellite-only models over the past decades: Geoiddifferences to the model EIGEN-6C2 as a function of spatial resolution.

## **Publications**

Barthelmes, F.; Köhler (2010): ICGEM - The International Centre for Global Earth Models, Second International Symposium of the International Gravity Field Service (Fairbanks, USA 2010).

Barthelmes, F.; Köhler, W. (2010): ICGEM - a Web Based Service for Using Global Earth Gravity Field Models. IAG Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TG-SMM2010) (Saint Petersburg, Russia 2010).

Barthelmes, F.; Köhler (2010): ICGEM – A Web Based Service for Using Global Earth Gravity Field Models, Arbeitskreis Geodäsie/Geophysik, Herbsttagung (Smolenice, Slovakia 2010)

Barthelmes, F. (2009): Definition of Functionals of the Geopotential and Their Calculation from Spherical Harmonic Models: Theory and formulas used by the calculation service of the International Centre for Global Earth Models (ICGEM), <http://icgem.gfz-potsdam.de>, Scientific Technical Report 09/02, Revised Edition, January 2013, Deutsches GeoForschungsZentrum GFZ, DOI 10.2312/GFZ.b103-0902-26

Barthelmes, F.; Köhler, W.; Kusche, J. (2008): ICGEM The International Centre for Global Earth Models, Observing and Forecasting the Ocean GODAE Final Symposium (Nice, France 2008).

Barthelmes, F.; Köhler, W.; Kusche, J. (2007): ICGEM - The International Centre for Global Earth Models, General Assembly European Geosciences Union (EGU) (Vienna, Austria 2007).

Barthelmes, F.; Köhler (2006): ICGEM - The International Centre for Global Earth Models, General Assembly European Geosciences Union (EGU) (Vienna, Austria 2006).

## **International Digital Elevation Model Service (IDEMS)**

<http://www.cse.dmu.ac.uk/EAPRS/iag/>

*Director: Philippa Berry (UK)*

Report not available

## International DORIS Service (IDS)

<http://ids.cls.fr/>

*Chairman: Pascal Willis (France)*

### Overview

The current report presents the different activities held by all components of the International DORIS Service (IDS). In a first step, we will present the current status of the DORIS system (available satellites and tracking network). In a second step, we will present the activities of the IDS Central Bureau (IDS Web site management and DORIS-related email distributions). We will then focus on the most recent activities conducted by the Analysis Centres (ACs) and the Analysis Coordination in preparation of ITRF2008. Finally, we will present other activities related to meetings and publications.

### Structure

#### DORIS satellites

During this report period (2007-2009), the number of DORIS satellites has remained between five and six (see Table 1).

Table 1: DORIS data available at IGN. As August 2009

Satellite	Start	End	Type
SPOT-2	31-MAR-90 04-NOV-92	04-JUL-90 15-JUL-09	Remote sensing
TOPEX/Poseidon	25-SEP-92	01-NOV-04	Altimetry
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	-	Remote sensing
SPOT-5	11-JUN-02	-	Remote sensing
Jason-1	15-JAN-02	-	Altimetry
ENVISAT	13-JUN-02	-	Altimetry, Environment
Jason-2	12-JUL-08	-	Altimetry

In mid 2008, a new DORIS satellite (Jason-2) was launched including a new generation receiver on-board : digital, 7-channel, allowing direct phase measurement like GPS (instead of Doppler data).

In the near future, several new DORIS satellites are already planned (and approved) : CRYOSAT-2, SARAL, HY-2A, Jason-3, ... This should increase or at least stabilize the number of DORIS satellites in the 2010-2016 time period. In July 2009, the SPOT-2 satellite had to be de-orbited and inactivated. A series of maneuvers changed the orbit so the spacecraft will re-enter the Earth's atmosphere in less than 25 years. SPOT-2 was launched in 1990 with a planned six-month test mission. After 19 years of successful operations, it has greatly exceeded the most optimistic expectations.

## DORIS tracking network

The DORIS permanent tracking network remains very stable (Figure 1). About 50% of the DORIS stations are in co-location with other geodetic space techniques : GPS (38), SLR (9) and VLBI (6).

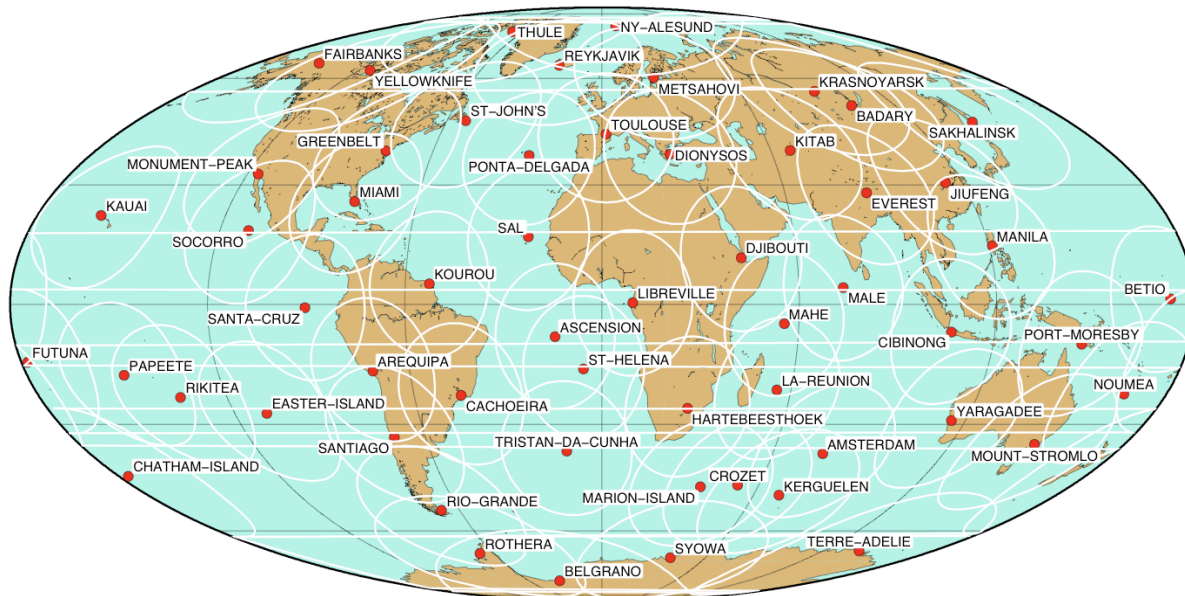


Figure 1: DORIS permanent tracking network. July 2009.

The renovation of the DORIS network is now terminated. Almost of DORIS beacons (55) are third generation beacons (except 2), and use a stable geodetic mount (cf Fagard, 2006).

## IDS Governing Board

Following the IDS status, a new Governing Board was elected at the end of 2008 (see Table 2).

Table 2: IDS Governing Board following elections in December 2008

Name	Institution	Country	Mandate
Hervé Fagard	IGN	France	Network representative
Pascale Ferrage	CNES	France	Member at large
Frank Lemoine	GSFC	USA	Analysis Coordinator
Chopo Ma	GSFC	USA	IERS representative
Carey Noll	GSFC	USA	Network representative
Michiel Otten	ESOC	Germany	IAG representative
John Ries	U. Texas/CSR	USA	Member at large
Laurent Soudarin	CLS	France	Director IDS Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Centre representative

## **IDS Central Bureau**

### *IDS Web site*

The IDS Central Bureau maintains the IDS Web site at <http://ids.cls.fr>. The IDS Web site archives information of direct interest to the IDS Analysis Centres and to the DORIS community in general:

- DORIS results such as plots and data of DORIS station coordinate time series at <http://ids.cls.fr/html/doris/ids-station-series.php3>
- DORIS station site logs at <http://ids.cls.fr/html/doris/sitelog.php3>
- daily statistics of Precise Orbit Determination (POD) residuals per station
- specific events affecting DORIS satellites (maneuvers, change of on-board software,..) or stations (discontinuity, data gap or temporary failures,...)

In particular, a kml file was created to allow a virtual tour of DORIS tracking stations on GoogleEarth.

Access to IDS Web site is still steadily increasing from month to month since Spring 2000. In early 2009, this Web site was accessed about 2000 times each month on a regular basis.

### *IDS Mail system*

Several types of emails are distributed by the IDS Central Bureau :

- DORISMail : general DORIS interest
- DORISReports : reports related to DORIS data and products
- AWG and IDS Analysis Forum : technical discussion between analysis centres, combination and coordination

Everyone is welcome to subscribe to any of these emails. See more details on [http://ids.cls.fr/html/report/doris\\_mails.html](http://ids.cls.fr/html/report/doris_mails.html)

## **IDS Data Centres**

The IDS data flow organization remains the same, but is now more robust. It is based on two data centres : one on the East Coast of the US (CDDIS a GSFC) and one in Europe (IGN in France). Recently, the two data centres were gradually upgraded in order to be exact mirrors of each other and to be able to continue on an operational basis, even if one of them is inaccessible due to a temporary failure.

These two data centres archive the DORIS data as well as the IDS products (station coordinates and velocity, geo-centre motion, earth orientation parameters, ionosphere data, etc.).

## IDS Analysis Centre

Like the other technique-services in IAG, IDS has now a large number of independent Analysis Centres.

Table 3: List of IDS Analysis Centres submitting time series of weekly station coordinates in preparation of ITRF2008. July 2009.

Acronym	Analysis Centre	Country	Software package
ESA	ESOC	Germany	NAPEOS
GAU	Geoscience Australia	Australia	GEODYN
GOP	Geodetic Observatory Pecny	Czech Rep.	Bernese
GSC	GSFC	USA	GEODYN
IGN	IGN	France	GIPSY/OASIS
INA	INASAN	Russia	GIPSY/OASIS
LCA	CNES/CLS	France	GINS/DYNAMO

In preparation for ITRF2008, seven AC's submitted long time series of DORIS results in SINEX format from 1993.0 to 2009.0 (Table 3). Besides these operational groups, several other groups are also considering to join in the future, such as NCL in Newcastle, UK. Even for those using the same software packages (IGN-INASAN for GIPSY/OASIS and GSFC-Geoscience Australia for GEODYN), great care was taken to define the processing strategies to be at the same level of quality but using different approaches (e.g. Gravity field model, tropospheric mapping functions, etc.).

This is a complete change for IDS, as in the past only two independent solutions were regularly submitted to the previous ITRF combinations. Several meetings were held by the Analysis Coordinator (Frank Lemoine), inviting all AC's to make them benefit from the experience of the other groups, to compare results, and to prepare for the AC submissions for ITRF2008.

## Activities

### IDS Combination

For the first time, IDS made a combined time series of all available weekly solutions (from 1993.0 to 2009.0).

For the first time, DORIS satellites orbits derived from the seven AC's were systematically intercompared. This allowed us to isolate processing anomalies and assured that the processing of the DORIS data was at a comparable level for all the AC's. The results were excellent, showing agreement at the 1-2 cm level in the radial component, even without trying to select compatible data processing strategies for models or parameter estimation.

Following the availability of ITRF2005, a new DPOD2005 coordinate data set was derived, expanding to new DORIS stations or to stations not considered in the original ITRF2005, due



to non-linear displacements. DORIS stations' discontinuities were also analyzed. A dedicated Web page was created : <http://www.ipgp.fr/~willis/DPOD2005.htm>

## **Meetings**

In the past 2 years the IDS organized the following meetings :

- IDS Workshop, Venice, Italy, 13-15 March 2006
- DORIS Analysis Working Group Meeting, Paris, France, 13-14 March, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 5-6 June, 2008
- IDS Workshop, Nice, France, 12-14 November, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 23-24 March, 2009

All presentations from these meetings are made available by the Central Bureau on the IDS Web site at [http://ids.cls.fr/html/events/ids\\_meetings.html](http://ids.cls.fr/html/events/ids_meetings.html)

## **Publications**

In 2006, a DORIS Special Issues was published in the Journal of Geodesy 80(8-11), including 17 peer-reviewed articles.

A second DORIS Special Issue is currently in preparation in Advances in Space Research.

IDS published a 2006-2008 activity report that was broadly distributed to all DORIS participants and relevant services

G. Tavernier, P. Ferrage, H. Fagard, F. Lemoine, C. Noll, R. Noomen, J.C. Ries, L. Soudarin, J.J. Valette, P. Willis, The International DORIS Service, January 2006 – December 2008 Report, 91 pages, [http://ids.cls.fr/html/report/governing\\_board.html#activity](http://ids.cls.fr/html/report/governing_board.html#activity).

All DORIS related articles published in international peer-reviewed journals are available on the IDS Web site at [http://ids.cls.fr/html/report/peer-reviewed\\_journals.html](http://ids.cls.fr/html/report/peer-reviewed_journals.html)

## **Conclusions**

In conclusion, even if the DORIS context is rather stable in terms of network and satellite constellation, a major change happened to the IDS as seven Analysis Centres now actively participate in operational DORIS data processing and as a combined IDS solution is now available in preparation of ITRF2008. The launch of the new Jason-2 satellite should also open some new opportunities in the IDS, as it brings more data (7-channel receiver), better quality (equivalent to 0.3 mm/s) and the possibility to process these data using a GPS-type technique (access to raw DORIS phase measurement instead of Doppler data). In the near future several new satellites of this type should be launched, insuring a minimum of four DORIS satellites for the 2010-2016 time period.

## **International Earth Rotation and Reference Systems Service (IERS)**

<http://www.iers.org>

*Chair of the Directing Board: Chopo Ma (USA) (until 31 December 2012),  
Brian Luzum (USA) (since 1 January 2013)  
Director of the Central Bureau: Bernd Richter (Germany) (until 31 March 2013),  
Daniela Thaller (since 1 April 2013)*

### **Overview**

The International Earth Rotation and Reference Systems Service marked its 25<sup>th</sup> anniversary of operations on 1 January 2013. It continues to provide Earth orientation data, terrestrial and celestial reference frames, as well as geophysical fluids data to the scientific and other operationally oriented communities.

Earth orientation data have been issued on a daily (and since 2012 also 4 times per day), weekly, and monthly basis, and new global geophysical fluids data were added. Work on new realizations of the International Terrestrial Reference System (ITRF2013) and the International Celestial Reference System (ICRF3) was started. The IERS Conventions (i.e. standards etc.) have been updated regularly. New Working Groups on SINEX Format and on Site Coordinate Time Series Format were established in 2011 and 2012, respectively.

The IERS continued to issue Technical Notes, Annual Reports, Bulletins, and electronic newsletters. It held a GGFC Workshop (April 2012), a Workshop on Local Surveys and Co-locations (May 2013), a Retreat (May 2013), and organized the Third GGOS Unified Analysis Workshop (September 2011).

The IERS Data and Information System (DIS) at the web site [www.iers.org](http://www.iers.org), maintained by the Central Bureau, has been updated, improved and enlarged continually. It presents information related to the IERS and the topics of Earth rotation and reference systems. As the central access point to all IERS products it provides tools for searching within the products (data and publications), to work with the products and to download them. The DIS provides links to other servers, among these to about 10 web sites run by other IERS components.

In 2013, changes in key positions of IERS occurred with a new Chair of the Directing Board and a new Director of the Central Bureau.

### **Structure**

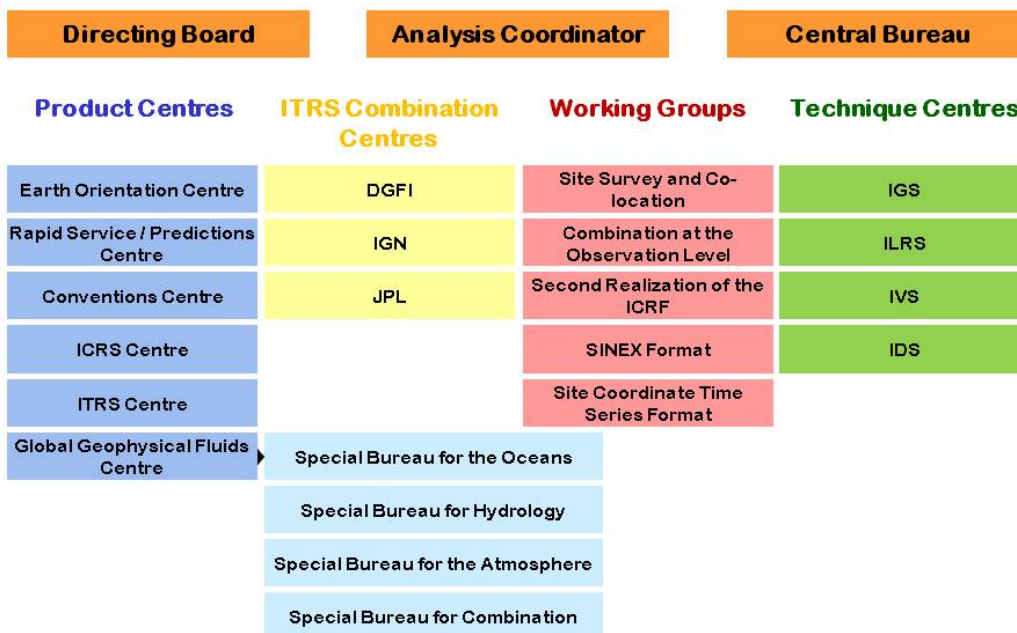
According to the Terms of Reference, the IERS consists of the following components:

- Technique Centres
- Product Centres
- ITRS Combination Centre(s)
- Analysis Coordinator
- Central Bureau
- Directing Board
- Working Groups

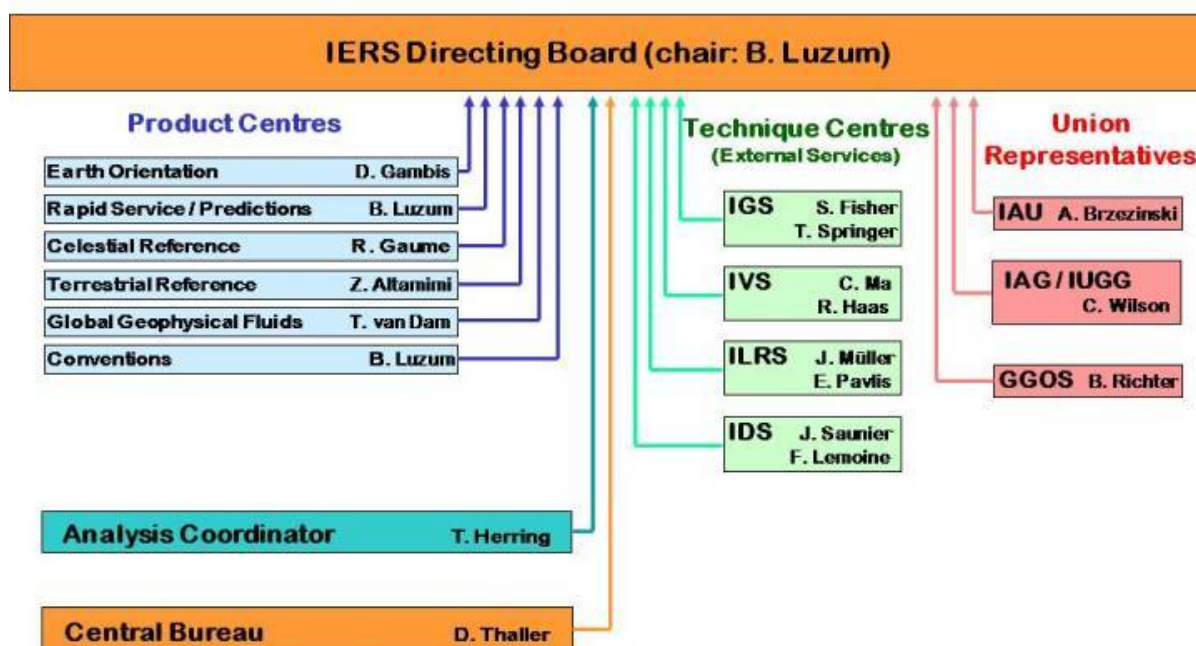
The Technique Centres are autonomous operations, structurally independent from the IERS, but which cooperate with the IERS.

As of June 2013, the following IERS components exist:

### IERS Components 2013



The current members of the Directing Board (representatives of scientific unions and of IERS' components) are:



## Activities

### Publications

The following IERS publications and newsletters appeared between mid-2011 and 2013 in electronic form:

- IERS Technical Note No. 37: Z. Altamimi, X. Collilieux and L. Métivier: Analysis and results of ITRF2008
- IERS Annual Reports 2008-09 and 2010
- IERS Bulletins A, B, C, and D (weekly to half-yearly)
- IERS Messages Nos. 191 to 232

### Workshops

The IERS organized three workshops and a retreat:

- *Third GGOS Unified Analysis Workshop (Zürich, Switzerland, 16 – 17 September 2011)*. The workshop was intended to be a forum for the exchange of information and results concerning both problems common to more than one service and problems specific to an individual service. It was aimed at increasing the common understanding of the individual techniques as they contribute to GGOS. The following sessions were held: Session 1: Products by the Services, Filling the GGOS Portal; Session 2: Modelling Based on External Data (Atmosphere, Ocean, ...), Modelling Deficiencies and Standards; Session 3: ITRF 20xx and Other Combined Products; Session 4: Co-location on Ground and in Space, GGOS Core Sites.
- *GGFC Workshop (Vienna, Austria, 20 April 2012)*. The meeting focused on assessing the errors in current environmental models and proposals for overcoming these limitations for use in geodetic and geophysical data analysis. 10 recommendations were formulated (combining the various products for atmospheric and hydrologic models).
- *IERS Workshop on Local Surveys and Co-locations (Paris, France, 21 – 22 May 2013)*. This second workshop on local ties, tie vectors, co-location sites and their use in the combination of space geodetic solutions provided a platform for discussion and diffusion of the most recent results. Particular emphasis was put on the systematic errors that affect both the space geodetic and the tie vector solutions, these latter being key elements to improve ITRF accuracy. A list of recommendations has been drafted, e.g. a local survey archive is planned.
- *IERS Retreat (Paris, France, 23 – 24 May 2013)*. The aim of the retreat was to establish directions for the IERS over next decade that will ensure its core role is met. The overall theme was to maintain the quality and regularity of the IERS' products and to ensure that the service continues to meet the needs of all of its users. The retreat covered the following sessions: Session 1: Towards "real-time" products; Session 2: Rigorous combined products; Session 3: Long-term stability and parameterization of the reference frame; Session 5: EOP predictions improvements; Session 6: Unification of product formats; Sessions 4+7: New products and mechanisms for IERS evolution.

Abstracts and presentations of these meetings are available at the IERS web site.

## Activities of the IERS components

### *Central components*

The *IERS Directing Board* (DB) met twice each year to decide on important matters of the Service like structural changes, overall strategy, creating working groups, launching projects, changing Terms of Reference, etc:

- Meeting No. 53 in San Francisco, December 3, 2011;
- No. 54 in Vienna, April 22, 2012;
- No. 55 in San Francisco, December 1, 2012;
- No. 56 in Paris, May 25, 2013.

Among the most important decisions made by the DB in 2011–2013 were the following:

- Accepted the provisional geophysical fluids products as operational ones.
- Approved the activity to establish a “survey operational entity” within the ITRS Centre.
- Agreed to establish IERS Working Groups on SINEX Format and on Site Coordinate Time Series Format.
- Accepted JPL as new ITRS Combination Centre.
- Elected a new Chair of the Directing Board.

The *Central Bureau* coordinated the work of the Directing Board and the IERS in general, organized meetings and issued publications. It replied to questions of users regarding IERS products and general topics of Earth rotation and reference systems. It further developed the IERS Data and Information System based on modern technologies for internet-based exchange of data and information like the application of the Extensible Markup Language (XML) and the generation and administration of ISO standardised metadata. The system provides general information on the structure and the components of the IERS and gives access to all products. For most IERS products, metadata according to ISO 19115 were produced. The move to a new data management system of retrieval, check, metadata extraction, format conversions, storage, and presentation was finished in May 2013.

The work of the *Analysis Coordinator* focused on preparing the Third GGOS Unified Analysis Workshop and the IERS Retreat (see above). He analysed the current state of EOP products and proposed to establish a unified EOP data format.

### *Technique Centres*

The Technique Centres are autonomous independent services, which cooperate with the IERS:

- *International GNSS Service* (IGS)
- *International Laser Ranging Service* (ILRS)
- *International VLBI Service for Geodesy and Astrometry* (IVS)
- *International DORIS Service* (IDS)

For the work of the Technique Centres, see their individual reports to IAG.

### *Product Centres*

The *Earth Orientation Centre* is responsible for monitoring of long-term earth orientation parameters, publications for time dissemination and leap second announcements. It issues IERS Bulletins B, C, and D and corresponding data files. Since December 2011, only final values of the C04 EOP series values are provided. The generation of C04 series has been made fully automated with daily quality checks and comparisons. EOPs are now available also in XML format.

The *Rapid Service/Prediction Centre* is responsible for providing Earth orientation parameters on a rapid turnaround basis, primarily for real-time-users and others needing the highest quality EOP information before the IERS final values are available. It issues IERS Bulletin A and corresponding data files. Further work has been dedicated to improvement of the centre's products. Since 2012, a new solution of ultra rapids is available 4 times per day. The short-term UT1–UTC predictions improved by nearly 25% since 2010 because of the reduced latency of VLBI intensive operations due to the electronic transfer of VLBI data. A backup of the EOP Combination and Prediction procedure, including web site for disseminating data, has been established at an offsite location.

The *Conventions Centre* started work on technical updates to the IERS Conventions (2010), with updates of existing content, expansion of models, and introducing new topics (non-tidal loading, SINEX format for modelling, ...). The Centre maintains a web site including pages for the Conventions updates.

Involvement by *ICRS Centre* personnel in the celestial reference frame VLBI program has continued, participating in extensive observing programmes. The ICRS Centre has continued the various tasks devoted to the monitoring of ICRF sources, the link with the dynamical system (through LLR, pulsar timing, and observations of asteroids), the construction of the LQAC (Large Quasar Astrometric Catalogue) and of the LQRF (Large Quasar Reference Frame). Together with the new IAU Division 1 Working Group on ICRF3, the ICRS Centre started work to prepare the next ICRF, which is expected to be finished by 2018.

The *ITRS Centre* participated in complete surveys of some co-location sites, contributed to specifications for ITRF densification, developed the tools and methodology for generating the ITRF from SINEX inputs from the various space geodesy techniques (in cooperation with the ITRS Combination Centres), and maintained the IERS network. In March 2013, the ITRS Centre issued a Call for Participation in ITRF2013. The IERS Directing Board approved the activity to establish a “Survey operational entity” within the ITRS Centre; its mission would be to supply local tie data and products as well as recommendations to surveyors and users. The ITRF web site has been newly designed and improved.

The *Global Geophysical Fluids Centre* (GGFC) has been re-organized since 2010. It consists now of four Special Bureaus for Oceans, Hydrology, Atmosphere, and Combination. The first product centres were recognized. The IERS Directing Board accepted the provisional geophysical fluids products as operational ones. An additional call for new products and for the Chair of Science Support Component was distributed in 2012. Several new products have been proposed and are now evaluated for latency and reliability until 2014. Together with the ITRS Centre, the GGFC issued a call for participation concerning tidal and non-tidal loading studies in 2012. It organized a GGFC workshop in April 2012 in Vienna (see above).

### *ITRS Combination Centres and Working Groups*

Three *ITRS Combination Centres* are responsible for providing ITRF products by combining ITRF inputs. The ITRS Combination Centre at DGFI focused on research regarding a common realization of the ITRS and ICRS. It realized for the first time the ITRS and the ICRS consistently in one common adjustment. The IERS Directing Board accepted JPL as new ITRS Combination Centre in December 2012.

Areas of work of the *Working Group on Site Survey and Co-location* are standards and documentation (guidelines, survey reports, etc.), coordination (share know-how and join efforts between survey teams), research (investigate discrepancies between space geodesy and tie vectors, alignment of tie vectors into a global frame), and cooperation. It was re-organized in 2012. The WG held a workshop in May 2013 (see above).

The major task of the *Working Group on Combination at the Observation Level* is to study methods and advantages of combining techniques at the observation level, searching for an optimal strategy to solve for geodetic parameters. The first action of the WG was to organize an inter-comparison campaign in order to homogenize the software packages used. The period chosen was the one corresponding to the three weeks of the CONT08 VLBI campaign. The combination has been performed for common parameters: station coordinates, Earth Orientation Parameters, orbit parameters and troposphere parameters. The multi-technique approach gives the opportunity to compare in a coherent way the solutions obtained from various techniques. This was demonstrated for the case of ZTD. Homogenized processing of CONT08 and CONT11 campaigns solving all parameters together are in progress; a long-term combination is expected to be submitted in the ITRF2013 framework. The working group maintains an online “Forum Multi-technique Combinations”.

The *Working Group on SINEX Format*, established in 2011, has been working on modifications in the SATELLITE/ID block and revision of Appendix II (mathematical background), as well as on other topics.

The objectives of the new *Working Group on Site Coordinate Time Series Format*, a joint WG of IERS and IAG, are a user-friendly format with data and metadata by definition of a common exchange format for coordinate time series for all geodetic techniques (DORIS, GNSS, SLR, VLBI) with all necessary information (data and metadata). The goal is to access products via web interfaces.

All working groups held several meetings, summaries and presentations of which are available at the IERS web site.

## **International Geoid Service (IGeS)**

<http://www.iges.polimi.it>

*President and Director: Riccardo Barzaghi (Italy)*

### **Overview**

In the period 2011-2013, the main scientific activities of IGeS have been related to the following research lines:

- methods for merging local geoid estimates;
- methods for defining a global height datum;
- support to research centres and national institutions on geoid estimation;
- organization of schools on geoid and height datum estimation;
- IGeS web site update.

High accuracy and reliable satellite based global geopotential models can be used either to merge local geoid solutions and to properly define a unified global height datum. This second issue is particularly relevant and is one of the GGOS themes (i.e. Theme 1: Unified Height System). Both problems are strictly related to the IGeS mission that is focussed on local/regional geoid estimation and evaluation.

The new methodologies that were developed for merging local geoids and for defining a global height datum are based on space-wise GOCE global geopotential model.

The procedure for merging geoids assumes that a bias exists between local estimates due to inconsistencies in defining the local height datum. By comparing these solutions with the GOCE derived model, this bias can be estimated and removed. The global height datum definition method which has been devised relies on GOCE geopotential model too. As for the method used in combining local geoids, height datum biases are assumed among areas covering the whole Earth. It can be proved that they can be estimated using a fully satellite derived global geopotential model which is not affected by these biases. Some numerical tests were performed on both methodologies and the results were presented at the EGU General Assembly 2012.

Furthermore, the support activity on geoid computation continued. IGeS has co-operated with the Centre for Geodesy and Geodynamics of Nigeria. Four researches of this Centre were hosted at IGeS in 2011 for two weeks. They attended a dedicated training course on geoid estimation theory and geoid estimation software. IGeS was also supporting the computation of the geoid in the San Paolo state in Brazil by hosting for one year (September 2011 to August 2012) a USP PhD student. A new geoid school was also organized during 2012. This school will be held in October 7th-11th, 2013 at the Universidad Tecnica Particular de Loja in Loja, Ecuador. This school will be devoted to geoid estimation and height datum definition. Contacts were also established with the International Centre for Theoretical Physics (ICTP) in Trieste (Italy) and with the Benha University in Cairo (Egypt) for organizing geoid schools in 2014. These two schools, if organized, will be important for involving in the geodetic community new researchers from Africa. Due to its location, the Cairo school will be possibly attended by a large number of people coming from Africa and Middle East. The same could be for the school at ICTP in Trieste because travelling supports and grants are expected from



this institution (as a matter of facts, one of the missions of ICTP is to support scientific activities in developing countries).

Finally, in 2012, IGeS web site has been totally renewed and the local geoid solution database has been improved by adding new local solutions.

## Activities

### 1. A method for merging local geoid estimates

Local geoid estimated in neighbouring countries often display inconsistency that can be mainly described by biases between the local solutions. Sometimes, it is required to define a unique solution merging two different geoid estimates thus removing the local biases. This can be properly done by using satellite only models that are not perturbed by local datum effects entering in the local geoid estimates. A two steps procedure has been devised based on GOCE geopotential model assuming that the residuals in geoid after removing the GOCE model can be represented as

$$N_{res} = N - N_L = b + N_H + e_{GOCE} + v$$

where  $b$  is the bias related to the local solution,  $N_L$  is the low frequency geoid component (the one that is assumed to be described by the GOCE model),  $N_H$  is the high frequency geoid component,  $e_{GOCE}$  is the GOCE model error and  $v$  is the noise implied by the local geoid estimate. In the first step, by least squares, one can get the bias estimate as

$$b = (D^T Q^{-1} D)^{-1} D^T Q^{-1} N_{res}$$

with

$$Q = C_{N_H} + C_{e_{GOCE}} + C_v$$

This bias is then removed from  $N$  thus computing an unbiased geoid, i.e.

$$N'_{res} = N - N_L - b$$

This is done for the two geoid estimates to be merged. Then the two unbiased estimates can be combined via a standard collocation procedure to get a common geoid over the computation area. The final merged solution is then obtained by adding back the  $N_L$  component implied by the GOCE model. This procedure has been tested by merging the Swiss and the Italian geoids. In Figure 1 a North-South section is plotted: the effectiveness of the procedure is clearly visible.

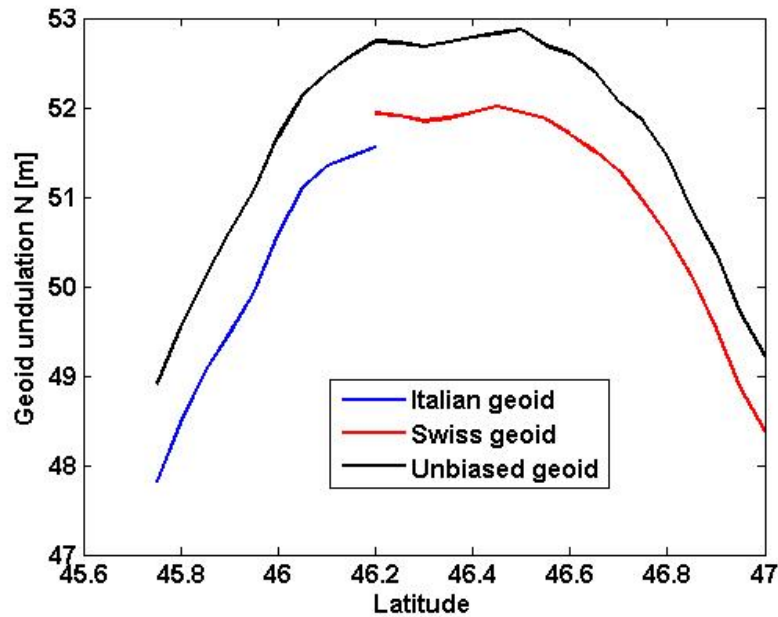


Figure 1: Merging the Italian and the Swiss geoid

This method has been described in the paper “A least-squares collocation procedure to merge local geoids with the aid of satellite-only gravity models: the Italian/Swiss geoids case study”, by Gilardoni, Reguzzoni and Sampietro, which has been accepted for publication on *Bollettino di Geofisica Teorica ed Applicata* in 2013.

## 2. A method for global height datum estimation

The height datum problem has been revised in terms of the scalar Molodensky approach. It has been assumed that different height systems refer to their own benchmarks. So, the earth surface can be patched into domains having different reference height systems. For each patch, a bias in the gravity potential is assumed, so that it holds

$$W(P_0^j) = W_0^j = W_0 + \delta W^j = U_0 + \delta W^j$$

where the patch  $S^j$  is referred to the benchmark point  $P_0^j$ . By developing this equation, one can get

$$\bar{\zeta}^j = -\frac{\delta W^j}{\gamma} = \tilde{\zeta}(P_1^j) - \frac{T(P_1^j)}{\gamma} = \tilde{\zeta}(P_1^j) - \frac{T_L(P_1^j)}{\gamma} - \frac{T_H(P_1^j)}{\gamma} \quad l=1, \dots, M \quad j=1, \dots, J$$

In this equation, the height anomaly biases  $\bar{\zeta}^j$  of the different patches can be estimated using the observed (biased) height anomalies ( $P_1^j$  earth surface point,  $\tilde{P}_1^j$  point on the biased telluroids)

$$\tilde{\zeta}(P_1^j) = h(P_1^j) - h(\tilde{P}_1^j) \quad l=1, \dots, M$$

and the anomalous potential estimate

$$T(P) = T_L(P) + T_H(P) = \sum_{n=2}^{200} \sum_{m=-n}^n T_{nm} Y_{nm}(P) + \sum_{n=201}^{+\infty} \sum_{m=-n}^n T_{nm} Y_{nm}(P)$$

Here the  $T_L$  component (the low frequency part) is given by the unbiased GOCE only model while the  $T_H$  component (the high frequency part) is assumed to be accounted for by the EGM2008 model up to  $n=2160$  (indeed this component is biased by the height datum but it can be proved that the induced error is of few millimetre).

Using this approach, an error budget has been performed. The earth surface has been divided into 158 patches and a data distribution has been assumed in order to have at least one point per patch. Also, different precisions for ellipsoidal and normal heights have been considered on the different patches. Assuming to estimate the  $\delta W^j$  by least squares, their standard deviation can be obtained. In Figure 2, the bias standard deviations are plotted.

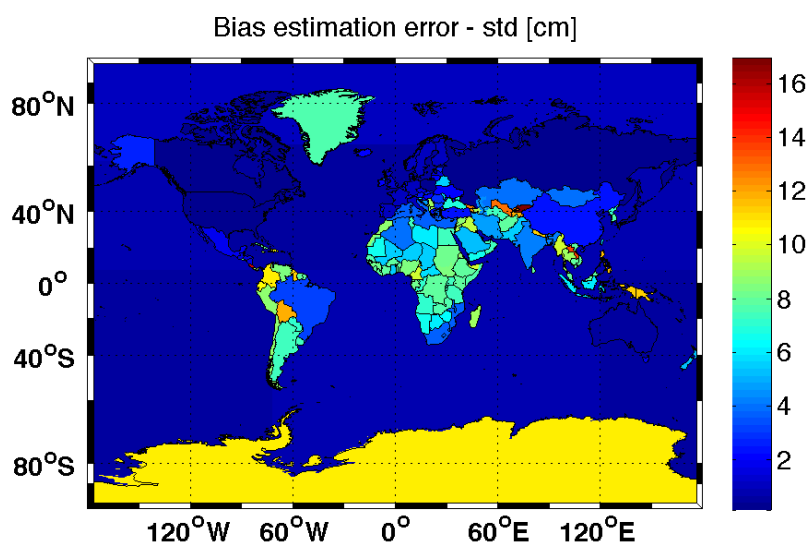


Figure 2: The  $\delta W^j$  standard deviations

The standard deviation values range from 1-2 cm up to 15 cm in limited areas of the earth. This procedure seems to be feasible and will be applied in the near future to local/regional areas, such as the whole Europe, to estimate a unified height system.

### 3. The support to researches and activities on geoid estimation

In spring 2011, from May 30th to June 14th, four researchers of the Centre of Geodesy and Geodynamics (National Space Resource and Development Agency, Nigeria) attended at IGeS a Special Course on Determination and Use of the Geoid. Every day, there were lectures for two or three hours. The rest of the day was devoted to individual learning with tutoring and to practice on geoid computation software using the computer facilities at IGeS. The detailed program is listed below:

May 30th	Basic concepts in geodesy and geoid computation
May 31st	Study of Lecture Notes with tutoring
June 1st	Global Models
June 6th; morning:	Terrain effect in geoid computation
June 6th; afternoon:	Residual Terrain Correction
June 7th	Practical examples on Terrain Effect computation
June 8th morning:	The core solution: theory of Collocation

June 8th afternoon:	The core solution: Stokes and FFT
June 9th	Practical examples on core solution computation
June 10th	Local geoid computation: review of all the steps
June 13th	Comparison of residual undulation computation methods
June 14th	Practical examples on geoid computation

The aim of this special course was, as requested from the researchers of the Centre of Geodesy and Geodynamics, to have an intensive training on geoid estimation allowing them to have the basic notions for estimating their own national geoid based on the available data in Nigeria. Contacts between them and IGeS have been frequent since this course.

In 2012, one PhD student from USP, San Paulo, Brazil, was hosted at IGeS in the framework of a co-operation between the two Institutions. He was involved in a project aiming at estimating the geoid in the San Paulo State. During his stay at IGeS, he was trained in geoid estimation procedure based on collocation and the “remove-restore” method. In order to estimate the RTC effect, a detailed DTM/bathymetry model was set up. This has been accomplished by merging the SRTM DTM with the available NOAA bathymetry of the Atlantic Ocean in the computation area. A check for possible outliers both in the gravity and in the GPS/levelling databases to be used in the geoid estimation process was also performed. Different global geopotential models (including those based on GOCE data) were tested to check for their impact on the estimate. The final geoid estimate based on collocation has been then compared to GPS/levelling data and previous geoid computations obtained with different methods (i.e. Helmert-Stokes). The collocation estimated geoid proved to be equivalent to the existing ones and close to the GPS/levelling independent data. Statistics related to this comparison are detailed in Table 1.

Table 1: San Paulo geoid statistics. Residuals between geoid estimates and GPS/levelling (363 points)

Geoid Model	E(m)	R.m.s. (m)	Max. (m)	Min. (m)
FFT(EGM2008-360)	0.13	0.23	0.58	-0.41
LSC(EGM2008-360)	0.16	0.25	0.72	-0.47
FFT(GOCE-DIR_R3)	0.11	0.21	0.49	-0.44
LSC(GOCE-DIR_R3)	0.09	0.20	0.56	-0.50
FFT(GOCE-TIM_R3)	0.11	0.22	0.51	-0.43
LSC(GOCE-TIM_R3)	0.09	0.20	0.58	-0.47
FFT(GOCO03S)	0.12	0.22	0.51	-0.43
LSC(GOCO03S)	0.09	0.20	0.54	-0.47
FFT(EIGEN-6C)	0.11	0.22	0.51	-0.45
LSC(EIGEN-6C)	0.09	0.20	0.51	-0.49

The geoid estimate based on Least Squares Collocation is displayed in Figure 3

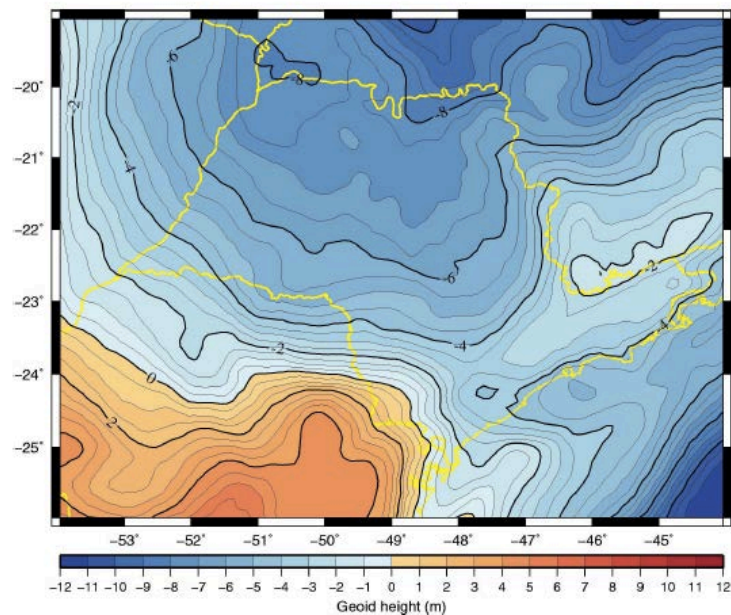


Figure 3: San Paulo geoid estimate using LSC

#### 4. The organization of schools on geoid and height datum estimation

A new school on geoid computation and height datum definition has been organized in Ecuador. This school will be held in October 7th-11th, 2013 at the Universidad Tecnica Particular de Loja in Loja and will be quite different with respect to the previous geoid schools. Besides the standard methods on geoid computation new items on height systems will be taught. The draft program has been set up and it is listed in the following

##### *Heights, height datum and Boundary Value Problems*

Definition of ellipsoidal, dynamical and orthometric heights and their observation equations; geoid and telluroid; the GBVP, reduction to the ellipsoid, mapping to the sphere, spherical harmonics.

##### *Global geopotential models and their use*

Creation of a Global Geopotential Model; computation of different functional; exercises on Global Models .

##### *Modelling the topographic effect*

Terrain Correction, Helmert reduction; from TC to Residual TC

##### *Local improvements of the geoid*

Remove-Restore method; Collocation; Geoid computation using FFT; Exercises on local geoid computation

##### *Height datum unification*

Modelling and estimation of offsets

## Vertical Datum Standardization

Vertical Datum establishment, standardization and unification : the South American case.

According to the present day registrations, more than thirty students will attend the school. The teachers of this school are: F. Sansò, N. Pavlis, D. Blitzkow, R. Barzaghi, M. Sideris and L. Sanchez.

Also, new forthcoming schools are going to be organized in Trieste and/or in Cairo. As already underlined, these schools will be particularly devoted to Africa with the aim of improving researches on physical geodesy in this continent.

## 5. The new IGeS website

During 2012, the IGeS website has been completely revised and improved. The geoid repository has been enriched with new local solutions, namely the Switzerland, the French, the new European EGG2008 and the US geoids. As usual, these geoid estimates can be downloaded from the web site according to a defined policy. Geoids can be freely available if coded as public, available on demand in case the authors asked to be informed before made them available, private if the geoid owners decided not to distribute them.

In the new web page, the IGeS Bulletins' archive has been made available. Any single issue can be downloaded directly from the web page. Also, the Newton's Bulletin issue are now available on line. In this case, both the full issue or single papers of the issue can be downloaded. The new IGeS web page is shown in Figure 4.

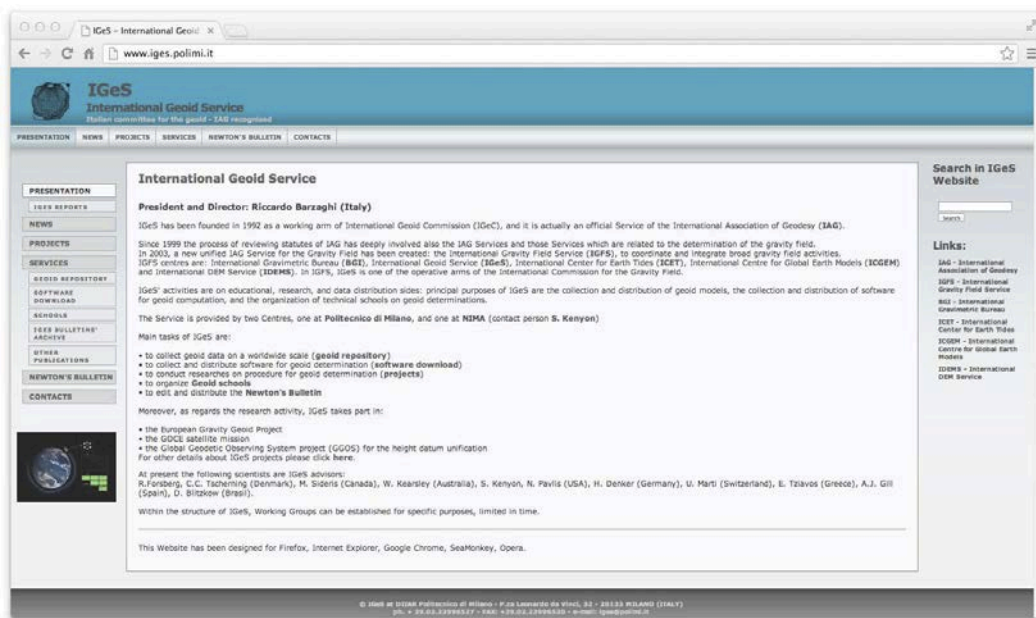


Figure 4: The new IGeS web page

## **International GNSS Service (IGS)**

<http://www.igs.org>

*Chair of the Governing Board: Urs Hugentobler (Germany)*  
*Director of the Central Bureau: Ruth Neilan (USA)*

### **Mission**

The IGS mission is to provide the highest-quality GNSS data, products, and services in support of the terrestrial reference frame, Earth observations and research, Positioning, Navigation and Timing (PNT), and other applications that benefit the scientific community and society.

### **Overview**

The IGS has continued to support scientific and other GNSS users through the 2011-2013 reporting period. The IGS provides essential products that both contribute to the realization of ITRF and enable very high accuracy positioning using GNSS technologies for scientific and a wide variety of other uses. IGS continues to refine the accuracy and consistency of its products by an ongoing process of both technique improvement and reprocessing of past data sets in order to achieve the highest quality results.

Rapidly forward moving technology has challenged the IGS in recent years. In particular, availability of new GNSSs and emerging real-time applications are driving a rapid modernization of the IGS infrastructure. Re-tooling of capabilities as well as extending relevant standards to handle the new signals have been key topics garnering significant attention within IGS.

In addition to many technical achievements, the IGS has taken proactive steps to further develop the IGS organization and improve its management. A comprehensive strategic planning process was undertaken in 2012, beginning with evaluating performance on the previous strategic plan and ending with redefining the IGS goals and objectives for the next four years. The resulting 2013-16 Strategic Plan is available for download in the publications section of the IGS website. The IGS Terms of Reference, as well as the associate members have been reviewed annually by the Governing Board and relevant committees since 2011. All current IGS organizational documents and committee/working group membership rosters are maintained on the organization section of the IGS website.

### **Events and Milestones**

Many milestones and significant events that occurred within IGS since 2011 are listed in Table 1.

The 2011-2013 period was highlighted by the June 2012 IGS Workshop in Olsztyn, Poland, which was attended by about 230 participants from around the world. A wide range of activities and projects were presented and discussed in all areas of IGS. The International Committee on GNSS working Group on GNSS Interoperability was held in conjunction with the IGS

Workshop, and included a joint session where the GNSS providers provided status updates to IGS.

The IGS has maintained a busy schedule, including reaching out to related groups of stakeholders by broadly participating in events and programs organized by organizations such as GGOS, FIG, ICSU/WDS, EGU, AGU, RTCM, COSPAR, ION, and others. In addition, the GGOS Executive Committee is co-chaired by IGS; and IGS shares reciprocal representation with IERS on each other's Boards.

Important milestones were reached on all of the IGS working groups and projects. Notably, the RINEX Working Group was established, and the MGEX Project and Real-time Service were launched.

More detailed information about the topics summarized herein can be found in the 2011 and 2012 IGS Technical Reports, which are available for download in the publications section of the IGS website.

Table 1: IGS Events and Milestones: Mid-2011 to Mid-2013

2011	First Reprocessing Campaign finalized (Repro1)
	Migration of IGS Time Scale generation to version 2.0 algorithm
	IGS08 Reference Frame introduced
	New antenna model introduced (igs08.atx)
	Uncalibrated Radome Experiment initiated
	Technical Report process re-introduced by AIUB
	39th GB Meeting in San Francisco (AGU)
2012	IGS Workshop on GNSS Biases, Bern, Switzerland
	Multi-GNSS Global Experiment initiated (M-GEX)
	GB Business Meeting in Vienna (EGU)
	40th GB Meeting and post Workshop Wrap-up Meeting in Olsztyn, Poland
	IGS Workshop in Olsztyn, Poland (joint Meeting with ICG WG-A "Compatibility and Interoperability")
	RINEX Working Group formed
	New Analysis Center, Wuhan University, China
	All Working Group Charters and memberships reviewed
	ACC2.0 development plan initiated
	IGS co-chairs IGMAS task force within ICG
	41st GB Meeting in San Francisco (AGU)
2013	Second Reprocessing Campaign initiated (Repro2)
	GB Business Meeting in Vienna (EGU)
	Revised Site Guidelines published
	Real-time Beta Service in introduced
	2008-12 Progress Assessment and Report Completed
	2013-17 Strategic Plan adopted
	IGS Associate membership reviewed



## **Publications, Presentations, Outreach**

Principal IGS publications since 2011 include the following, which are available for download from the publications or mail sections of the IGS website:

- 2007-2012 Progress Report: assesses performance in achieving the
- 2013-17 Strategic Plan: sets five year direction for IGS
- 2013 IGS Site Guidelines: updates IGS site and network related best practices
- 2011 and 2012 Technical Reports: documents detailed progress of all the IGS components, reported annually
- IGS Analysis and Product Reports: data analysis and product reports are routinely submitted through IGS mail lists
- Special IGS issue of the Journal of Geodesy: (see <http://www.springerlink.com/content/0949-7714/83/3-4/>)

Selected list of presentations at international meetings:

- PPP-RTK Symposium, March 2012 Frankfurt/Main, U. Hugentobler, "From GPS to GNSS – Challenges and Prospects"
- FIG Working Week, May 2012, Rome, R. Neilan, "The IGS in Support of Science and Society – new Roles, New Challenges, New Products"
- 3rd China Satellite Navigation Conference, May 2012, Guangzhou, C. Rizos, "The IGS in the Multi-GNSS Era: New Roles, New Products, New Challenges"
- Asia Oceania Geoscience Society, August 2012, C. Rizos, R. Neilan, "New Roles, New Challenges and New Products for the International GNSS Service (IGS) "
- 3rd Colloquium Galileo Science, August 2012, Copenhagen, R. Weber "The IGS Multi-GNSS Global Experiment"
- INTERGEO, October 2012, Hannover, C. Rizos, "The International GNSS Service (IGS): Supporting the Geospatial Industry"
- ICG-7, November 2012, Beijing, C. Rizos, "The IGS: A Multi-GNSS Service"
- EGU April 2013, M Caissy, et. al. "The IGS Real-time Service"
- Ottawa PPP Workshop, June 2013, M. Caissy, et. al. "The IGS Real-Time Service – Meeting the Needs of the IGS Real-Time PPP User Community"
- US PNT Advisory Board Meeting, June 2013, M. Caissy, IGS RTS briefing

Articles

- Caissy, M., L. Agrotis, G. Weber, M. Hernandez-Pajares, U. Hugentobler: "Coming Soon: The IGS Real-Time Service", GPS World, June 2012.
- Rebischung, P., J. Griffiths, J. Ray, R. Schmid, X. Collilieux, B. Garayt "IGS08: the IGS realization of ITRF2008", GPS Solutions 16(4), 483-494.
- Rizos, C.: "GNSS Service Analysis Workshop Held in Poland", GIM International Magazine, November 2012.
- Weber, R., U. Hugentobler, R. Neilan: "IGS M-GEX – The IGS Multi-GNSS Global Experiment", Proceedings of the 3rd International Colloquium on Scientific and Fundamental Aspects of the Galileo Program.

In addition, numerous publications have referenced IGS since 2011. A current list of citations is publicly available in the publications section of the IGS website.

## IGS Structure

The IGS is a self-governed federation of 216 organizations from around the world that collectively operate a global infrastructure of tracking stations, data centres and analysis centres to provide high quality Global Navigation Satellite System (GNSS) data products. The IGS products are provided openly for the benefit of all scientific, educational, and commercial users. The IGS is governed by an international Governing Board (Table 2) that is elected by designated Associate Members who represent the principal IGS participants. Executive management of the IGS is carried out by the Central Bureau, as is coordination of the IGS Tracking Network and management of the IGS web portal that provides centralized access to IGS products and information. IGS products are generated by combining results from different Analysis Centres under the direction of the Analysis Coordinator and specific Product Coordinators. Introduction of new products and specific technical issues are addressed through Pilot Projects and Working Groups of technical experts (Table 3). The IGS organization is depicted in figure 1.

Table 2: IGS Governing Board Members

Name	Affiliation	Role
Zuheir Altamimi	<i>Institut National de l'Information Géographique et Forestière, France</i>	IAG Representative
Felicitas Arias	<i>Bureau International des Poids et Mesures, France</i>	BIPM/CCTF Representative
Claude Boucher	<i>Institut National de l'Information Géographique et Forestière, France</i>	IERS Representative to IGS
Carine Bruyninx	<i>Royal Observatory of Belgium, Observatoire Royal de Belgique (ORB), Belgium</i>	IGS Network Representative
Mark Caissy	<i>Natural Resources Canada / Ressources naturelles Canada</i>	Real-time Working Group, Chair
Yamin Dang	<i>Chinese Academy of Surveying and Mapping, Beijing</i>	Appointed (IGS)
Shailen Desai	<i>Jet Propulsion Laboratory, USA</i>	Analysis Center Representative
Steven Fisher	<i>IGS Central Bureau, Jet Propulsion Laboratory, USA</i>	IGS Central Bureau, Secretariat
Bruno Garayt	<i>Institut National de l'Information Géographique et Forestière, France</i>	IGS Reference Frame Coordinator
Jake Griffiths	<i>NOAA, National Geodetic Survey, USA</i>	Analysis Center Coordinator
Christine Hackman	<i>United States Naval Observatory, USA</i>	Troposphere Working Group, Chair
Urs Hugentobler <sup>EC</sup>	<i>Technische Universität München, Germany</i>	Board Chair, Analysis Center Representative
Gary Johnston	<i>Geoscience Australia</i>	Network Representative
Andrzej Krankowski	<i>University of Warmia and Mazury in Olsztyn, Poland</i>	Ionosphere Working Group, Chair
Ken MacLeod	<i>Natural Resources Canada / Ressources naturelles Canada</i>	RINEX-RTCM Working Group, Chair

Charles Meertens <sup>EC</sup>	<i>UNAVCO, USA</i>	Appointed (IGS)
Oliver Montenbruck	<i>Deutsches Zentrum für Luft- und Raumfahrt e. V., Germany</i>	GNSS Working Group, Chair
Ruth Neilan <sup>EC</sup>	<i>IGS Central Bureau, Jet Propulsion Laboratory, USA</i>	Director of IGS Central Bureau
Carey Noll	<i>NASA Goddard Space Flight Center, USA</i>	Data Center Representative, Data Center Working Group, Chair
James Park	<i>Korean Astronomy and Space Science Institute, South Korea</i>	Appointed, IGS
Chris Rizos <sup>EC</sup>	<i>University of New South Wales, Australia</i>	President of IAG
Ignacio Romero	<i>ESA/European Space Operations Centre, Germany</i>	Infrastructure Committee, Chair
Stefan Schaer	<i>Federal Office of Topography, Switzerland</i>	Calibration & Bias Working Group, Chair
Ralf Schmid	<i>Deutsches Geodätisches Forschungsinstitut, Germany</i>	Antenna Working Group, Chair
Tilo Schöne	<i>Deutsches GeoForschungsZentrum Potsdam, Germany</i>	TIGA Working Group, Chair
Ken Senior	<i>Naval Research Laboratory, USA</i>	IGS Clock Products Coordinator
Tim Springer <sup>EC</sup>	<i>ESA/European Space Operations Center, Germany</i>	Analysis Center Representative
Richard Wonnacott	<i>Chief Directorate: National Geo-spatial Information, South Africa</i>	Appointed (IGS)
Marek Ziebart	<i>University College London, UK</i>	Satellite Vehicle Orbit Dynamics Working Group, Chair

Table 3: IGS Projects and Working Groups

Project or Working Group	Purpose
Tide Gauge Benchmark Monitoring Project –TIGA	Monitor long-term sea-level change, attempt to de-couple crustal motion/subsidence at coastal sites from their tide gauge records
Real-Time WG/RT Service	Demonstrate for IGS real-time network and applications
Reference Frame WG	Global reference frame, Earth orientation, station positions and velocities determined by GPS
Ionosphere WG	Ionospheric science research, global ionospheric maps
Clock Products WG	Global sub-nanosecond time transfer, and IGS time-scale, jointly with the Bureau International des Poids et Mesures (BIPM)
Troposphere WG	Estimate water vapor in atmosphere from the GPS signal delay
Global Navigation Satellite Systems WG/ MGEX Project	Determine actions necessary for IGS to co-opt new GNSS systems, European Union Galileo system, China's COMPASS, and GPS modernization
Data Center WG	Coordination among IGS data centres and support for increasing number of products and real-time.
Calibration and Bias WG	Update various values for consistent analysis processing, e.g., differential code biases, cc2nocc, etc.
Antenna WG	Coordinates research in the field of GNSS receiver and satellite antenna phase centre determination.
Space Vehicle Orbit Dynamics WG	Improved understanding and modeling of satellite dynamics towards further improvement of precise orbit determination.

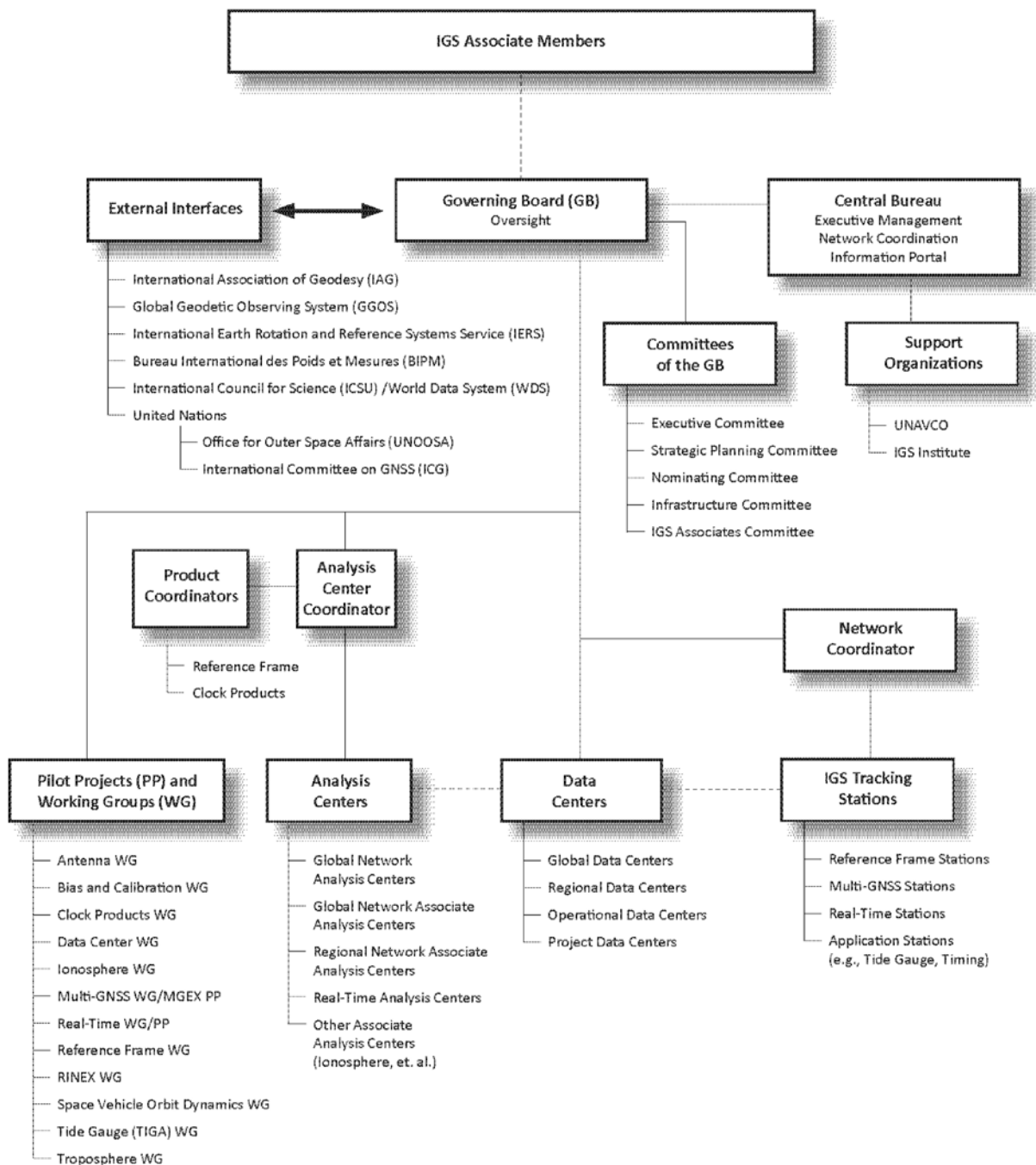


Figure 1: IGS Structure and Association with International Scientific Organizations, as of 2012

## Activities

### Operational Activities

Approximately 440 stations are maintained and operated globally by many institutions and station operators, making tracking data available at latencies ranging from daily RINEX files to real-time streams available for free public use (Figure 2). The Central Bureau assumes responsibility for day-to-day management, interaction with station operators, and answering



Table 4: IGS Product Quality and Availability

**IGS Quality of Service**

The IGS continuously monitors the accuracy of its products through intercomparison of results between Analysis Centers. IGS strives to deliver its products on a highly available basis as shown below. Due to the volunteer nature of IGS, availability of products is not guaranteed.

GPS Satellite Ephemerides / Satellite and Station Clocks		Sample Interval	Accuracy	Latency	Continuity	Availability
Broadcast (for comparison)	Orbits	1 s	~100 cm	real time	Continuous	99.99%
	Sat. Clocks		~5 ns RMS; ~2.5 ns Sdev			
Ultra-Rapid (predicted half)	Orbits	15 min	~5 cm	predicted	4x daily, at 03, 09, 15, 21 UTC	95%
	Sat. Clocks		~3 ns RMS; ~1.5 Sdev			
Ultra-Rapid (observed half)	Orbits	15 min	~3 cm	3-9 hours	4x daily, at 03, 09, 15, 21 UTC	95%
	Sat. Clocks		~150 ps RMS; ~50 ps Sdev			
Rapid	Orbits	15 min	~2.5 cm	17-41 hours	daily, at 17 UTC	95%
	Sat. & Stn. Clocks	5 min	~75 ps RMS; ~25 ps Sdev			
Final	Orbits	15 min	~2 cm	12-18 days	weekly, every Thursday	99%
	Sat. & Stn. Clocks	Sat: 30 s; Stn.: 5 min	75 ps RMS; 20 ps Sdev			
Real-time	Orbits	5-60 s	~5 cm	25 seconds	Continuous	95%
	Sat. Clocks	5 s	300 ps RMS; 120 ps Sdev			

**Note 1:** Orbit accuracies are 1D mean RMS values over the three XYZ geocentric components. IGS accuracy limits, except for predicted orbits, are based on comparisons with independent laser ranging results and discontinuities between consecutive days. The precision is better.

**Note 2:** The accuracy (neglecting any contributions from internal instrumental delays, which must be calibrated separately) of all clocks is expressed relative to the IGS timescale, which is linearly aligned to GPS time in one-day segments. The standard deviation (Sdev) values are computed by removing a separate bias for each satellite and station clock, whereas this is not done for the RMS values.

**Note 3:** Availability :percentage of time that accuracy and continuity of service meet stated specification.

GLONASS Satellite Ephemerides	Sample Interval	Accuracy	Latency	Continuity	Availability
Final	15 min	~3 cm	12-18 days	weekly, every Thursday	99%

Geocentric Coordinates of IGS Tracking Stations (over 250 Sites)		Sample Interval	Accuracy	Latency	Continuity	Availability
Final Positions	Horizontal	weekly	3 mm	11-17 days	weekly, every Wednesday	99%
	Vertical		6 mm			
Final Velocities	Horizontal	weekly	2 mm/yr	11-17 days	weekly, every Wednesday	99%
	Vertical		3 mm/yr			

Earth Rotation Parameters		Sample Interval	Accuracy	Latency	Continuity	Availability
Ultra-Rapid (predicted half)	Polar Motion	daily integrations at 00, 06, 12, 18 UTC	~200 μas	real time	4x daily, at 03, 09, 15, 21 UTC	99%
	Polar Motion Rate		~300 μas/day			
	Length-of-day		~50 μs			
Ultra-Rapid (observed half)	Polar Motion	daily integrations at 00, 06, 12, 18 UTC	~50 μas	3-9 hours	4x daily, at 03, 09, 15, 21 UTC	99%
	Polar Motion Rate		~250 μas/day			
	Length-of-day		~10 μs			
Rapid	Polar Motion	daily integrations at 12 UTC	~40 μas	17-41 hours	daily at 17 UTC	99%
	Polar Motion Rate		~200 μas/day			
	Length-of-day		~10 μs			
Final	Polar Motion	daily integrations at 12 UTC	0.03 mas	~11-17 days	weekly, every Wednesday	99%
	Polar Motion Rate		~150 μas/day			
	Length-of-day		0.01 μs			

**Note 1:** 100 μas = 3.1 mm of equatorial rotation; 10 μs = 4.6 mm of equatorial rotation.

**Note 2:** The IGS uses VLBI results from IERS Bulletin A to partially calibrate for LOD biases over 21-day sliding window, but residual time-correlated LOD errors remain.

Atmospheric Parameters	Sample Interval	Accuracy	Latency	Continuity	Availability
IGS Final Tropospheric Delay: zenith path delay (ZPD) plus north, east gradients	5 min	~4 mm for ZPD	~3 weeks	daily	99%
Ionosphere TEC Grid	2 hours; 5 deg (Lon.) x 2.5 deg (Lat.)	2-8 TECU	~11 days	weekly	99%
Rapid ionosphere TEC Grid	2 hours; 5 deg (Lon.) x 2.5 deg (Lat.)	2-9 TECU	<24 hours	daily	95%

## **IGS Workshop 2012**

The July 2012 IGS Workshop was hosted by Andrzej Krankowski and his team at the University of Warmia and Mazury in Olsztyn, Poland. The workshop format and program were developed by the Scientific Organizing Committee, led by Shailen Desai of JPL. About 230 participants attended. Scientific sessions covered the status and achievements of the IGS Multi-GNSS Experiment; the IGS network infrastructure and real-time activities; modeling of observations and station motions; modeling of atmosphere delays and applications; space vehicle dynamics and attitude; clock modeling and time scale realization; antenna calibration; geodetic applications of IGS products; and the relevance of the IGS for the geodetic and wider community. Jointly with the IGS Workshop, the meeting of Working Group-A, "Compatibility and Interoperability" of the International Committee on GNSS (ICG), took place providing an opportunity for interaction and exchange between IGS and system providers. The workshop presentations, posters, and recommendations can be found at <http://www.igs.org/presents/poland2012/>. The Chairman's workshop summary may be found in IGS Mail 6635.

## **Governance**

The IGS has been proactive in advancing its organization and management. Since 2011, the IGS has taken these actions, among others, to improve governance and organizational performance:

- Working group charters and membership: All working group charters and membership rosters have been reviewed for relevancy and to assure the appropriate technical experts remain involved.
- Associate membership roster: The process for selecting associate members has been reviewed and updated by the IGS Governing Board, resulting in the formation of the Associate Membership Committee. The constituency of associate members is reviewed annually.
- Performance benchmark and revised strategic plan: A comprehensive strategic planning process was undertaken in 2012, beginning with benchmarking performance on the previous strategic plan and ending with redefining the IGS goals and objectives. The resulting 2013-16 Strategic Plan is available for download in the publications section of the IGS website.

## **External Coordination and Outreach:**

The IGS coordinates extensively with many external organizations to promote the IGS and develop key partnerships with participants and users:

- International Association of Geodesy/Global Geodetic Observing System (IAG/GGOS): The IGS coordinates extensively with GGOS, including membership of the coordinating board and within the Bureau for Networks and Communications.
- United Nations/International Committee on GNSS (ICG): Working Group D on Reference Frames, Timing and Applications is co-chaired by the IGS CB Director, as is the International GNSS Monitoring and Assessment System (IGMAS) Task Force. The annual ICG Meeting is typically attended by several IGS participants.
- International Earth Rotation and Reference Systems Service (IERS): IGS and IERS have continued to extensively cooperate in the realization of ITRF, as well as reciprocally participating on each other's boards.

- Radio Technical Commission for Maritime Services, Subcommittee on Differential GNSS (RTCM-SC104): The IGS holds voting membership on this international standards organization for Differential GNSS, and chairs the RINEX WG.
- International Federation of Surveyors (FIG): FIG represents the single largest user community of IGS products, and is also a potential channel for extending the IGS network. IGS and FIG are coordinating to reach out to users, as well as to advocate for precision geodesy within organizations such as the ICG.
- Regional reference frame activities: The IGS coordinates extensively at multiple levels with regional reference frame activities, such as AFREF, SIRGAS, APREF, NAREF, and EUREF.
- Sea level activities: Through the Tide Gauge Working Group, IGS participates within the Global Sea Level Observing System (GLOSS) to precisely locate tide gauges within the ITRF.

Additionally, IGS has engaged with many user communities representing different regions and disciplines by participating in scientific workshops and conferences with presentations and chairing of sessions. Examples of conference and workshops attended include: International Council of Science/World Data System (WDS), the American Geophysical Union (AGU) and European Geosciences Union (EGU), the International Union of Geodesy and Geophysics (IUGG), the International Association of Geodesy (IAG), the Asia Oceania Geosciences Society, the U.S. Institute of Navigation, the China Satellite Navigation Conference, the Colloquium on Scientific Applications of Galileo, and others.

## **Working Group and Project Highlights**

### *IGS08 Reference Frame*

The IGS has adopted the new IGS08 reference frame, which is closely related to ITRF2008. IGS08 is based on a selected globally distributed subset of 232 well-performing ITRF2008 ground stations. Details relating to IGS08 are contained in IGSMAIL-6354 (see <http://igs.org/pipermail/igsmail/>).

### *Reprocessing Campaigns*

Results of the first IGS reprocessing campaign (Repro1) covering the period 1994-2007 were announced in April 2010 (see IGSMAIL-6136). Repro1 results served as the IGS contribution to ITRF2008, and related product files have been finalized and distributed to the IGS Global Data Centres for access by users. Details relating to the Repro1 Campaign are available online at <http://acc.igs.org/reprocess.html>. A second reprocessing campaign (Repro2) has been initiated in 2013 to include updated procedures and data since Repro1. Repro2 results will be used in the generation of ITRF2013.

### *New Ground Antenna Model Introduced*

Coincident with the IGS08 Reference Frame release, the IGS adopted a new antenna phase centre model (igs08.atx) based on updated absolute calibrations of the ground antennas. Satellite antenna phase centre offsets were readjusted to the ITRF2008 scale.



### *Multi-GNSS Global Experiment (MGEX)*

A focused Multi-GNSS experiment (MGEX) was initiated by the GNSS Working Group. MGEX was developed to establish a data set of new GNSS signals, including the new GPS signals, new Russian GLONASS signals, the Japanese QZSS, the Chinese BeiDou, and the European Union's Galileo, for experimentation. Participating stations are anticipated to eventually form the core of a multi-GNSS IGS network and service.

### *Real-time Service*

The strategy for an IGS real-time service has been developed, and an initial beta service has been launched to promote development of applications, such as natural disaster monitoring and warning, requiring low latency access to IGS products. Real-time protocols and station standards have been developed by the Real-time Pilot Project participants, working in cooperation with the Infrastructure Committee. Standards for the real-time GNSS messages are being promoted in cooperation with the Radio Technical Commission for Maritime Services, Subcommittee on Differential GNSS (RTCM-SC104), which is the principal international standards organization for real-time GNSS services. There are 188 stations and 10 analysis centres participating in the Real Time Pilot Project.

### *Infrastructure Improvements*

The Infrastructure Committee (IC) has focussed on improving the IGS network, as well as planning the changeover of the IGS infrastructure to support Multi-GNSS and real-time efforts, while maintaining integrity of core products. The IC has led efforts to revise the IGS site guidelines to promote proper practice in operating GNSS stations. The most recent revision in 2012 added new procedures for upgrading station equipment designed to minimize disruption to the IGS reference frame, as well operating standards for stations participating within the Real-time Service. The IC has also led an experiment to assess the effects of 21 IGS stations that are co-located with SLR or VLBI sites where radomes have not been calibrated to IGS standards. This will aid in mapping any discontinuities that may arise as equipment is upgraded at these stations. Analysis is currently in progress for a number of the participating stations.

### *Receiver Independent Exchange Format (RINEX)*

The RINEX Working Group has assumed leadership in maintenance and further development of the RINEX data exchange standard, in cooperation with RTCM-SC104, and has led the recent release of RINEX 3.x. The RINEX Working Group is working in cooperation with the IC to prepare a transition plan to RINEX 3.x over the next few years, as well as encouraging and supporting the development of open software tools for data handling and quality control.

### *Official Tide Gauge Product*

The IGS is now providing an official tide gauge product to GLOSS. With the introduction of an official IGS product, the TIGA project status has been elevated from pilot project to working group, thus signifying a permanent status of this effort within IGS.

### *Improved Satellite Force Models*

The Satellite Orbit and Dynamics Working Group has developed improved satellite radiation pressure models, which are available to IGS through the University College London website. These models are expected to improve the quality of the IGS orbit products once implemented by the IGS analysis centres.

### *Bias and Calibration Research*

The Bias and Calibration Working Group has been actively coordinating research activities related to bias retrieval, analysis, and monitoring. The goal of this effort is to develop procedures for consistent handling of biases between different GNSS receiver types and constellations.

### *Troposphere Product*

Coordination of IGS troposphere activities – including computation of IGS Final Troposphere Estimates and chairing the IGS Troposphere Working Group – was transferred from the NASA Jet Propulsion Laboratory (Pasadena, California, USA) to the United States Naval Observatory (Washington, DC, USA). Daily zenith path delay estimates are being generated with an approximate three-week latency for all active IGS sites, based on Precise Point Positioning techniques. IGS Final Troposphere estimates are used by scientists worldwide to support climate-change and meteorological studies, and 17.3 million estimates files were downloaded in 2012 alone.

### *Ionosphere Product*

In support of low latency users, such as potential single frequency RTS users, the Ionosphere Working Group has developed a higher temporal and spatial resolution IGS combined global ionosphere map (GIM) with a resolution of 15 min, 1 degrees and 1 degrees in time, longitude and latitude respectively. This product is currently experimentally supported by IGS as additional analysis centres develop capabilities to support this product.

### *Combination Software:*

Plans have been developed to update the IGS combination software jointly by the CODE and ESOC analysis centres, together with the Vienna University of Technology (Technische Universität Wien). This is the first major revision of this software since IGS began generating combination products in 1994. This revision is envisioned to allow for Multi-GNSS product combination and improve traceability of IGS products and maintainability of the software.

## **International Gravimetric Bureau (Bureau Gravimétrique International, BGI)**

<http://bgi.obs-mip.fr>

*Director: Sylvain Bonvalot (France)*

### **Overview**

The International Gravimetric Bureau (BGI) has been created in 1951 by the IUGG (International Union in Geophysics and Geodesy) with the aim to collect on a world-wide basis, all gravity measurements to generate a global digital database of gravity data for any public or private user. The technological and scientific evolutions which occurred over the last 50 years in the area of gravimetry (improvements in field, airborne and seaborne gravity meters, development of absolute gravity meters, space gravity missions, etc.) provided significant increases of the number, diversity and accuracy of the gravity field observables. Following these evolutions, BGI has contributed to provide original databases and services for a wide international community concerned by the studies of the Earth gravity field.

The BGI is an official service of the International Association of Geodesy (IAG) and since 2003 it is coordinated with others IAG services (IGeS, ICET, ICGEM, IDEMS) by the International Gravity Field Service (IGFS). It also directly contributes to the activities of the IAG Commission 2 “Gravity Field” and of the IAG Global Geodetic Observing System (GGOS). It is recognized by the International Council for Science (ICSU) successively as one of the services of the Federation of Astronomical and Geophysical Services (FAGS) and of the World Data System (WDS) created in 2008.

*For more information:*

- The International Gravimetric Bureau. In : “The Geodesist’s Handbook, 2012”, H. Drewes, H. Hornik, J. Adam, S. Rozsa Eds. (International Association of Geodesy). Journal of Geodesy, Volume 86, Number 10, October 2012, pp. 946-949.
- BGI website : <http://bgi.obs-mip.fr/>

### **Mission and objectives**

As a service of IAG/IGFS, BGI aims ensuring the data inventory and the long term availability of the gravity measurements acquired on Earth. Hence, one of the main task of BGI is to collect all gravity measurements (relative or absolute) and pertinent information about the Earth’s gravity field, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes.

The database of relative measurements contains over 12 million of observations compiled and computerized from land, marine and airborne gravity surveys. For several decades, it has been extensively used for the definition of Earth gravity field models and for many applications in geodesy, geophysics, oceanography, metrology, satellite orbit computation, etc.

More recently, a database for absolute gravity measurements was also set up and put into operation in joint cooperation between BGI and BKG (Bundesamt für Kartographie und Geodäsie, Germany). This new global database initiated in 2008, now displays and makes accessible data and information on available absolute gravity measurements.

In addition, BGI provides other additional services in the area of gravimetry (validation for regional or global projects, online access to reference gravity stations, expertise, bibliography database, etc.). It also contributes to R&D activities (global gravity modeling, data interpretation, software developments, etc.), to data acquisition (relative or absolute gravity surveys), and to educational activities (teaching and summer schools on gravity data acquisition and processing, tutorials and educational materials in gravimetry, etc.).

BGI activities are mostly carried out in the frame of national and international collaborations with many institutions involved in the acquisition or in the use of gravity measurements. For instance, new international collaborations have been initiated in the last few years in the area of absolute gravimetry, global gravity modeling, combination of satellite & surface data, etc.

Most of services provided by BGI such as consultations and requests of gravity database, products, documentations, etc. are accessible through the BGI website (<http://bgi.obs-mip.fr/>). Data, products or software available at BGI are mostly dedicated to support scientific and academic activities.

## **Structure and membership**

### *National support*

BGI has had its offices located in France (Paris, then Toulouse) since its creation. Since 1979, it has been housed in the premises of the Centre National d'Etudes Spatiales (CNES) / Groupe de Recherche en Géodésie Spatiale (GRGS) and of the Observatoire Midi-Pyrénées (OMP). Today, BGI is also recognized as a permanent service accredited by french Institut National des Sciences de l'Univers (INSU). In 2013, all BGI offices and staff will move to a new building within the OMP Toulouse. The address and contacts are unchanged.

The activities of BGI in France are supported by most of the national Institutions / Agencies and Universities involved in the acquisition or use of gravity data for a wide range of applications (research, education, exploration, reference system, metrology...). This comprises : Centre National d'Etudes Spatiales (CNES) / Groupe de Recherche en Géodésie Spatiale (GRGS), Institut National des Sciences de l'Univers (INSU), Institut Géographique National (IGN), Bureau de Recherches Géologiques et Minières (BRGM), Institut de Physique du Globe de Paris (IPGP), Institut de Recherche pour le Développement (IRD), Service Hydrographique et Océanographique de la Marine (SHOM), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Ecole Supérieure des Géomètres et Topographes (ESGT) and several laboratories of the Universities of Toulouse (GET), Montpellier (GM), and Strasbourg (EOST/IPGS). The contribution of each supporting institution is defined and updated each four years in a general agreement / MOU approved by all respective Directors.

### *International collaborations*

International collaborations are mostly carried out with other IAG services or commissions in the frame of IGFS activities as well as directly with BGI users.

In 2008, a new partnership has been established between BGI and the Bundesamt für Kartographie und Geodäsie (BKG) Germany for the realization and the maintenance of the global database of absolute gravity measurements now operated jointly by BGI and BKG.

In the last few years, active collaborations also took place with NGA (USA), DTU (Denmark) or Curtin University (Australia) for the computation or the validation of the global Bouguer and Isostatic gravity anomalies performed for the World Gravity Map project led by BGI.

The figure 1 summarizes the main structure and collaboration of BGI.



**Figure 1 :** International and national structure of BGI and main recent international collaborations

### Permanent staff (full time or part time)

*Central Bureau, Toulouse (CNES-GRGS, IRD, CNRS-INSU, OMP)*

S. Bonvalot *Geophysics – absolute & relative gravimetry (Director)*  
 G. Balmino *Geodesist - space geodesy*  
 A. Briais *Geologist / Geophysicist – marine gravimetry*  
 R. Biancale *Geodesist - space geodesy*  
 N. Lestieu *Secretary*  
 G. Gabalda *Geophysicist – absolute & relative gravimetry*  
 L. Seoane *Geodesist - Satellite gravimetry (new permanent position since 2012)*  
 F. Reinquin *Geodesist - database manager / software developer*

*Others teams and contributors (France)*

Paris (IGN-LAREG I. Panet, G. Pajot, O. Jamet) ; Paris (IPGP : M. Diament, S. Deroussi, J. Penguen) ; Orléans (BRGM : G. Martelet, A. Peyrefitte) ; Strasbourg (EOST : J. Hinderer, S. Rozat, JP. Boy, JB. Daniel) ; Montpellier (Géosciences : N. Le Moigne, C. Champollion, S. Mazzotti) ; Brest (IFREMER : E. Moussat, L. Petit de la Villeon) ; Brest (SHOM : M.F. Lalancette, D. Rouxel) ; Le Mans (ESGT : J. Cali, J. Verdun).

*Associated contributors (Germany)*

Frankfurt / Leipzig (BKG : H. Wilmes, H. Wziontek)

## Activities

According to the 2011-2015 project plan, the main BGI activities for 2011-2013 aimed (i) at consolidating the terrestrial gravity database (relative and absolute) and encouraging the collection and compilation of incoming datasets, (ii) at developing new products and services for the Earth's science community, and (iii) at making easier the consultation and diffusion of gravity data and products for end-users, through user-friendly Internet interfaces.

In the same time, BGI also continued operating with its supporting organizations other activities in gravimetry (research, software development, teaching, expertise, field surveys, etc.) with the aim to maintain a high level of competence and to improve the efficiency and the quality of its services.

We have thus contributed to the following activities:

- Processing and assistance to users regarding data requests
- Maintenance and modernization of the databases (absolute gravity data for instance)
- Maintenance and modernization of the website and development of new web-services
- Update of the data validation procedures for land gravity surveys
- Finalization of the World Gravity Map project realized for the Commission for the Geological Map of the World and UNESCO.
- Participation to IAG activities and scientific assemblies
- Contribution to outreach / educational activities
- Contribution to gravity surveys

The main results and activities are summarized hereafter.

## Global gravity databases and related web services

Most of the databases and services provided by BGI are available from the BGI website (<http://bgi.obs-mip.fr>). An updated version has been realized in 2012. It gives access to four main global database of gravity observations : 1) Relative measurements from land surveys; 2) Relative measurements from marine surveys; 3) Reference gravity stations related to the former IGSN71 and Potsdam 1930 networks, 4) Absolute measurements.

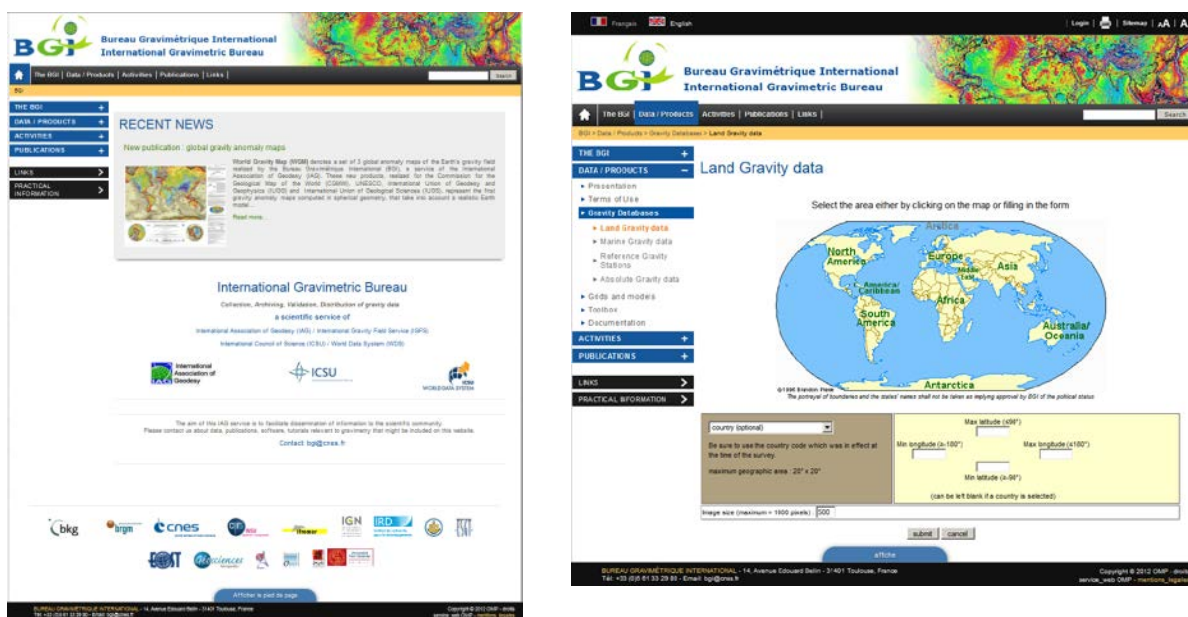


Figure 2: Left) Main page of the BGI website. Right) Data consultation/request page (<http://bgi.obs-mip.fr>)

### Overview of the BGI gravity database

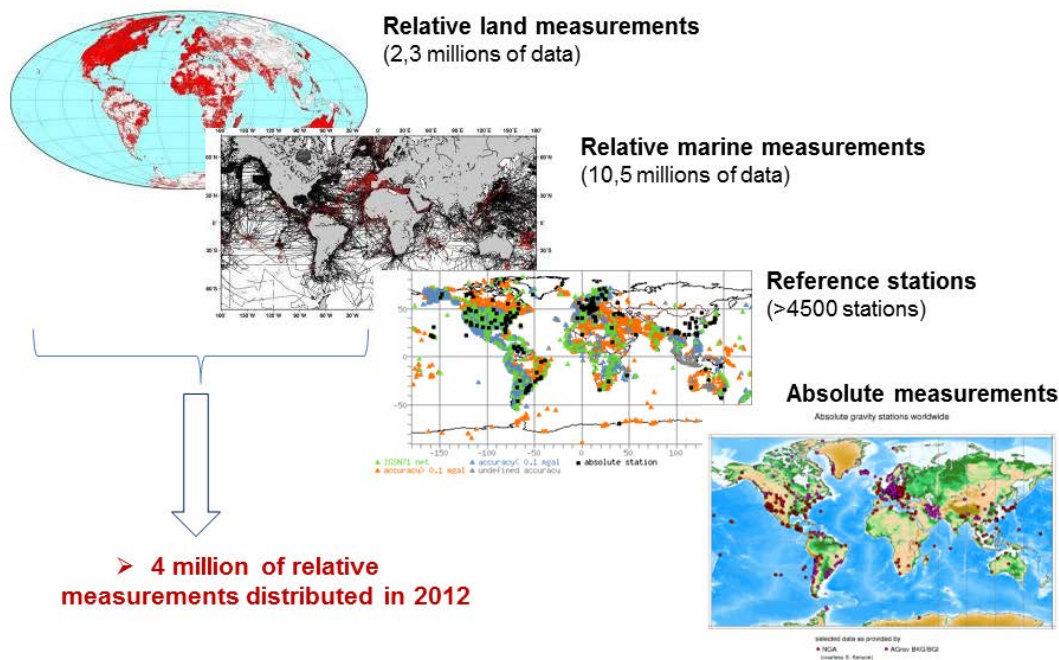


Figure 3: Overview of the global gravity database maintained at BGI

### Relative gravity database

The most frequent service BGI can provide is the consultation and retrieval of gravity data and information over local or regional areas. Data requests are issued through the BGI website and are processed electronically (email, ftp transfer or direct download). A few millions of relative data are currently distributed each year to scientific users (over 4 million in 2012).

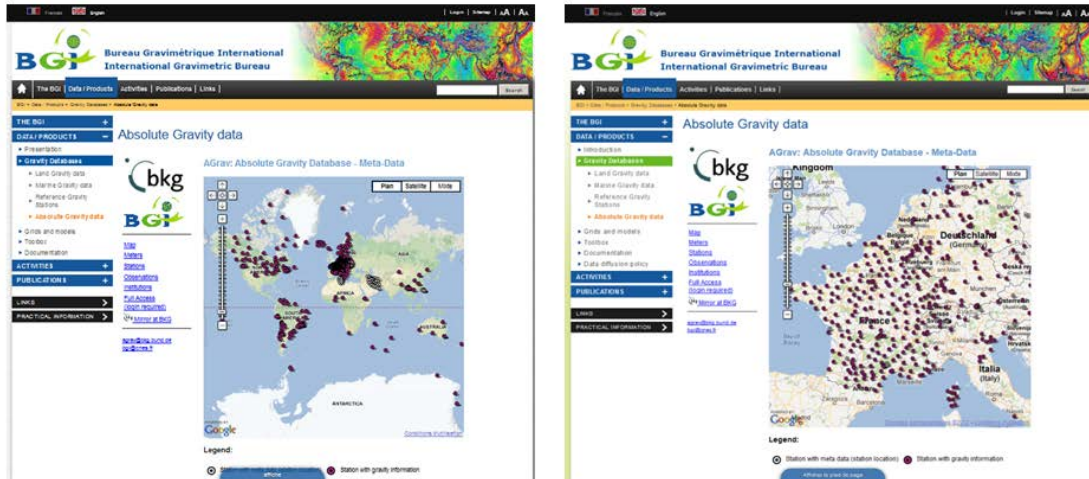
### Absolute gravity database

The global database for absolute gravity measurements was set up and put into operation in 2008 in joint cooperation between BGI and BKG (Bundesamt für Kartographie und Geodäsie, Germany). This relational absolute gravity database (AGrav) is capable of storing information about stations, instruments, observations and involved institutions. By this, it allows the exchange of meta-data and the provision of contact details of the responsible institutions on the one hand and the storage and long term availability of gravity data and processing details on the other hand.

The database can be accessed by a web based interface (based on a Google map interface) at two mirrored sites at BGI (<http://bgi.obs-mip.fr>) and BKG (<http://agrav.bkg.bund.de/agrav-meta/>). It provides publicly available meta-data as well as complete datasets for community of users contributing to the archive. A simple exchange format (project files) was selected which includes all relevant information and is known by the majority of users, avoiding additional effort. In this way the upload of data to the database is possible, using a web based upload form.

The provided information ranges from meta-data (localization of stations) up to full information on the absolute determination of the gravity field on a given site (raw or processed data, description of measurement sites, etc.). The collection and archiving of absolute gravity data is in progress. Scientists involved in the acquisition of absolute gravity measurements are invited to contribute with their own observations to this new global

database. The database is expected to become the foundation for a future international gravity reference system (replacing the obsolete IGSN71) and will serve as a pool for geophysical interpretation of absolute gravity observations on a global scale. More information can be found in Wziontek et al. (2011).



**Data entries in progress - Current status (August 2013)**  
**768 stations / 2607 records / 45 instruments / 41 Institutions (24 countries)**

Figure 4: Internet Interface of the Absolute Gravity database (BGI-BKG)  
 (<http://bgi.obs-mip.fr> - <http://agrav.bkg.bund.de/agrav-meta>)

The database includes (summer 2013): 768 Stations, 2607 Observations (2424 with gravity value), 45 Gravimeters: 28 FG5, 6 A10, and 11 other (FGL: 1, GABL: 1, GBL-M: 1, IMGC: 2, JILA: 5, ZZG: 1), provided by 41 Institutions from 24 countries.

An improved database is currently in development at BKG. This new database, now based on open-source software (OpenStreetMap), keeps a similar structure but will provide new functionalities and a link to the superconducting gravity times series (interactive maps, plot of time series, link to SG observations from GGP network, etc.).

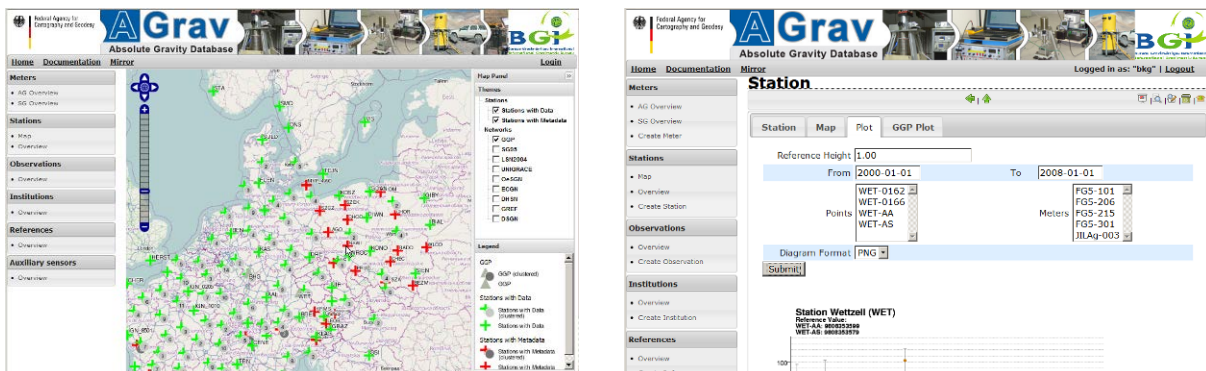


Figure 5: Snapshots of the future Internet Interface of the Absolute Gravity database (BGI-BKG)



## New on-line services (data and products)

### *Prediction of gravity value from the BGI database*

BGI also receive requests from users who need to know the expected gravity value at a given site for metrology purposes. A new application has thus been developed to predict the gravity value at any point on Earth for given geographic coordinates and altitude. The theoretical gravity is calculated in GRS80 system using the Somigliana formula. If enough gravity data are available from the relative BGI database in the surrounding area, a prediction of the expected gravity value is also computed at the same location from the interpolation of the available surface data. Both theoretical and predicted gravity values are computed at the geoid level and at the given elevation. Example of the resulting plot provided to the user is given on fig. 6.

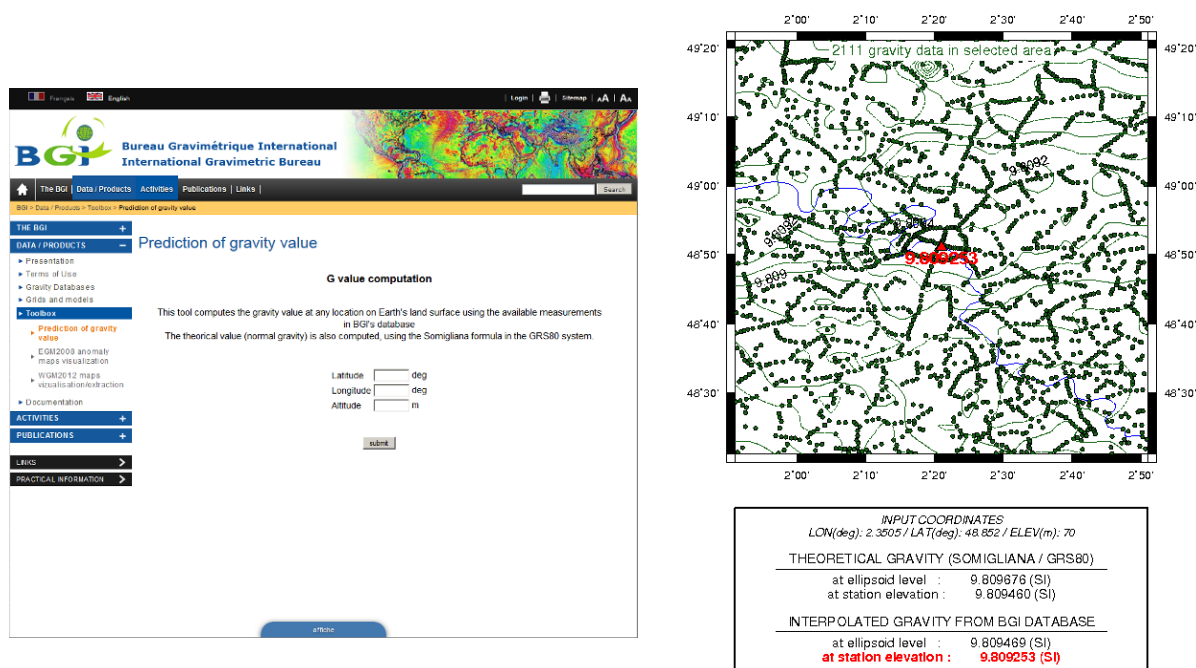


Figure 6 : Web page and resulting plot for the prediction of the gravity value at a given point <http://bgi.omp.obs-mip.fr/index.php/eng/Data-Products/Toolbox/Prediction-of-gravity-value>

### *On-line availability of the BGI Bulletins collection (1959 – 2003)*

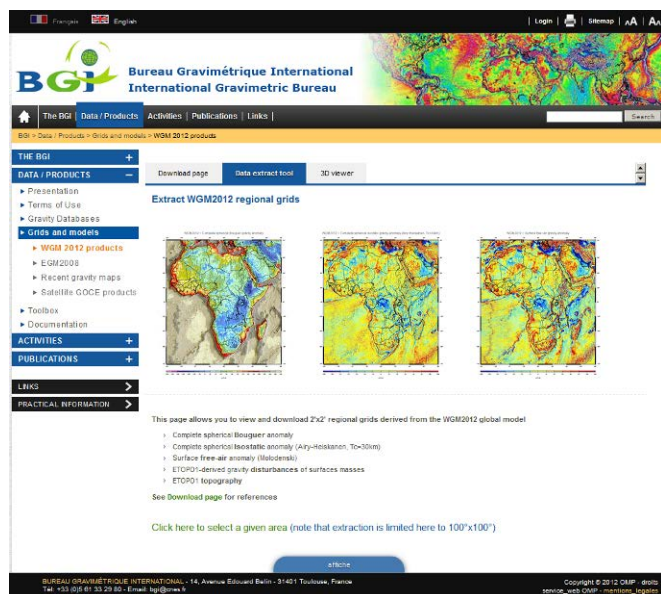
For several decades (1959 to 2003), the BGI has edited a biennial publication of the BGI Bulletin containing both internal matters on BGI activities and contributing research papers in the area of gravimetry. We carried out the digitalization of the full series of the BGI Bulletins and summaries in order to provide on-line access (downloadable PDF files) on the BGI website ([http://bgi.obs-mip.fr/publications/bgi\\_bulletin](http://bgi.obs-mip.fr/publications/bgi_bulletin)). This task has been achieved in August 2013.

The publication of the BGI Bulletins ended in 2003 and was replaced by the Newton's Bulletin published in collaboration with the International Geoid Service (IGeS) and distributed electronically. On-line versions of the issues of the Newton's Bulletins are available on both websites of IGeS (<http://www.iges.polimi.it/Newton/newton.html>) and BGI ([http://bgi.obs-mip.fr/publications/newton\\_bulletin](http://bgi.obs-mip.fr/publications/newton_bulletin)).

## Global grids of Bouguer, Isostatic and free-air gravity anomalies (WGM2012 release)

We recently put an on-line access to any users the 2012 release of the Earth's gravity anomalies computed in spherical geometry at BGI for the WGM (World Gravity Map) project (see details below). The WGM2012 release includes digital grids of the complete Bouguer anomaly and isostatic anomalies (including terrain corrections up to 1 min resolution) and surface free-air anomaly.

The global digital grids (2'x2' resolution) are available to download. An interactive tool is also available to make regional extraction and plots of the gravity anomalies for a given region (<http://bgi.obs-mip.fr/data-products/Grids-and-models/wgm2012>).



The screenshot shows the BGI website interface for downloading WGM2012 regional grids. The page title is "Extract WGM2012 regional grids". It features three small maps of regional gravity anomalies. Below the maps, there is a list of download options for three types of anomalies:

- 1. Complete spherical Bouguer gravity anomaly**
  - Download 2 min resolution netcdf GMT grid : [WGM2012\\_Bouguer\\_ponc\\_2min](#)
  - Download 2 min resolution Ascii grid (xyz ZIP file) : [WGM2012\\_Bouguer\\_ponc\\_2min](#)
  - Download Ascii GMT color table : [PALET\\_WGM\\_Bouguer\\_Global.cpt](#)
- 2. Complete spherical Isostatic gravity anomaly (Airy-Heiskanen, Tc=30 km)**
  - Download 2 min resolution netcdf GMT grid : [WGM2012\\_Isostatic\\_ponc\\_2min](#)
  - Download 2 min resolution Ascii grid (xyz ZIP file) : [WGM2012\\_Isostatic\\_ponc\\_2min](#)
  - Download Ascii GMT color table : [PALET\\_WGM\\_Isostatic\\_Global.cpt](#)
- 3. Free-air gravity anomaly on the Earth's surface (Molodenski)**
  - Download 2 min resolution netcdf GMT grid : [WGM2012\\_Freeair\\_ponc\\_2min](#)
  - Download 2 min resolution Ascii grid (xyz ZIP file) : [WGM2012\\_Freeair\\_ponc\\_2min](#)
  - Download Ascii GMT color table : [PALET\\_WGM\\_Freeair\\_Global.cpt](#)

At the bottom of the page, there is a footer with contact information for the Bureau Gravimétrique International (BGI) and a copyright notice for 2012.

Figure 7 : Web page for the download and extraction of the WGM2012 Earth's gravity anomalies. <http://bgi.obs-mip.fr/data-products/Grids-and-models/wgm2012>.

## World Gravity Map (WGM)

The WGM project, launched in early 2008 by BGI in collaboration with Commission for the Geological Map of the World (CGMW) and UNESCO, has been finalized in 2012 with its first release (WGM2012). The aim of the WGM project is to provide to the scientific community high-resolution digital maps and grids of the Earth's gravity anomalies (Bouguer, isostatic, free-air) using the best available gravity information and based on rigorous computations that are consistent with geodetic and geophysical definitions of gravity anomalies. This project, supported by the International Association of Geodesy (IAG/IGFS), the International Union of Geodesy and Geophysics (IUGG) and the International Union of Geological Sciences (IUGS), also aims to complement a set of global geological and geophysical digital maps published by CGMW and UNESCO for educative and research purposes.

In 2012, we published the first release of the World Gravity Map (Bonvalot et al., 2012). This set of 3 global maps represents the first anomaly maps of the Earth's gravity field computed in spherical geometry, that take into account a realistic Earth model. The anomaly maps (Bouguer, isostatic and surface free-air) were derived from the most recent reference Earth gravity models (EGM2008, DTU10). They include 1'x1' resolution terrain corrections derived

from the ETOPO1 relief model that consider the contribution of most surface masses (atmosphere, land, oceans, inland seas, lakes, ice caps and ice shelves).

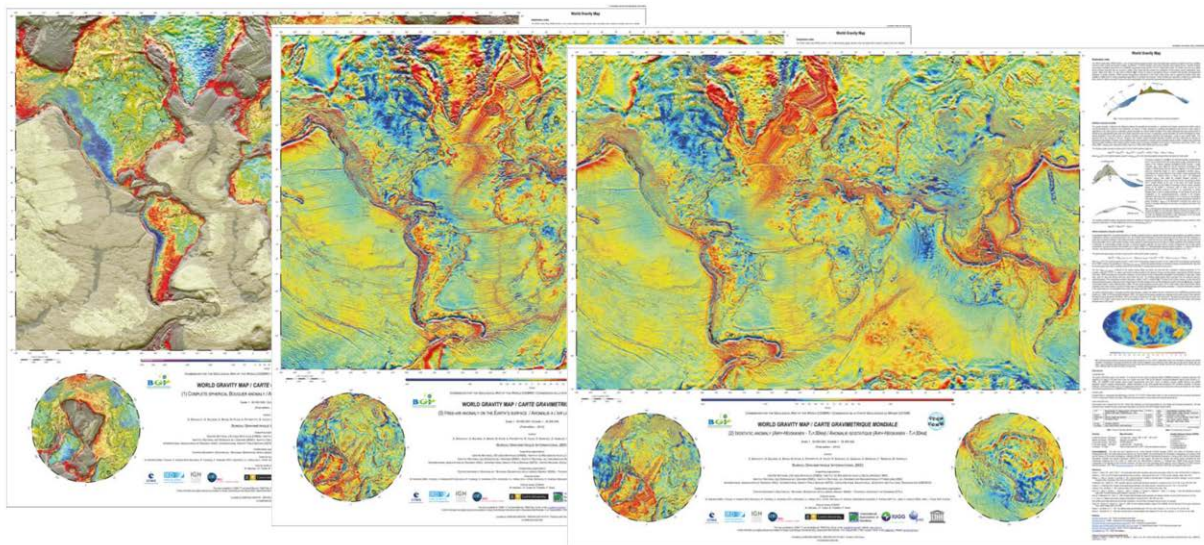


Figure 8: World Gravity Maps (Bonvalot et al., 2012). The 1:50 000 000 maps include Complete Spherical Bouguer anomaly, Complete spherical isostatic anomaly, Free-air anomaly on the Earth's surface (Molodenski).

Here, the complete spherical Bouguer anomaly is determined over the whole Earth by computing in a single step the gravity contribution of all mentioned surface masses above or below the mean sea surface. In the same way, the contribution of their compensation at the crustal-mantle boundary is also computed in spherical geometry on the base of isostatic equilibrium (Airy-Heiskanen model) to determine the corresponding isostatic anomaly. A spherical harmonic approach has been used to provide homogeneous and accurate global computations of gravity corrections and anomalies up to degree 10800 (1'x1' half-wavelength equivalent spatial resolution). To achieve this level of accuracy, new theoretical developments were required in order to handle spherical harmonics to ultra-high degrees (Balmino et al., 2011).

As these new products are believed to provide useful and homogeneous information on the Earth's static gravity field anomalies at regional and global scales in many applications for education or research, we made them available to any user on the BGI website. In addition, we also provide an interactive tool to enable users to perform their own extraction and plot of gravity anomalies derived from the WGM2012 model (see previous section "New on-line services").

Further releases are expected to include more surface data (field, marine or airborne surveys) as well as GOCE data to improve the short wavelengths of the gravity field.

## Theoretical and software developments

### *Spherical Harmonic analysis and synthesis to ultra-high resolution (d/o 32400)*

A specific algorithm was developed to enable the computation of associated Legendre functions to any degree (and order); it was successfully tested up to degree 32400. All analysis and synthesis were performed with it, in 64 bits arithmetic and with semi-empirical control of the significant terms in order to prevent from calculus underflows and overflows (according to IEEE limitations), also in preserving the efficiency of a specific regular grid processing scheme. See Balmino et al. (2011) for more details.

### *Interactive validation of land gravity surveys (NASA World Win application)*

A new application is currently under development for the validation of land gravity surveys. This new application, developed in Java language and based on interactive interfaces and maps (based on NASA WorldWind application), aims at replacing the old data processing tool DIVA used at BGI for many years. Example of snapshots are shown on fig 9.

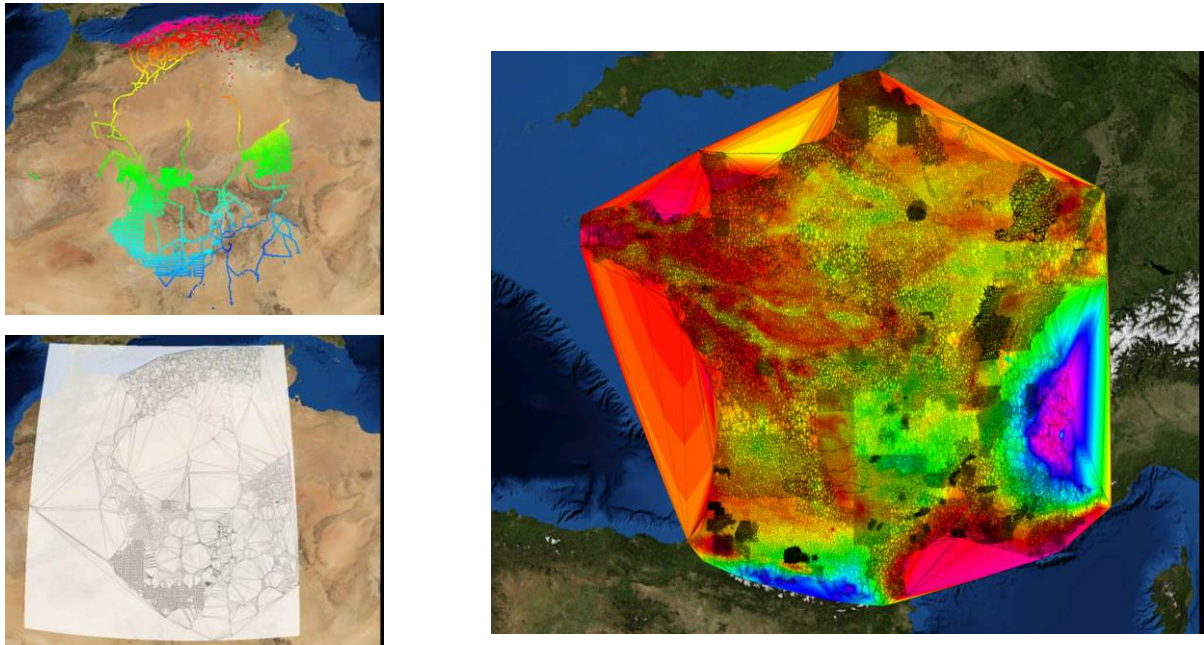


Figure 9: Snapshots of the interactive software for land gravity data validation

### **Contribution to relative and absolute gravity surveys**

Scientific teams associated to BGI have also contributed during the last years to various field surveys for absolute or relative gravity measurements in South America (Chile, Peru, French Guiana), Africa (Niger, Benin, Djibouti), Asia (Bouthan) and Europe.

### **Participation to scientific conferences and workshops**

- *ESA Living Planet Symposium 2013 (Edinburgh, UK - 09/ 2013)*
- *IAG Scientific Assembly 2013 – 150 years of IAG (Potsdam, Germany - 09/2013)*
- *TGSMM Terrestrial Gravimetry (St. Petersburg, Russia - 09/2013)*
- *AGU 2013 (San Francisco, USA, 12/2013)*
- *IAG/IGFS Int. Symposium on Gravity, Geoid, Height Systems (Venice, Italie, 10/2012)*
- *EGU 2012 (Vienne, Austria, 04/2012)*
- *Workshop on Absolute Gravimetry (Boulder Co, USA, 09/2012)*
- *IUGG General Assembly (Melbourne, 08/2012)*
- *AGU Fall Meeting, (San Francisco, USA, 12/2011)*
- *4<sup>th</sup> International GOCE User Workshop (Munich, Germany, 03/2011)*

### **Contribution to Scientific Organizing Committees**

- *IGFS 3<sup>rd</sup> Scientific Assembly (Shanghai, China, 2014)*
- *IAG Scientific Assembly 2013 – 150 years of IAG (Potsdam, Germany - 09/2013)*
- *TGSMM Terrestrial Gravimetry (St. Petersburg, Russia - 09/2013)*

## Perspectives

Here are listed the main perspectives for the next years.

### Improvement of the global gravity databases and services

We will continue in collaboration with BKG Germany the development and set up of the new version of the of the Absolute Gravity database AGrav.

In the same time, we will continue the integration of incoming dataset from relative or absolute gravity surveys. We encourage any user or institution to contribute to the IAG databases. The status of information derived from airborne gravity surveys (grids for instance) should be discussed to be included in the BGI database to improve the global data coverage.

### Global / Regional gravity modeling (new products incl. GOCE and surface data)

Within IGFS activities or other research projects, we are developing new collaborations with other groups also involved in the determination or analysis of global gravity field models as for instance with NGA (USA), Curtin Univ (Australia), IGN/IPG Paris (France). Through these collaborations, we expect to join research efforts for the future determination or the evaluation of global gravity models based on surface and satellite (GOCE for instance) gravity data.

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## International Gravity Field Service (IGFS)

<http://www.igfs.net>

*Chairman (until 2013-03-31): Rene Forsberg (Denmark)*

*Chairman (from 2013-04-01): Riccardo Barzaghi (Italy)*

*Director of the Technical Centre: Steve Kenyon (USA)*

*Director of the Central Bureau: Iginio Marson (Italy)*

### Overview

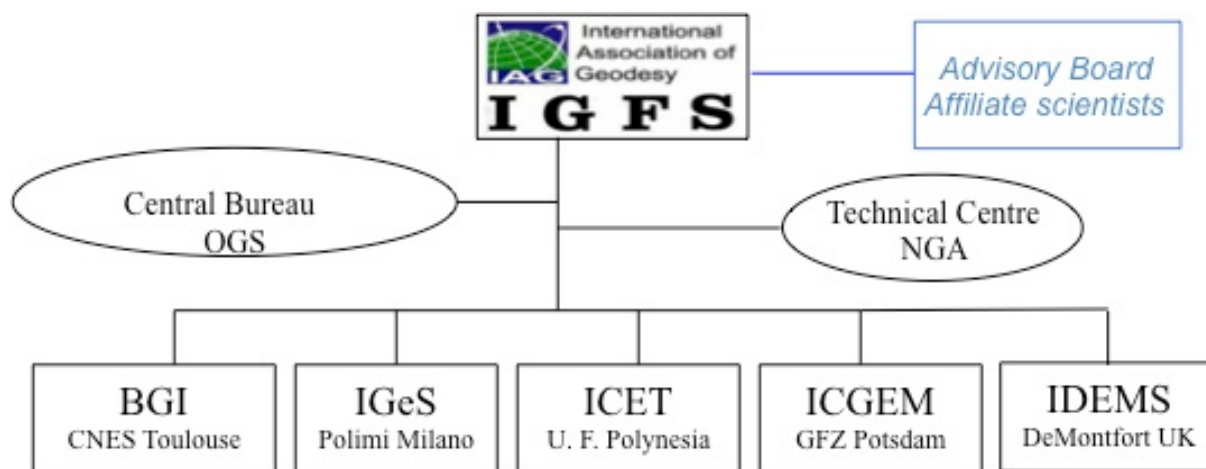
IGFS activities in the mid-term period 2011-2013 were mainly addressed to coordinate collection, validation, archiving and testing of gravity field related data; to coordinate exchange of software of relevance for gravity field activities; to coordinate courses on gravity field estimation; to distribute information materials related to the earth's gravity field. Most of these activities, though performed in a direct way by the related gravity Services, have been supervised and harmonized by IGFS. Other important IGFS actions were related to GGOS activities. IGFS representatives participated to GGOS meetings (particularly those of the Bureau for Network and Communications) to present some recent development on gravity data acquisition that are of relevance for GGOS. Another common activity in coordination with GGOS is based on the researches of the Working Group on Vertical datum Standardization. The activities of this WG are in the framework of GGOS Theme 1 – Global Vertical Datum. Also, other scientific activities were developed on gravity field. They are in connection with IAG Commission 2 (Gravity Field). Three Joint Study Groups have been actively operating in assessing the precision of the GOCE global geopotential models, in defining methods for comparing absolute gravimeter observations and in establishing a new global absolute gravity reference system. These researches are of particular relevance for the geodetic community. The realization of the Absolute Gravity Reference System is a key issue in Geodesy. The IGNS71 is the current realization that strictly needs for an update due also to the relevant improvements in absolute gravimeters that occurred in the last decades. The same holds for the assessment of GOCE global geopotential models. As it was done for EGM2008, comparisons with existing ground based data set are extremely important in order to assess the precision of the different GOCE models, obtained following different approaches. This also in relationship to new planned missions aimed at improving the present day GOCE models precision.

Furthermore, in 2012, IGFS was supporting, directly and via its Central Bureau, the organization of the International Symposium on Gravity, Geoid and Height System GGHS2012 in cooperation with IAG Commission 2. The symposium was held in Venice, from October 9<sup>th</sup> to October 12<sup>th</sup>, 2012. IGFS is also planning and organizing, always in cooperation with Commission 2, the forthcoming 3<sup>rd</sup> IGFS General Assembly that will be in Shanghai (beginning of July 2014).

Finally, the IGFS Central Bureau has realized the new IGFS web page which will possibly be a tool for better informing the geodetic community on gravity field related topics.

## Structure

The IGFS structure is described in Figure 1.



*BGI=Bureau Gravimétrique International*  
*IGeS=International Geoid Service*  
*ICET=International Centre for Earth Tides*  
*ICGEM=International Centre for Global Earth Models*  
*IDEMS=International DEM Services*  
*OGS=Istituto Nazionale di Oceanografia e Geofisica Sperimentale*  
*NGA=National Geospatial-Intelligence Agency*

Figure 1: The IGFS structure

IGFS coordinates the activities of the related Services via the Advisory Board, its Central Bureau at OGS and the Technical Centre at NGA. This structure allows a deeper relationship among the different Services working on gravity field. IGFS also provide a common interface towards other IAG bodies such as GGOS, in order e.g. to come to a standardization of the gravity “products”. Within IGFS, Joint Working Groups are coordinated with Commission 2, namely JWG2.1 (International and Regional Comparison Campaigns of Absolute Gravimeters), JWG2.2 (Absolute Gravimeters and Absolute Gravity Reference System), JWG2.3 (Assessment of GOCE Geopotential Models). Furthermore, a Working Group on Vertical Datum Standardization was established jointly with GGOS Theme 1- Global Vertical Datum.

There is also a proposal for a new IAG/IGFS Service as the evolution of the Global Geodynamic Project (GGP).

On April 1<sup>st</sup>, 2013, a new chairman, Riccardo Barzaghi from Politecnico di Milano (Italy), started managing IGFS thus substituting Rene Forsberg from The National Space Institute (Denmark).

## Activities

As previously mentioned, the Gravity Services have developed many activities that have been coordinated and documented by IGFS. Particularly, BGI has developed and finalized the

World Gravity Map project. Bouguer, Isostatic and free-air gravity anomalies are available, since 2012, either as spherical harmonic expansions or 1'× 1' digital grids (see Figure 2).

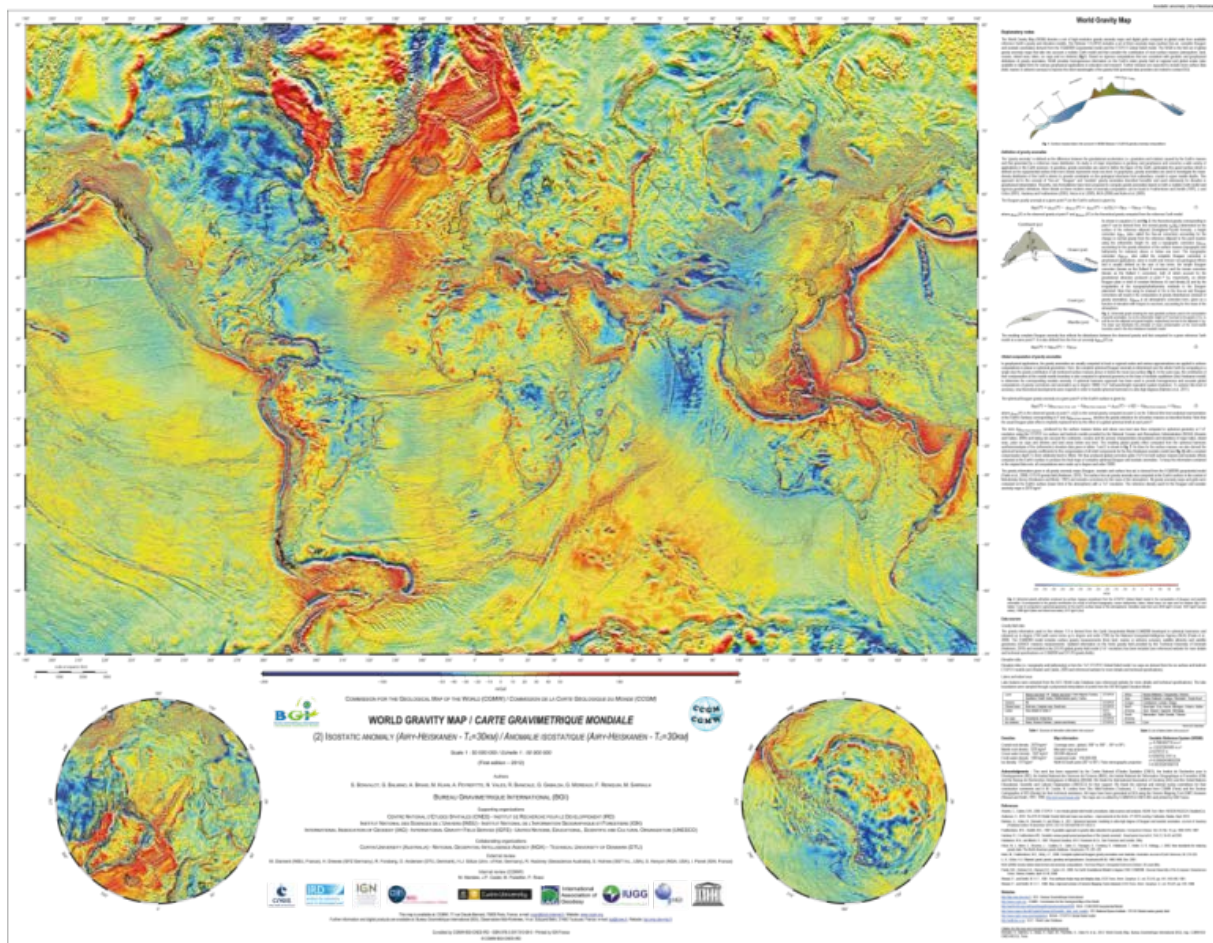


Figure 2: The World Gravity Map by BGI

Improvements are expected by including new airborne and ground based gravity data and satellite GOCE models. As an example, in Figure 3, the Antarctica aerogravity surveys planned by DTU (blue) and University of Texas (green) in 2008-2011 and 2009-2011 are shown.

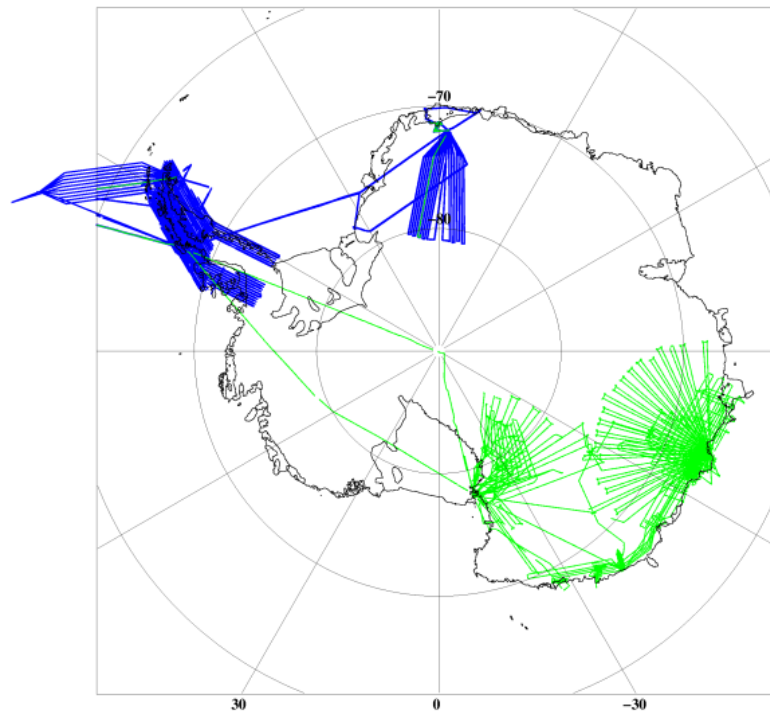


Figure 3: Aerogravity Surveys in Antarctica

Also GOCE data were processed and global GOCE gradients have been computed in a Local North-Oriented Frame (LNOF) and in the Instrument Frame (GRF frame) and will be soon available to the geodetic and the geophysical community (see Figure 4).

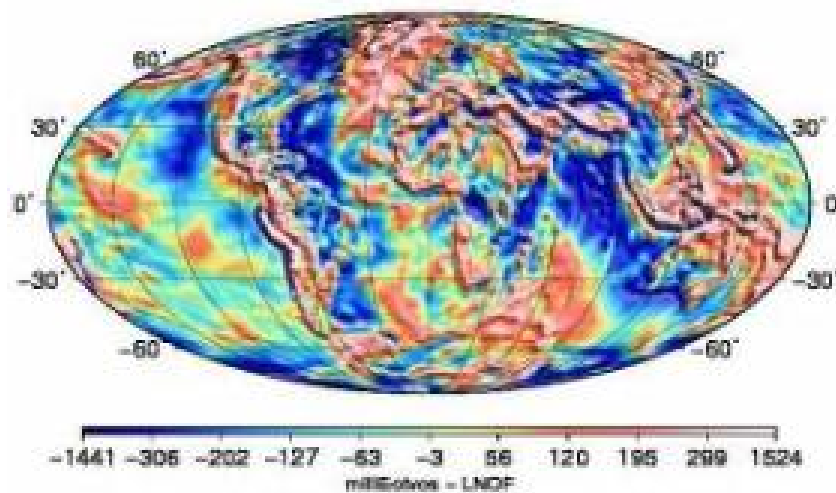


Figure 4: The ZZ gradient in LNOF frame (mEötvös)

Furthermore BGI is developing in co-operation with BKG an absolute gravity database that contains data from 699 stations, from 41 different institutions and 41 different instruments (at November 2012). The information contained in these data is of strong interest in many geodetic/geophysical investigations. In Figure 5, the gravity variation in time in one of the Global Geodynamics Project (GGP) station is displayed.

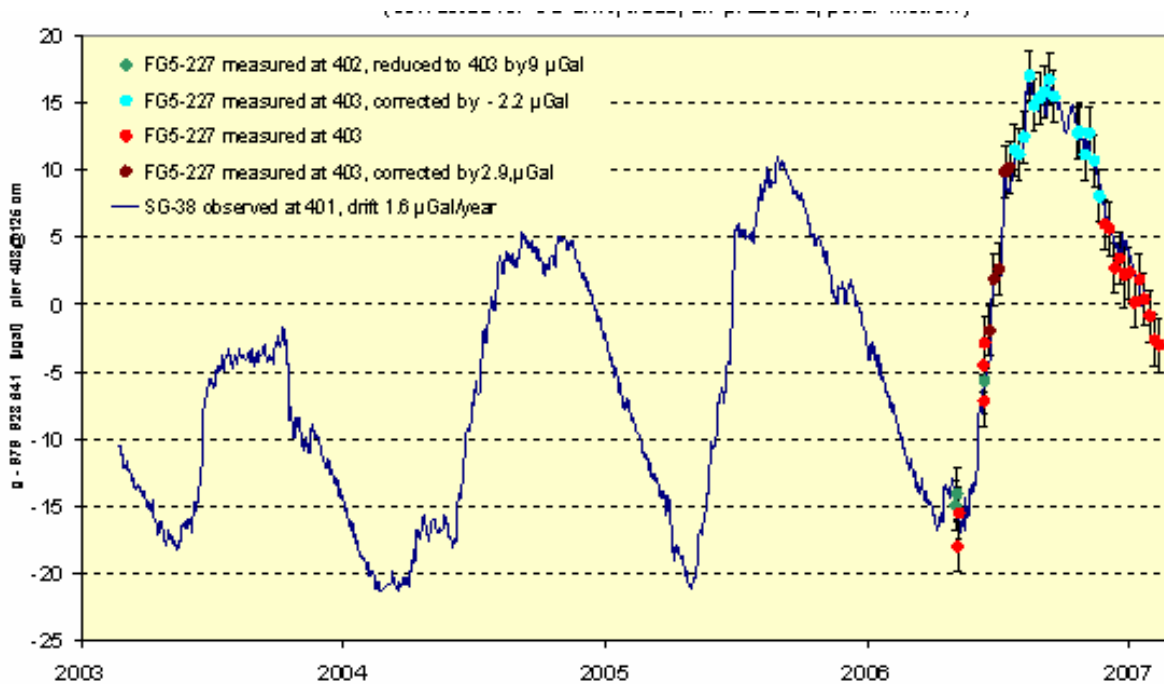


Figure 5: The gravity filed variations at Conception

ICET has contributed to this project by processing the GGP data uploaded to the ICET and GFZ database for earth tides.

ICGEM and IGeS have collected both global geopotential models and local geoid solutions which are available through their own web pages that are linked to the IGFS web page. Presently, at ICGEM 122 geopotential models area available and can be downloaded via the ICGEM web page. On line interactive visualization tools can be used and evaluation of global model effects can be obtained via web interface (see Figure 6).

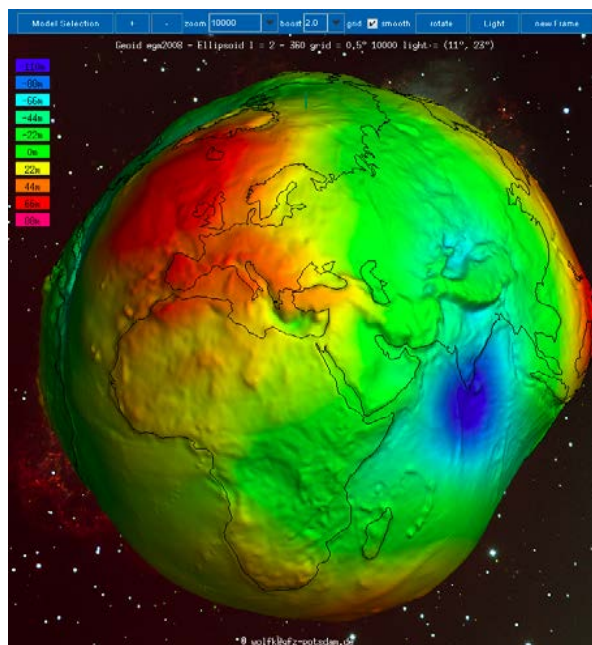


Figure 6: The visualization tool of global geopotential model at ICGEM

Validation of global models is also provided both in the spectral domain and by direct comparison with GPS/levelling data.

The IGeS web page has been totally renewed in order to provide a better service to the users. At present, 34 estimated geoids are stored in IGeS database and can be downloaded, either freely or on demand, through the web page (see Figure 7). They are frequently requested by users that are interested in detailed geoid solutions over limited portions of the Earth.

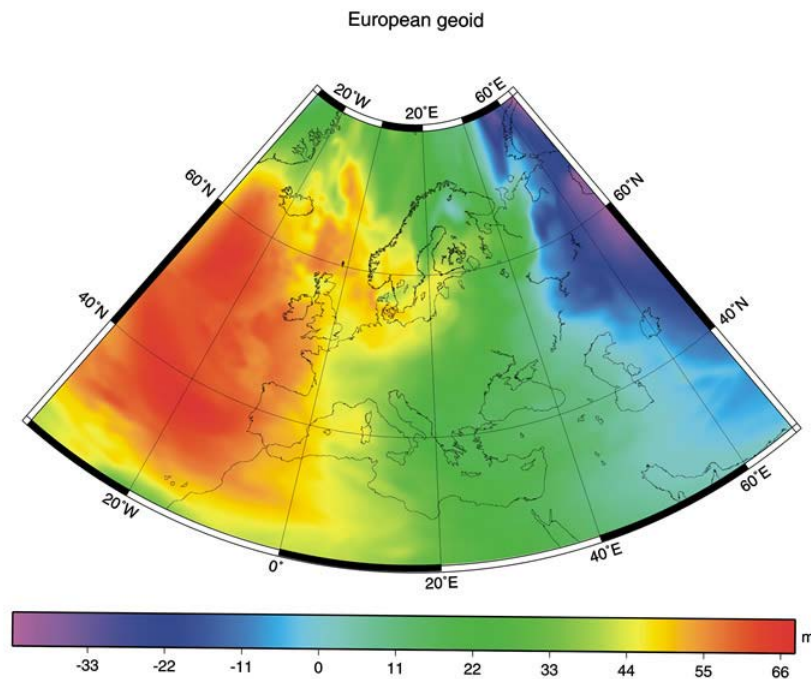


Figure 7: The European geoid EGG2008 available at IGeS

Finally, it must be considered the important role of IDEMS which distributes and validates global DEM models which are important for estimating and removing from the data the terrain effect. As it is well known, this is strictly needed in any geodetic computation for estimating the gravity and the geoid.

The publication of technical papers is also one of the activity which is coordinated and sponsored by IGFS.

IGeS and BGI are issuing via their web pages the Newton's Bulletin which contains technical papers on geoid computation, gravity data handling and gravity campaigns. Another publication related to the gravity field services is issued by ICET which regularly publishes the Bulletin International des Marées Terrestres (BIM) in electronic form through its web page.

All these activities are documented in the IGFS web page where an overview is given and the activities are listed (<http://www.igfs.net>). A new web page will be established at OGS which will manage it as IGFS Central Bureau (the page is under construction and will be soon available at the following address: <http://www.gravityfield.org/>).

Another important activity which is performed by IGFS in cooperation with IAG Commission 2 is to organize Symposia and Schools on geoid computation.

In October 9-12, 2012, the International Symposium on Gravity, Geoid and Height System GGHS2012 has been organized in Venice (San Servolo Island). The session outline is presented in the following:

- session 1: gravimetry and gravity networks
- session 2: global gravity field modelling, assessments and applications
- session 3: future gravity field missions
- session 4: advances in precise local and regional high-resolution geoid modeling
- session 5: establishment and unification of vertical reference systems
- session 6: gravity field and mass transport modelling
- session 7: modelling and inversion of gravity-solid earth coupling
- session 8: gravity field of planetary bodies

As one can see, the most relevant topics related to the gravity field analysis and estimation have been discussed. Most of the presented papers have been submitted for publication (after peer review) on IAG Symposia Series published by Springer.

Furthermore, a new Symposium is going to be organized by IGFS and IAG Commission 2 in Shanghai. It is the 3<sup>rd</sup> IGFS General Assembly that will be held at the beginning of July, 2014. The tentative list of topics that have been proposed and discussed by the SOC members contains the following themes:

- Gravimetry (aerograv, absolute and relative gravity observations, gravity network)
- Global geopotential models and vertical datum unification
- Local geoid/gravity modelling
- Satellite gravity
- Mass movements in the earth system
- Inverse gravimetric problems

This Symposium will be announced at the forthcoming IAG meeting in Potsdam.

Finally, a new school has been organized in 2012. It will be held at the Universidad Tecnica Particular de Loja, Loja (Ecuador) in October, 7-11, 2013. It is the XI Geoid School which continues the IGeS schools tradition, even though it is not only focussed on geoid computation. A new important topic has been added, namely the one related to the definition of a global height datum. The detailed program is given in the following together with the names of the teachers:

- Heights, height datum and Boundary Value Problems (Sansò)
- Global geopotential models and their use (Pavlis)
- Modelling the topographic effect (Blitzkow)
- Local improvements of the geoid (Barzaghi)
- Height datum unification (Sideris)
- Vertical Datum Standardization (Sánchez)

Forthcoming schools are going to be organized in Trieste and/or in Cairo (in 2014). These are particularly important for Africa and can be seen as a starting point for improving researches on physical geodesy in this continent.

## International Laser Ranging Service (ILRS)

<http://ilrs.gsfc.nasa.gov>

E. C. Pavlis<sup>11</sup>, M. R. Pearlman<sup>12</sup>, C. E. Noll<sup>13</sup>, G. Appleby<sup>14</sup>, J. Müller<sup>15</sup>

### Overview

The ILRS is the international source that provides Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data and data products for scientific and engineering programs with the main focus on Earth and Lunar applications. The basic observables are the precise two-way time-of-flight of ultrashort laser pulses from ground stations to retroreflector arrays on satellites and the Moon and the one-way time-of-flight measurements to spaceborne receivers (transponder). These data sets are made available to the community through the CDDIS and the EDC archives, and are also used by the ILRS to generate fundamental data products, including: accurate satellite ephemerides, Earth orientation parameters, three-dimensional coordinates and velocities of the ILRS tracking stations, time-varying geocentre coordinates, static and time-varying coefficients of the Earth's gravity field, fundamental physical constants, lunar ephemerides and librations, and lunar orientation parameters.

SLR is one of the four space geodetic techniques (along with VLBI, GNSS and DORIS) whose observations are the basis for the development of the International Terrestrial Reference Frame, which is maintained by the IERS. SLR defines the origin of the reference frame, the Earth centre-of-mass and along with VLBI, its scale. The ILRS generates daily a standard product of station positions and Earth orientation based on the analysis of the data collected over the previous seven days, for submission to the IERS, and produces LAGEOS/ LARES combination solutions for maintenance and improvement of the International Terrestrial Reference Frame (ITRF). The latest requirement is to improve the reference frame to an accuracy of 1 mm accuracy and 0.1 mm/year stability, a factor of 10 – 20 improvement over the current product. To address this requirement, the SLR community will need to significantly improve the quantity and quality of ranging to the geodetic constellation (LAGEOS-1, LAGEOS-2, and LARES) to support the definition of the reference frame, and to the GNSS constellations to support the global distribution of the reference frame.

The ILRS participates in the Global Geodetic Observing System (GGOS) organized under the IAG to integrate and help coordinate the Service activities.

### ILRS Structure

The ILRS Organization (see Figure 1) includes the following permanent components:

- Tracking Stations organized into Subnetworks
- Operations Centres

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<sup>12</sup> *Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA USA 02138, USA*

<sup>13</sup> *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*

<sup>14</sup> *NERC Space Geodesy Facility, Herstmonceux Castle, Hailsham, East Sussex, BN27 1RN, UK*

<sup>15</sup> *University of Hannover/Institut für Erdmessung, Hannover, GERMANY*



- Global and Regional Data Centres
- Analysis and Associate Analysis Centres
- Central Bureau
- Working Groups

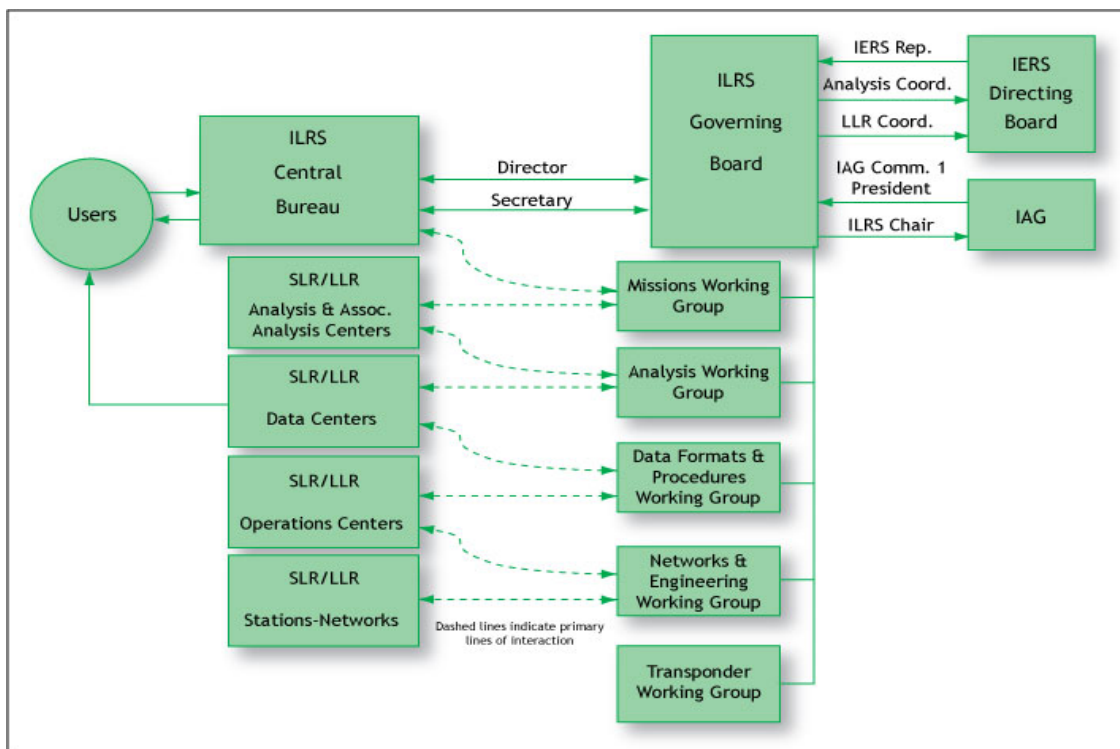


Figure 1. The organization of the International Laser Ranging Service (ILRS).

The role of these components and their inter-relationship is presented on the ILRS website (<http://ilrs.gsfc.nasa.gov/about/organization/index.html>).

The Governing Board (GB) is responsible for the general direction of the service. It defines official ILRS policy and products, determines satellite-tracking priorities, develops standards and procedures, and interacts with other services and organizations. The members of the current Governing Board, selected and elected for a two year term, are listed in Table 1. The election process for the next Board is underway; the new Board will formally take office at the 18<sup>th</sup> International Workshop on Laser Ranging in Japan, November 2013.

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG) carry out policy formulation for the ILRS. The WGs are intended to provide the expertise necessary to make technical decisions, to plan programmatic courses of action, and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau. All GB members serve on at least one of the five WGs, led by a Coordinator and Deputy Coordinator (see Table 1). The WGs continue to attract talented people from the general ILRS membership who contributed greatly to the success of these efforts.

Table 1. ILRS Governing Board (as of July 2013)

Tonie van Dam	Ex-Officio, President of IAG Commission 1	Luxembourg
Michael Pearlman	Ex-Officio, Director, ILRS Central Bureau	USA
Carey Noll	Ex-Officio, Secretary, ILRS Central Bureau	USA
Bob Schutz	Appointed, IERS Representative to ILRS	USA
Giuseppe Bianco	Appointed, EUROLAS	Italy
Francis Pierron	Appointed, EUROLAS	France
David McCormick	Appointed, NASA	USA
Jan McGarry	Appointed, NASA	USA
Wu Bin	Appointed, WPLTN	China
Hiroo Kunimori	Appointed, WPLTN	Japan
Vincenza Luceri	Elected, Analysis Representative, Analysis Working Group Deputy Coordinator	Italy
Erricos C. Pavlis	Elected, Analysis Representative, Analysis Working Group Coordinator	USA
Horst Mueller	Elected, Data Centres Rep., Data Formats and Procedures WG Coordinator	Germany
Jürgen Müller	Elected, Lunar Representative	Germany
Graham Appleby	Elected, At-Large, Missions Working Group Coordinator, Governing Board Chair	UK
Georg Kirchner	Elected, At-Large, Networks and Engineering Working Group Coordinator	Austria

## Data Products

The ILRS products consist of SINEX files of weekly-averaged station coordinates and daily Earth Orientation Parameters (x-pole, y-pole and excess length-of-day, LOD) estimated from 7-day arcs of SLR tracking of the two LAGEOS and two Etalon satellites. As of May 1, 2012, the weekly analysis product is no longer the official ILRS Analysis product (thence reserved for Pilot Project use only), replaced by the same type of analysis performed on a DAILY basis by sliding the 7-day period covered by the arc by one day forward every day. This allows the ILRS to respond to two main users of its products: the ITRS Combination Centres and the IERS EOP Prediction Service at USNO. The former requires a single analysis per week, the latter however requires as “fresh” EOP estimates as possible, which the “sliding” daily analysis readily provides. Two types of products are distributed for each 7-day period: a loosely constrained estimation of coordinates and EOP and an EOP solution, derived from the previous one and constrained to an ITRF, currently ITRF2008. Official ILRS Analysis Centres (AC) and Combination Centres (CC) generate these products with individual and combined solutions respectively. Both the individual and combined solutions follow strict standards agreed upon within the ILRS Analysis Working Group (AWG) to provide high quality products consistent with the IERS Conventions. This description refers to the status as of July 2013. Each official ILRS solution is obtained through the combination of solutions submitted by the official ILRS Analysis Centres:

- ASI, Agenzia Spaziale Italiana
- BKG, Bundesamt für Kartographie und Geodäsie

- DGFI, Deutsches Geodätisches Forschungsinstitut
- ESA, European Space Agency
- GA, Geosciences Australia (up until the end of 2012)
- GFZ, GeoForschungsZentrum Potsdam
- GRGS, Observatoire de Cote d'Azur
- JCET, Joint Center for Earth Systems Technology and Goddard Space Flight Center
- NSGF, NERC Space Geodesy Facility

These ACs have been certified through a benchmark process developed and adopted by the AWG. The official Primary Combination Center (ASI) and the official Backup Combination Center (JCET) follow strict timelines for these routinely provided products.

In addition to operational products, solutions obtained from re-analysis have been provided covering the period back to 1983 in support of ITRF development. The ILRS products are available, via ftp from the official ILRS Data Centres CDDIS/NASA Goddard (<ftp://cddis.gsfc.nasa.gov/>) and EDC/DGFI (<ftp://ftp.dgfi.badw-muenchen.de>).

The individual ILRS AC and CC contributions as well as the combinations are monitored on a daily basis in graphical and statistical presentation of these time series through a dedicated website hosted by the JCET AC at [http://geodesy.jcet.umbc.edu/ALL\\_PLOTS/](http://geodesy.jcet.umbc.edu/ALL_PLOTS/).

The main focus of the Analysis WG activities over this period was the improvement of modeling used in the reduction of the SLR data and generation of the official products. In particular, all ACs made major efforts to comply with the adopted analysis standards and the IERS Conventions 2010. Since the delivery of the ILRS contribution to ITRF2008, the AWG has launched an ongoing set of Pilot Projects to test, evaluate and adopt new models and practices that will limit or mitigate the effect of systematic errors in the ILRS data. Part of this effort was the development, evaluation and adoption of a new model for the application of the “centre-of-mass” (CoM) offset corrections for the LAGEOS and Etalon target satellites. The new model developed by the Signal Processing Study Group (G. Appleby and T. Otsubo) is a further enhancement of the one made available in 2010. The latest version considers not only the specific geometry of the target satellites, but also the variable mode of operations at each specific ground station tracking system. This makes the model station-dependent and time-dependent at the same time. The model will be adopted after the evaluation of the test period during the summer of 2013. It is crucial to have this model applied before the AWG efforts turn to the estimation of systematic errors in general. This is a task to be completed prior to the reanalysis for the development of the ILRS contribution to ITRF2013 by early 2014. During the reporting period the ILRS adopted a new data format (CRD) and starting on May 1, 2012, the AWG switched to the use of the new format. At the same time, the official analysis product of the ILRS was changed to the DAILY analysis product, based on the data from the immediate prior seven days. Over the past three years, the daily product was generated on an experimental basis, primarily for use by the IERS EOP Prediction Service at USNO. ILRS thus provided USNO with an as fresh as possible SLR-derived EOP product. Once accepted by USNO, the more frequent series were adopted as the official positioning and EOP product of the ILRS. Work is now underway to complete the test phase of an additional official ILRS product, the precision orbital files for the LAGEOS and Etalon satellites. As far as the LLR analysis activities, a new service has been instituted via a web application, where one can obtain predictions for LLR observations at a specific site and they can also have their LLR data checked for validity, prior to submitting them to the Data Centres for archival. Currently, the LLR group are in the process of developing a unique data set of all

available LLR data in the newly adopted CRD format, in order to better serve the community and to conform with the ILRS standards.

## Satellite Laser Ranging

### ILRS Network

The present ILRS network includes over forty stations in 23 countries (see Figure 2). During the last two years, new Russian stations joined the Network in Arkhyz, Zelenchukskaya, Svetloe, and Badary, filling in a very important geographic gap. SLR and LLR data are again flowing from the new MEO station at Grasse, France. A new SLR station is currently in Sejong, Korea and two new stations are under construction in India. New SLR stations are also being planned for Metsahovi (Finland) and Ny Alesund (Norway). Large gaps are still very prominent in Africa and South America and discussions are underway with several groups on the hope of addressing this shortcoming.



Figure 2. ILRS network (as of July 2013).

Stations designated as operational have met the minimum ILRS qualification for data quantity and quality. Several stations dominated the network with the Yarragadee, Changchun, Zimmerwald and Mt. Stromlo stations being the strongest performers. In general, stations continue to improve performance. During the twelve-month period from April 2012 to March 2013, 22 stations met the ILRS minimum requirement for total numbers of passes tracked (see Figure 3). The San Juan station performance continues to be impressive as does Wettzell, Matera, Goddard and Graz. In addition to San Juan, the rest of the Chinese SLR network continues its very strong support for the ILRS network. The improved orbital coverage over the Pacific region should have a very fundamental impact on our ILRS data products.

Several stations are operating with kHz lasers and fast detectors allowing them to be much more productive with pass interleaving. Some have demonstrated mm precision normal points, a fundamental step toward addressing the new reference frame requirements.

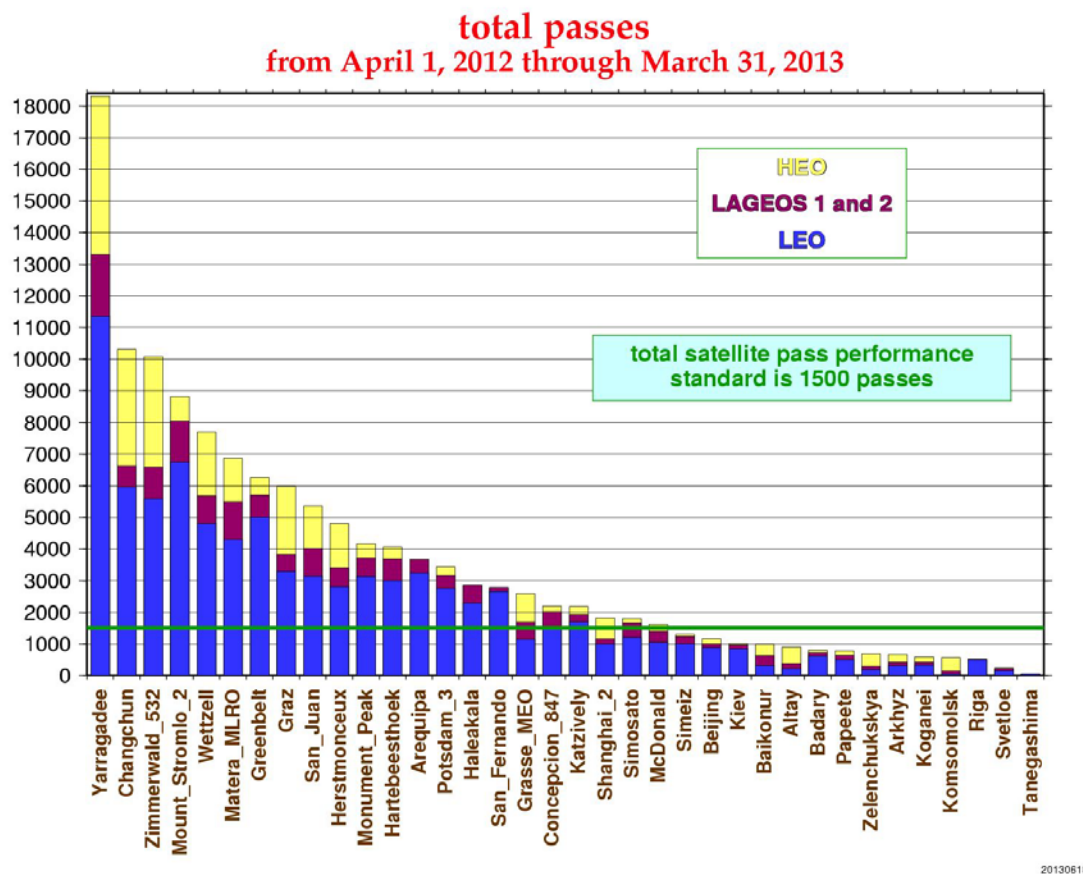


Figure 3. ILRS network performance (total passes).

## Satellite Missions

The ILRS is currently tracking 40 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions (see Figure 4). The stations with lunar capability are also tracking the lunar reflectors. In response to tandem missions (e.g., GRACE-A/-B, TanDEM-X/TerraSAR) and general overlapping schedules, many stations are tracking satellites with interleaving procedures.

The ILRS assigns satellite priorities in an attempt to maximize data yield on the full satellite complex while at the same time placing greatest emphasis on the most immediate data needs. Priorities provide guidelines for the network stations, but stations may occasionally deviate from the priorities to support regional activities or national initiatives and to expand tracking coverage in regions with multiple stations. Tracking priorities are set by the Governing Board, based on application to the Central Bureau and recommendation of the Missions Working Group (see [http://ilrs.gsfc.nasa.gov/missions/mission\\_operations/priorities/index.html](http://ilrs.gsfc.nasa.gov/missions/mission_operations/priorities/index.html)).

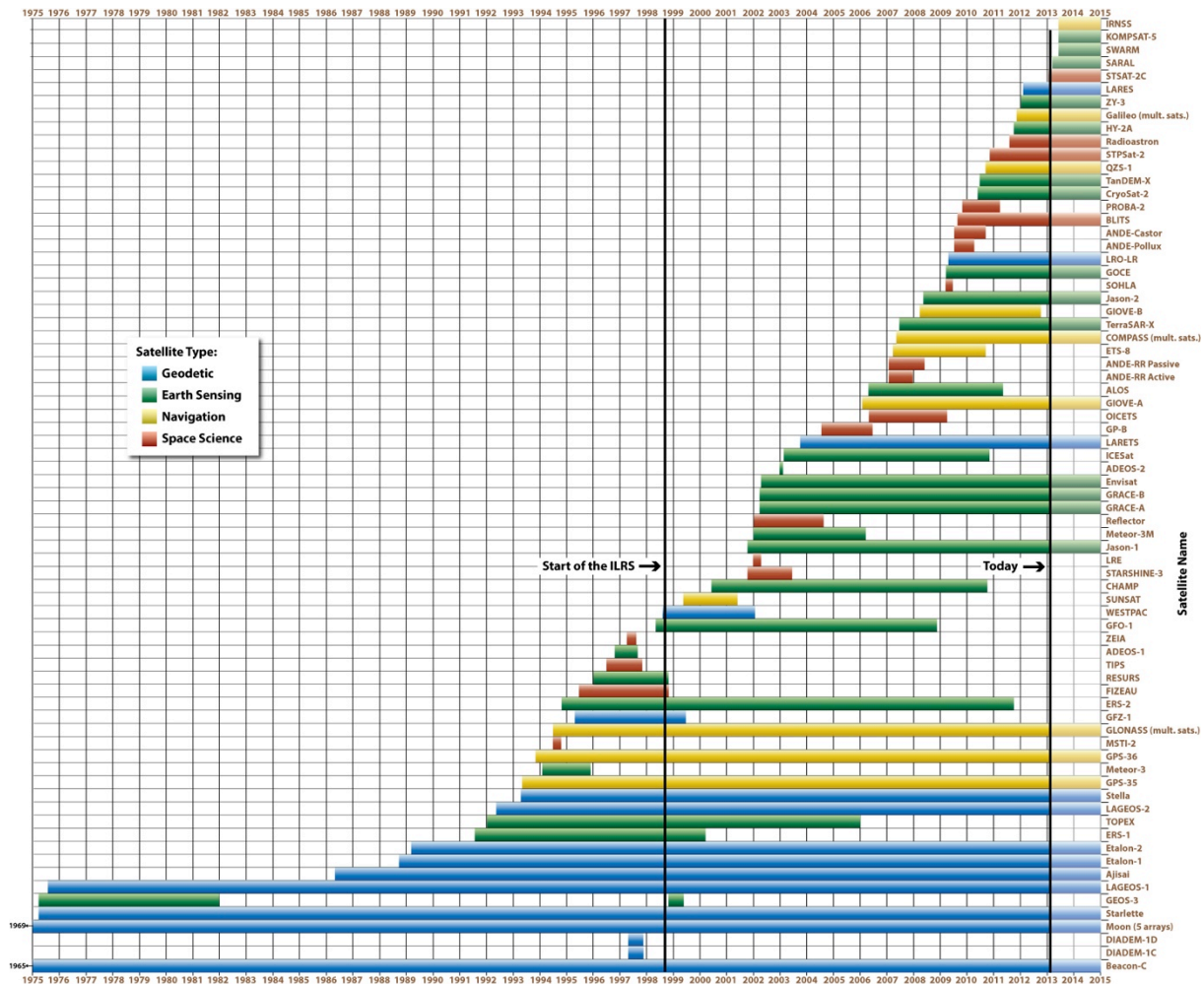


Figure 4. The past, current and future tracking roster for the ILRS network.

Missions are added to the ILRS tracking roster as new satellites are launched and as new requirements are adopted. Missions for completed programs are deleted from the ILRS (see Figure 4). Notable recent losses include the altimeter missions Envisat (ESA) and Jason-1 (NASA/CNES), after over ten years of ILRS support for each fully-operational mission. The ILRS continues to track Envisat to provide ephemerides and orientation data to help with trajectory/safety planning.

During this reporting period, LARES was added to the geodetic satellite constellation to support the reference frame and relativity studies. Several new satellites were added in Geosynchronous, Inclined geosynchronous and MEO orbits). The ILRS tracking roster presently includes six GLONASS satellites (102, 109, 110, 118, 129, 130), four Compass (G1, I3, I5, M3) and four Galileo satellites (101, 102, 103, 104). Following discussions at the ILRS Technical Workshop, Satellite, Lunar and Planetary Laser Ranging: Characterizing the Space Segment," in Frascati, Italy in November 2012, and elsewhere, several stations routinely track segments of passes of all 24 active GLONASS satellites. The newer “high” satellites are using retroreflector arrays that satisfy the ILRS standard. As a result stations are having greater success with daylight ranging.

The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS website ([http://ilrs.gsfc.nasa.gov/docs/2009/ilrmsr\\_0901.pdf](http://ilrs.gsfc.nasa.gov/docs/2009/ilrmsr_0901.pdf)).

The form provides the ILRS with the following information: a description of the mission objectives, mission requirements, responsible individuals and contact information, timeline, satellite subsystems, and details of the retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 2 along with their sponsors, intended application, and projected launch dates.

Table 2. Recently Launched and Upcoming Missions (as of July 2013)

Satellite Name	Sponsor	Purpose	Launch Date
<b>Recently Launched</b>			
Compass (5 satellites)	Chinese Defense Ministry	Positioning, navigation, timing	2007-2012
Galileo (4 satellites)	ESA	Positioning, navigation, timing	2011-2012
LARES	ASI/ESA	Geodesy, relativity	Feb-2012
SARAL	CNES/ISRO	Earth observation	Feb-2013
STPSat-2	AFRL	Spacecraft development	Nov-2010
STSAT-2C	Mest/KAIST	Spacecraft development	Jan-2013
<b>Approved by ILRS for Future SLR Tracking</b>			
IRNSS	ISRO	Positioning, navigation, timing	Jul-2013
KOMPSAT-5	KARI,	Earth observation	Aug-2013
SWARM	ESA	Earth observation	Dec-2013
<b>Future Satellites with Retroreflectors</b>			
ANDE-3	NRL	Atmospheric density determination	Dec-2013
GPS-III	U.S. DoD, DoT	Positioning, navigation, timing	TBD
HY-2B	CNES, CNSA	Earth observation	2012
HY-2C	CNES, CNSA	Earth observation	2015
HY-2D	CNES, CNSA	Earth observation	2019
ICESat-2	NASA	Ice sheet mass balance, sea level	2016
Jason-3	NASA, CNES, Eumetsat, NOAA	Oceanography, climate change	2015
Sentinel-3A and -3B	ESA (GMES)	Oceanography	2014
SWOT	NASA, CNES	SAR altimeter	2016

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

The ILRS network has been involved in one-way ranging and time transfer programs. The first time transfer experiment T2L2 continues to demonstrate improved time transfer capa-

bilities with the Jason-2 satellite; to date, time transfer to an accuracy of 100 ps has been demonstrated with potential of greater accuracy as the data analysis continues. A second time transfer proposal (ELT) utilizing a laser link for the atomic clock ensemble in space (ACES) mission on the ISS has progressed to the point that it is ready to be accepted for the baseline design of ACES. The ILRS actively supports the Lunar Reconnaissance Orbiter, where one-way laser ranging from a subset of the ILRS Network is being used to improve the orbit determination for the laser altimeter and surface positioning. Approximately a dozen ground stations have supported one-way ranging to LRO. The network has just past 3000 hours of tracking. Ground-based hardware simulations for planning and designing for laser transponder have been also been carried out by several groups looking forward to interplanetary ranging.

### **Lunar Laser Ranging (LLR) Network**

The LLR results are considered among the most important science return of the Apollo era. Currently, four active Lunar Laser Ranging (LLR) sites track the Moon routinely: the McDonald Observatory in Texas, USA, the Observatoire de la Côte d'Azur, France, the APOLLO site in New Mexico, USA and the Matera Laser Ranging station in Italy. The German Geodetic Observatory at Wettzell is still working on its system hoping to soon join the LLR tracking network. The measurement statistics of 2012 (Figure 5) exemplarily shows that about one third of the data have been collected at the APOLLO site, almost 60% of the data at the French site near Grasse.

Figure 6 illustrates the 2012 statistics for the observed reflectors, where - thanks to APOLLO and the upgraded French system - a much better coverage of all reflectors could be achieved than in the previous years. Figure 7 shows the entire LLR data set 1970-2012, indicating the amount of data collected by each of the active LLR sites in each year. It is about 17,700 normal points in total. A steady increase of LLR NP in the last years is obvious. Current LLR data are collected, archived and distributed under the auspices of ILRS. All former and current LLR data are electronically accessible through the CDDIS in Greenbelt, Maryland.

LLR data analysis is mainly carried out by four major LLR analysis centres: Jet Propulsion Laboratory (JPL), Pasadena, USA; Center for Astrophysics (CfA), Cambridge, USA; Paris Observatory Lunar Analysis Center (POLAC), Paris, France; Institute of Geodesy (IfE), University of Hannover, Germany.

One general objective is to achieve the mm level of accuracy for LLR data analysis. To meet this challenge, all elements of the tracking process have to be modelled at appropriate (relativistic) approximation, i.e., the orbits of the major bodies of the solar system, the rotation and deformation of Earth and Moon, the signal propagation, but also the involved reference and time systems. LLR remains one of the best tools to test General Relativity in the solar system. It allows for constraining gravitational physics parameters related to the strong equivalence principle, geodetic precession, preferred-frame effects, the time variability of the gravitational constant and others.

The four analysis centres have started a comparison initiative to mutually improve the various codes. Additionally from 2010 until 2012, an ISSI (International Space Science Institute, Berne, Switzerland) workshop series has been run dedicated to "Theory and model for the new generation of the Lunar Laser Ranging data", where experts from various disciplines discussed future challenges in LLR observation, modeling and analysis.



At the Observatoire de Paris, an “assisting tool” has been developed to support lunar tracking by providing predictions of future LLR observations as well as a validation of past LLR normal points. This tool and further information can be accessed via the ILRS website (<http://ilrs.gsfc.nasa.gov/science/scienceContributions/lunar.html>).

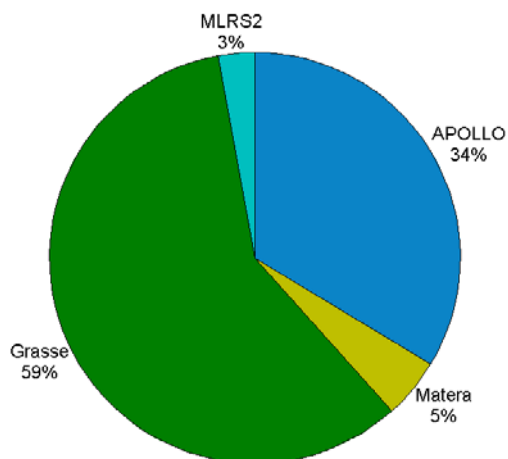


Figure 5. Observatory statistics in 2012.

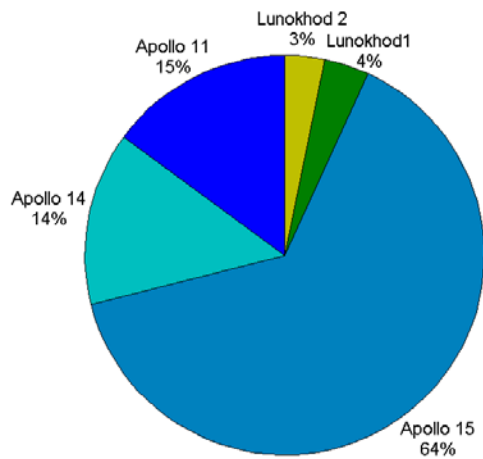


Figure 6. Reflector statistics in 2012.

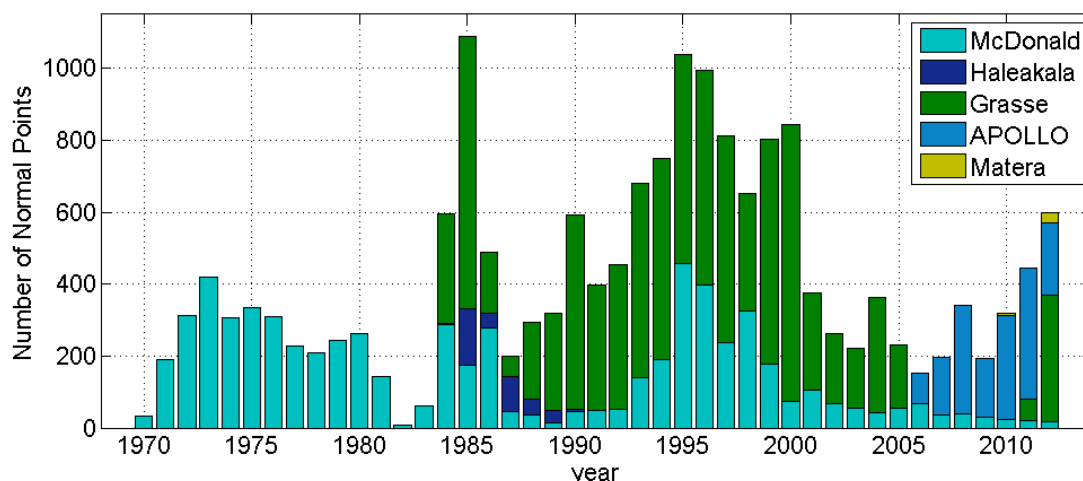


Figure 7. Data yield of the global LLR network of stations (up to 2012).

## Recent Activities

In April 2013, the ILRS was accepted as a network member of the International Council for Science (ICSU) World Data System (WDS). The WDS strives to enable open and long-term access to multidisciplinary scientific data, data services, products and information. The WDS works to ensure long-term stewardship of data and data services to a global scientific user community. The ILRS is a network member of the WDS, representing its two data centres and coordinating their activities within the WDS.

### ILRS Meetings

The ILRS organizes regular meetings of the Governing Board, General Assembly and working groups. These meetings are typically held in conjunction with ILRS workshops, such as

the fall technical workshops (oriented toward SLR practitioners) or the biannual International Workshop on Laser Ranging. A summary of recent and planned ILRS meetings is shown in Table 3. Minutes and presentations from these meetings are available from the ILRS website ([http://ilrs.gsfc.nasa.gov/about/reports/meeting\\_reports.html](http://ilrs.gsfc.nasa.gov/about/reports/meeting_reports.html)).

The ILRS also conducts meetings of the Central Bureau on a monthly basis. These meetings review network stations and support for upcoming missions as well as coordinate support of upcoming missions, monitoring and managing the ILRS infrastructure, and future directions and activities, such as the implementation of the new ILRS website.

Table 3. Recent ILRS Meetings (as of July 2013)

Timeframe	Location	Meeting
May 2011	Bad Kötzing, Germany	17 <sup>th</sup> International Workshop on Laser Ranging ILRS Governing Board meeting ILRS Working Group meetings ILRS General Assembly
September 2011	Zurich, Switzerland	ILRS Analysis Working Group meeting
December 2011	San Francisco CA, USA	ILRS Governing Board meeting
April 2012	Vienna, Austria	ILRS Governing Board meeting ILRS Working Group meetings
November 2012	Frascati, Italy	ILRS Technical Workshop “Satellite, Lunar, and Planetary Laser Ranging: Characterizing the Space Segment” ILRS Governing Board meeting ILRS Working Group meetings
April 2013	Vienna, Austria	ILRS Analysis Working Group meeting
November 2013	Fujiyoshida, Japan	18 <sup>th</sup> International Workshop on Laser Ranging ILRS Governing Board meeting ILRS Working Group meetings ILRS General Assembly

The ILRS Technical Workshop 2012: “Satellite, Lunar and Planetary Laser Ranging: characterizing the space segment” was held at the Frascati National Laboratories of the INFN-LNF, Frascati, Italy on November 5-9, 2012, in conjunction with a one-day Workshop on “ASI-INFN ETRUSCO-2 Project of Technological Development and Test of SLR Payloads for GNSS Satellites.” The meeting focused on the laser ranging space segment including retro-reflector arrays for Earth orbiting satellites and the moon, with special attention to the expanding role of ranging to GNSS and geosynchronous satellites. Topics also included receivers in space for time transfer experiments (T2L2), one-way ranging to lunar orbiters (LRO) and interplanetary spacecraft (MLA, MOLA), and data relay systems.

The next International Laser Ranging Workshop will be held in Fujiyoshida Japan, November 11-15, 2013. The theme of the 18<sup>th</sup> workshop will be “Pursuing Ultimate Accuracy and Creating New Synergies.” An important topic for this workshop will be maximizing accuracy in the network with the intent of enhancing the potential for laser ranging by including activities in relevant fields.

### *Publications*

Detailed reports from past meetings can be found on the ILRS website. ILRS Biannual Reports summarize activities within the service over the period since the previous release. They are available as hard copy from the CB or online at the ILRS website. The ILRS published the 2009-2010 ILRS Report in late 2012. This latest volume is the fifth published report for the ILRS and concentrated on achievements and work in progress rather than ILRS organizational elements.

In October 2012, the ILRS Central Bureau implemented a new design for the ILRS website, <http://ilrs.gsfc.nasa.gov>. The redesign process allowed for a review of the organization of the site and its contents, ensuring information was made current and remained useful to the laser ranging community.

ILRS Analysis Centre reports and inputs are used by the Central Bureau for review of station performance and to provide feedback to the stations when necessary. Special weekly reports on on-going campaigns are issued by email. The CB also generates quarterly Performance Report Cards and posts them on the ILRS website. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. These results include independent assessments of station performance from several of the ILRS analysis/associate analysis centres. The statistics are presented in tabular form by station and sorted by total passes in descending order. Plots of data volume (passes, normal points, and minutes of data) and RMS (LAGEOS, Starlette, calibration) are created from this information and available on the ILRS website. Plots, updated frequently, of multiple satellite normal point RMS and number of full-rate points per normal point as a function of local time and range have been added to the ILRS website station pages.

## International VLBI Service for Geodesy and Astrometry (IVS)

<http://ivscc.gsfc.nasa.gov>

*Chair of the Directing Board: Axel Nothnagel (Germany)*

*Director of the Coordinating Center: Dirk Behrend (USA)*

### Overview

This report summarizes the activities and events of the International VLBI Service for Geodesy and Astrometry (IVS) during the report period of 2011–2013.

### Activities

#### Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) is an approved service of the International Association of Geodesy (IAG) since 1999 and of the International Astronomical Union (IAU) since 2000. The goals of the IVS, which is an international collaboration of organizations that operate or support Very Long Baseline Interferometry (VLBI) components, are

- to provide a service to support geodetic, geophysical and astrometric research and operational activities,
- to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique, and
- to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

The VLBI technique has been employed in geodesy for more than 40 years. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI's technical limitations. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing numerous quasar positions as the best approach to an inertial reference frame, VLBI significantly contributed to the tremendous progress made in geodesy over the last decades. VLBI was a primary tool for understanding the global phenomena changing the “Solid Earth”. Today VLBI continuously monitors Earth orientation parameters as well as crustal movements in order to maintain global reference frames, coordinated within the IVS.

Being tasked by IAG and IAU with the provision of timely and, highly accurate products (Earth Orientation Parameters, EOP; Terrestrial Reference Frame, TRF; Celestial Reference Frame, CRF), but having no funds of its own, IVS strongly depends on the voluntary support of individual agencies that form the IVS.

#### Organization and Meetings

The Directing Board determines policies, adopts standards, and approves the scientific and operational goals for IVS. The Directing Board exercises general oversight of the activities of IVS including modifications to the organization that are deemed appropriate and necessary to maintain efficiency and reliability.

Taking effect in January 2013, Bill Petrachenko of Natural Resources Canada took over the position of the IVS Technology Coordinator from Alan Whitney. After 13 years of service, Axel Nothnagel handed over the responsibilities of the IVS Analysis Coordinator to John Gipson of NVI, Inc./NASA Goddard Space Flight Center on March 8, 2013.

The IVS held Directing Board elections for four representative and three at-large positions in Dec2012/Jan2013. The new sixteen Directing Board members elected Axel Nothnagel of the University of Bonn as the successor to Harald Schuh as chair of the IVS for the next four years (until spring 2017).

Table 1. Members of the IVS Directing Board during the report period (2011–2013).

<b>a) Current Board members (June 2013)</b>			
<b>Directing Board Member</b>	<b>Institution, Country</b>	<b>Functions</b>	<b>Recent Term</b>
Dirk Behrend	NVI, Inc./NASA GSFC, USA	Coordinating Center Director	—
Alessandra Bertarini	IGG, University of Bonn, Germany	Correlators and Operation Centers Representative	Feb 2011 – Feb 2015
Patrick Charlot	Bordeaux Observatory	IAU Representative	—
John Gipson	NVI, Inc./NASA GSFC, USA	Analysis Coordinator	—
Rüdiger Haas	Onsala Space Observatory, Sweden	Technology Development Centers Representative	Feb 2013 – Feb 2017
Hayo Hase	BKG, Germany; TIGO, Chile	Networks Representative	Feb 2011 – Feb 2015
Ed Himwich	NVI, Inc./NASA GSFC, USA	Network Coordinator	—
Alexander Ipatov	Institute of Applied Astronomy, Russia	At Large Member	Feb 2013 – Feb 2015
Shinobu Kurihara	Geospatial Information Authority, Japan	At Large Member	Feb 2013 – Feb 2015
Jim Lovell	University of Tasmania, Hobart, Australia	Networks Representative	Feb 2013 – Feb 2017
Chopo Ma	NASA Goddard Space Flight Center, USA	IERS Representative	—
Arthur Niell	Haystack Observatory, USA	Analysis and Data Centers Representative	Feb 2013 – Feb 2015
Axel Nothnagel	IGG, University of Bonn, Germany	Analysis and Data Centers Representative, Chair	Feb 2013 – Feb 2017
Bill Petrachenko	Natural Resources Canada	Technology Coordinator	—
Harald Schuh	GFZ Potsdam, Germany	IAG Representative	—
Fengchun Shu	Shanghai Astronomical Observatory, China	At Large Member	Feb 2013 – Feb 2015

<b>b) Previous Board members in 2011–2013</b>			
Jesús Gómez González	National Geographical Institute, Spain	At Large Member	Feb 2011 – Feb 2013
Oleg Titov	Geoscience Australia	Analysis and Data Centers Representative	Feb 2009 – Feb 2013
Gino Tuccari	IRA/INAF, Italy	Networks Representative	Feb 2009 – Feb 2013
Alan Whitney	Haystack Observatory, USA	Technology Coordinator	—

From 21-22 September 2011, the IVS Directing Board (plus a few invited guests) held a retreat at Hohe Wand, Austria. The main goals of the retreat were a review of the IVS organization and its mandate, functions, and components as well as the definition of focus areas for future IVS work and activities. The retreat participants agreed that the IVS organization, mandate, and functions as outlined in the IVS Terms of Reference (ToR) continued to fulfill the requirements of the global geodetic/astrometric VLBI science and associated user communities. The ToR were revised to simplify and modernize the wording, to add the Global Geodetic Observing System (GGOS), and to increase the Board by the addition of a second Analysis Center representative. The revised ToR were approved by the Board in the subsequent Board meeting and then officially ratified by the IAG in December. The revised ToR can be found, for instance, on the IVS Web site at the URL <http://ivscc.gsfc.nasa.gov/about/org/documents/ivsTOR.html>. In terms of focus areas, the retreat participants felt that emphasis should be put on improving quality control, internal and external outreach, VLBI2010 infrastructure, real-time observation and product creation (including automation), and expanding research and research fields. The results of the discussion were compiled into a declaration (Hohe Wand Declaration).

The IVS organizes biennial General Meetings and biennial Technical Operations Workshops. Other workshops such as the Analysis Workshops and VLBI2010 technical meetings are held in conjunction with larger meetings and are organized once or twice a year. Table 2 gives an overview of the IVS meetings during the report period.

Table 2. IVS meetings during the report period (2011-2013).

Time	Meeting	Location
31 March 2011	12 <sup>th</sup> IVS Analysis Workshop	Bonn, Germany
9-12 May 2011	6 <sup>th</sup> IVS Technical Operations Workshop	Westford, MA, USA
13-16 November 2011	10 <sup>th</sup> International e-VLBI Workshop	Broederstroom, South Africa
1-2 March 2012	VLBI2010 Workshop on Technical Specifications (TecSpec)	Bad Kötzing, Germany
4-9 March 2012	7 <sup>th</sup> IVS General Meeting	Madrid, Spain
8 March 2012	13 <sup>th</sup> IVS Analysis Workshop	Madrid, Spain
22-24 October 2012	1 <sup>st</sup> International VLBI Technology Workshop	Westford, MA, USA
2-5 March 2013	VLBI Training School	Espoo, Finland
5 March 2013	14 <sup>th</sup> IVS Analysis Workshop	Espoo, Finland
6-9 May 2013	7 <sup>th</sup> IVS Technical Operations Workshop	Westford, MA, USA

Noteworthy among the list of meetings are for one the VLBI2010 Workshop on Technical Specifications (TecSpec), which was tailored towards the station side of VLBI2010 and thus focused almost exclusively on the station specifications and hardware. Items covered went from the fast-slewing antennas to wideband feeds and front-ends to back-ends and recorders. Additional topics included e-transfer and e-VLBI, monitor and control, and clock distribution. The TecSpec workshop attracted almost 100 people, testament to the very high interest in the new VLBI system. At the 7<sup>th</sup> IVS General Meeting (GM2012), the new acronym for the next generation VLBI network was introduced: the new network was christened “VGOS” (VLBI2010 Global Observing System). With 150 participants from 25 countries representing 65 institutions, GM2012 was the ideal venue to launch the next-generation IVS network.

Another noteworthy meeting was the VLBI Training School in Espoo, Finland. This was the first such school organized by the IVS (through Working Group 6) and it is anticipated to be repeated in a three-year rhythm. Over a period of four days about 50 participants were schooled in all aspects of the VLBI technique. The school was very successful in training young researchers in the VLBI technique thus paving the way to preparing the next generation of VLBI experts in parallel to the development of the next-generation VLBI system.

### *Working Groups*

*VLBI Data Structures.* The Working Group 4 on VLBI Data Structures examines the data structure currently used in VLBI data processing and investigates what data structure is likely to be needed in the future. It will design a data structure that meets current and anticipated requirements for individual VLBI sessions including a cataloguing, archiving and distribution system. Further, it will prepare the transition capability through conversion of the current data structure as well as cataloguing and archiving software to the new system.

*Space Science Applications.* The Working Group 5 on Space Science Applications investigates synergies between IVS and VLBI space science applications, looks for mutually beneficial collaborations, and prepares a white paper giving recommendations for future actions.

*VLBI Education.* The Working Group 6 on VLBI Education explores educational activities, such as summer schools or training seminars, which will help in the formation of a new generation of VLBI experts.

## **Observing Program and Special Campaigns**

### *Observing Program*

The observing program for 2011–2013 included the following sessions:

- EOP: Two rapid turnaround sessions each week, mostly with 8 stations, some with 9 or 10 stations depending on station availability. These networks were designed with the goal of having comparable  $x_p$  and  $y_p$  results. Data bases are available no later than 15 days after each session. Daily 1-hour UT1 Intensive measurements on five days (Monday through Friday, Int1) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA), on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan), and since August 2007 on Monday mornings (Int3) in the middle of the 36-hour gap between the Int1 and Int2 Intensive series on the network Wettzell (Germany), Ny-Ålesund (Norway), and Tsukuba (Japan).
- TRF: Bi-monthly TRF sessions with 14–16 stations using all stations at least two times per year.
- CRF: Bi-monthly RDV sessions using the Very Long Baseline Array (VLBA) and up to eight geodetic stations, plus astrometric sessions to observe mostly southern sky sources.
- Monthly R&D sessions to investigate instrumental effects, research the network offset problem, and study ways for technique and product improvement.
- Triennial ~two-week continuous sessions to demonstrate the best results that VLBI can offer, aiming for the highest sustained accuracy.

Although certain sessions have primary goals, such as CRF, all sessions are scheduled so that they contribute to all geodetic and astrometric products. Sessions in the observing program that were recorded and correlated using K5 technology had the same accuracy and timeliness

goals as those using Mark 5. On average, a total of about 1400 station days per year were used in around 180 geodetic sessions during the year keeping the average days per week which are covered by VLBI network sessions at 3.5.

### *CONT11*

In September 2011, a 15-day continuous VLBI observation campaign called CONT11 was observed. As in previous campaigns, CONT11 acquired state-of-the-art VLBI data to demonstrate the highest accuracy of which the current VLBI system is capable. Among many possible studies, the data will be used for high-resolution Earth rotation studies, investigations of reference frame stability, and investigations of daily to sub-daily site motions. The scientific use of the previous continuous VLBI campaign (CONT08) was, among other places, published in a special issue of the *Journal of Geodesy*. The observing network consisted of thirteen IVS stations (see Figure 1). The actual observing was done at a rate of 512 Mbps on the basis of UT days with each CONT11 day running from 0 UT to 24 UT. UT-day observing is needed to facilitate the most accurate combination and comparison with results from other techniques. For the duration of the CONT11 campaign an ultra-rapid dUT1 determination was performed on the baseline Onsala–Tsukuba. Dedicated fiber lines were set up in order to e-transfer the data to the Tsukuba correlator. Near real-time correlation and analysis was performed using a sliding window in the analysis with the analysis software C5++. dUT1 estimates were obtained with very low latency during the ongoing CONT11 campaign and displayed on a dedicated Web page.

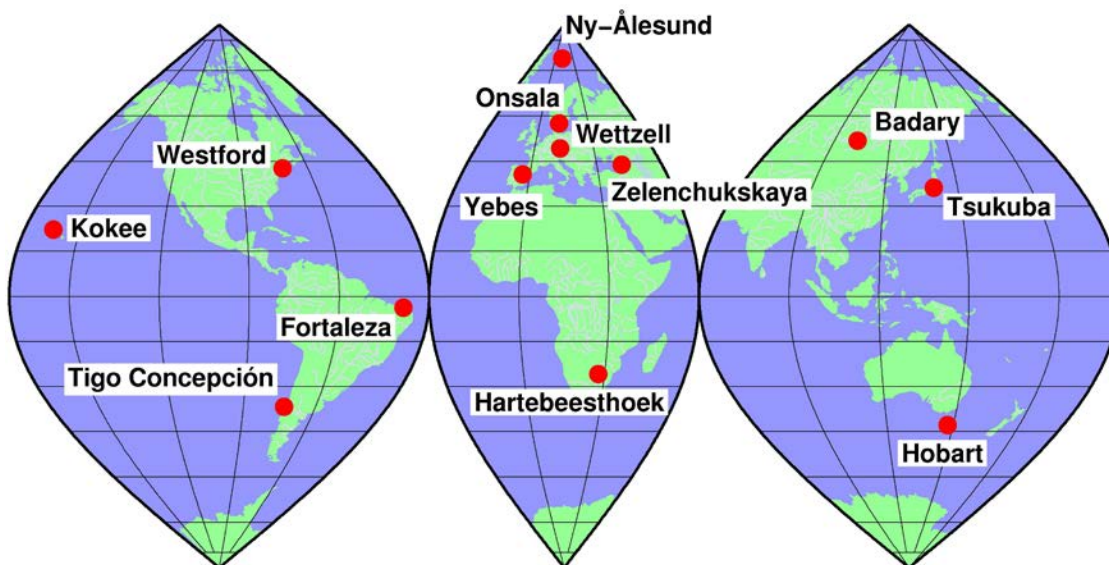


Figure 1. Geographical distribution of the thirteen IVS stations that participated in the CONT11 campaign in September 2011.

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## **Analysis**

### *Earth Orientation Parameters.*

The operational combination was carried out by the IVS Combination Center at the German Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt a.M. The input for the combination work were datum-free (constraint-free) normal equation systems in SINEX format (Solution INdependent EXchange format) containing elements for radio source positions, Earth orientation parameters, and radio telescope coordinates. Two primary combined EOP results were produced: rapid combination solutions and quarterly combination solutions. The rapid solutions were updated twice a week and contained only the IVS-R1 and IVS-R4 sessions; new data points were added as soon as the SINEX files of at least four IVS Analysis Centres were available. The long-term series were generated on a quarterly basis and included all 24-hour sessions since 1984. The quarterly series included long-term EOP series, station positions, and velocities. The results of the combination process were uploaded to the IVS Data Centres. The combined rapid EOP series, as well as the results of the quality control of the Analysis Centre results, were also available directly at the BKG/DGFI Combination Centre Web page (<http://ccivs.bkg.bund.de/>) or via the IVS Analysis Coordinator Web site ([http://lupus.gsfc.nasa.gov/IVS-AC\\_products.htm](http://lupus.gsfc.nasa.gov/IVS-AC_products.htm)). The inclusion of new Analysis Centres continued, a newly designed Web page was brought online, and the Web-based analysis tools were further enhanced.

### *Atmospheric Gradient Modeling*

At the 13<sup>th</sup> IVS Analysis Workshop it was decided that the Chen and Herring model (1997) should be the conventional model of the IVS, using the constant  $C = 0.0031$  for estimating the hydrostatic gradient. Since the hydrostatic contribution is the biggest one and the coefficient for the total gradient contribution is only slightly different ( $C = 0.0032$ ), no noticeable effect on the estimates is expected. The MacMillan model (1995) produces essentially the same results, but for consistency with the analyses of the IGS, the Chen and Herring model was adopted.

## **Technology Development**

### *DiFX Software Correlator for Geodetic VLBI*

The so-called DiFX software correlator was originally developed at Swinburne University in Australia by Adam Deller, primarily for astronomical VLBI use. The development of an economical and powerful software correlator, a dream less than a decade ago, has been made possible by the relentless march of Moore's Law to provide powerful inexpensive clustered PCs with high-speed data interconnections that can distribute and correlate VLBI data in an

efficient manner. Several institutions that support geodetic VLBI correlation processing now have DiFX correlators (MPIfR, U.S. Naval Observatory, and Haystack Observatory) and have been working to augment the core DiFX software to meet the needs of geodetic VLBI. This includes the integration of much of the Mark IV post-correlation software involving data-management, output data formats, fringe finding and delay estimates, and editing/quality-assurance software. In addition, a substantial amount of work has been done to support the VDIF data-input format and to support correlation of mismatched sample rates and recording bandwidths.

### *VLBI2010 Broadband System*

The VLBI2010 system continues to be developed at several locations:

1. The VLBI2010 13-m ‘twin-telescopes’ installed at Wettzell were formally inaugurated in April 2013. RMS surface accuracy is better than 60 micrometers, and the antenna and the subreflector are aligned. A tri-band feed will be installed soon, followed by measurements of G/T and pointing tests. A new broadband “Eleven” feed and accompanying receiver and recording systems are currently being installed.
2. The broadband ‘QRFH’ 2–14 GHz broadband feed from Caltech was successfully tested on the VLBI2010 prototype antenna at NASA/GGAO and will soon also be installed on the Westford antenna. Experimental results for beam patterns and efficiencies closely match theoretical predictions. The QRFH feed can be easily re-designed to accommodate a wide variety of antenna geometries.
3. Digital-backend development continues in China, Europe, Japan, Russia, and the United States. A VLBI Digital-Backend Intercomparison Workshop was conducted at Haystack Observatory in October 2012 to test inter-compatibility between independently developed DBE units.
4. Mark 6 VLBI data system: The Mark 6 system is entering service at 8 Gbps. Several successful experiments have already been conducted, and the system continues to be made more robust. Routine service at 8 Gbps is expected in the first half of 2013, with expansion to 16 Gbps by the end of 2013.
5. A number of VLBI2010 data-taking sessions between Westford and NASA/GSFC were conducted during 2012, including several operating at 8 Gbps/station. Many were recorded onto four Mark 5C units at each station using RDBE backend units as data sources, at an aggregate data rate of 8 Gbps/station, but a single Mark 6 is now able to replace the four Mark 5C units. More of the processing of VLBI2010 data continues to be moved from the Mark IV correlator to the DiFX correlator at Haystack Observatory as the DiFX correlator becomes more capable of processing VLBI2010 data.

### *Successful 24-hour test of VGOS Broadband Delay System*

On May 21, 2013, the first 24-hour session using the VGOS broadband delay system was observed on the GGAO12M–Westford baseline. The antennas, RDBE digital backends, and Mark-5C recorders were all operated under Field System control. The VGOS-ready 12-meter GGAO antenna and the 18-meter Westford antenna were each equipped with a cooled QRFH feed tailored to the specific antenna optics, followed by two cooled low noise amplifiers, one for each polarization. With a minimum scan length of 30 seconds and the minimum SNR set to 15 per band-polarization, the schedule achieved 48 scans per hour. Four 512-MHz-bands spanning 3.2 to 8.8 GHz within the available 2–12 GHz range were recorded at 2 Gbps (1 Gbps for each linear polarization) for a total of 37 Terabytes per station. Over 99% of the scans yielded good correlation.

## VGOS

At its 7th General Meeting, the IVS inaugurated the VLBI2010 Global Observing System (VGOS). On completion VGOS will be a global network of new fast radio telescopes (up to 12 deg/s) and high capacity data acquisition systems (up to 8 Gbps) optimized for Earth orientation and terrestrial reference frame determinations. Consideration of radical modernization of geodetic VLBI infrastructure began in 2002 leading to community agreement on the VLBI2010 concept. Since then the concept has been elaborated to include cutting edge technology and specifications to optimize accuracy, reliability, and near real-time data delivery while controlling costs. The concept includes more than one radio telescope per site (wherever possible), remote-controlled continuous observations, and automated correlation and data analysis. In this decade several projects have already successfully started to implement parts of the VLBI2010 technology. New radio telescope projects and data acquisition developments are underway world-wide. Simulations have shown that the VLBI2010 Global Observing System can outperform the past observations by almost an order of magnitude. VGOS will be the VLBI component of the Global Geodetic Observing System (GGOS).

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## Permanent Service for Mean Sea Level (PSMSL)

<http://www.psmsl.org>

*Director: Lesley J. Rickards (UK)*

### Overview

The Permanent Service for Mean Sea Level (PSMSL) is based at the National Oceanography Centre (NOC, formerly Proudman Oceanographic Laboratory (POL)) on the campus of the University of Liverpool in the UK. It acts as the global data bank for long term sea level information from tide gauges, and provides a wider service to the sea level community. For many years it has been a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and operates under the auspices of the International Council for Science (ICSU). PSMSL is in the process of applying for membership of the new ICSU World Data System (WDS).

PSMSL was established in 1933 by Joseph Proudman who became its first Secretary. Thus 2013 marks the 80th anniversary of the founding of PSMSL. To celebrate this milestone, PSMSL has organised or co-organised three meetings:

- A session at EGU 2013: Global and regional sea level rise and variability: from past to future (April 2013).
- A symposium entitled "Implications of sea level change for the coastal zone - A symposium to mark the 80th anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the IAHS/IAPSO/IASPEI Joint Assembly in Gothenburg, Sweden (July 2013).
- A workshop in Liverpool, UK, on major research topics in sea level science. The workshop, to be held in October, will include talks reviewing aspects of the IPCC Fifth Assessment Report (Working Group I). There will also be presentations covering many aspects of regional variability in sea level.

The primary aim of the PSMSL is to provide the global data bank for long term sea level information from tide gauges. PSMSL has continued to increase its efforts in this regard and over the last 2 years over 41000 station-months of data were entered into the PSMSL database, increasing the total PSMSL data holdings to over 717000 station-months. The entire PSMSL data set is available from the website: [www.psmsl.org](http://www.psmsl.org), along with new products to aid access and exploration of the data set (e.g. station, trend and anomaly maps). In addition, the PSMSL, together with the British Oceanographic Data Centre (BODC), are responsible for the archive of delayed-mode higher-frequency sea level data (e.g. hourly values and higher frequency) from the Global Sea Level Observing System (GLOSS) core network.

The PSMSL has continued its close involvement in the development of a sea level network in Africa (through the Ocean Data and Information Network for Africa – ODINAfrica – project) through colleagues in the Ocean Engineering and Technology Group (OETG) of NOC. The OETG have worked with local tide gauge operators as necessary on the installation, maintenance and resolution of problems at the African and Indian Ocean tide gauges. In particular, they have continued to provide advice to GLOSS on OTT gauges, data transmission and Broadband Global Area Network (BGAN) systems. Specifically, over the last 2 years ongoing training and support has been provided to the tide gauge operators for the tide gauges in Cameroon, Ghana and Nigeria.

Technology development to support the GLOSS programme has included design and assembly of a second generation sea level measuring station system that requires limited operator intervention, and the development of a facility and methodology for calibration of offsets in the measured range of the radar and for estimation of radar range accuracy; obviating the need for local operators to make dipping measurements.

PSMSL staff have continued to be active in a variety of international meetings, working groups, conferences and workshops including IOC GE-GLOSS and IOC Coordination Groups for tsunami warning systems, IPCC, GGOS, and EGU. In addition, they have answered many enquires relating to sea level and have appeared on radio and television discussing aspects of sea level change.

## **Activities**

### **1. Introduction**

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has operated at the National Oceanography Centre (NOC), Liverpool (and its predecessors), with the aims of providing the global data bank for long term sea level information from tide gauges, and of providing a wider Service to the sea level community. It was a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) until its dissolution and works under the auspices of the International Council for Science (ICSU) and is applying for membership of the new ICSU World Data System (WDS).

The data set and ancillary information are provided free of charge and are made available to the international scientific community through the PSMSL website. The metadata includes descriptions of benchmarks and their locations, types of instrumentation and frequency of data collection (where available) as well as notes on other issues that we feel the users should be aware of (e.g. earthquakes that are known to have occurred in the vicinity or subsidence due to local groundwater extraction). The free access to data by users is central to the PSMSL's mission, and conversely no supplier is ever paid for their data, nor are licensing terms ever entered into.

### **2. Staffing and funding**

Dr. Lesley Rickards continues as the Director of the PSMSL. The main PSMSL scientific staff concerned with the collection and analysis of monthly mean sea level data have been Prof. Philip Woodworth, Dr. Simon Holgate, Dr. Svetlana Jevrejeva and Dr. Mark Tamisiea. Ms. Kathy Gordon continues to be responsible for management of the mean sea level data set and Dr. Andrew Matthews has worked on re-structuring the database, improving data delivery and providing new tools to aid data input, quality control and reporting. Last year saw the departure of Dr. Simon Holgate, who we thank for all of his contributions over the last 10 years. And we welcome Dr. Simon Williams, already a well-established scientist within NOC, to the PSMSL scientific staff.

Alongside the monthly mean sea level data collection, the PSMSL, together with BODC, is responsible for an archive of delayed-mode higher-frequency sea level data from the GLOSS network. This activity has so far included Miss Elizabeth Bradshaw and other colleagues in the British Oceanographic Data Centre (BODC).

Funding continues to be provided by the UK Natural Environment Research Council (NERC, the parent body of NOC). The document prepared in 2010 by PSMSL for NERC as part of its review of National Capability to aid future funding decisions resulted in PSMSL being one of the two areas in NOC given a high rating enabling us to continue to operate at the same level of funding. The document highlighted PSMSL's unique role and the synergy generated by its co-location with NOC.

### **3. PSMSL-related scientific meetings, activities and events**

PSMSL staff have continued to be active participants in the IOC Group of Experts on the Global Sea Level Observing System (GLOSS) and Global Geodetic Observing System (GGOS) meetings, and co-convened sea level sessions at the EGU. PSMSL has contributed to the IPCC Fifth Assessment Report with Dr Svetlana Jevrejeva a lead author for Working Group I, Prof. Philip Woodworth a review editor and other PSMSL staff also contributing.

2013 marks the 80th anniversary of the foundation of the PSMSL. To commemorate this PSMSL is hosting or co-convening the following events:

- A workshop in Liverpool, UK, on major research topics in sea level science. The workshop, to be held in October, will include talks reviewing aspects of the IPCC Fifth Assessment Report (Working Group I). There will also be presentations covering many aspects of regional variability in sea level.
- A symposium entitled "Implications of sea level change for the coastal zone - A symposium to mark the 80th anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the IAHS/IAPSO/IASPEI Joint Assembly in Gothenburg, Sweden (July 2013).
- A session at EGU 2013: Global and regional sea level rise and variability: from past to future (April 2013).

### **4. Collection, analysis, publication and interpretation of monthly and annual means of sea level from the global network of tide gauges**

Between August 2011 and July 2013, approximately 41181 station-months of MSL data from about 866 stations were added to the PSMSL databank (and a further 2978 months were updated), bringing the total PSMSL data holdings to over 717504 station-months from 2170 stations. Most of the data originated from Europe and North America together with significant data sets from Japan and Australia. There are gaps in data receipts from parts of SE Asia, central and South America; these are presently being targeted to try to improve data flow. Africa continues to receive special attention through ODINAfrica and the Indian Ocean Tsunami Warning System (IOTWS), although data flow has improved considerably over the last decade. Close links have been maintained with the University of Hawaii Sea Level Center and other international sea level data centres.

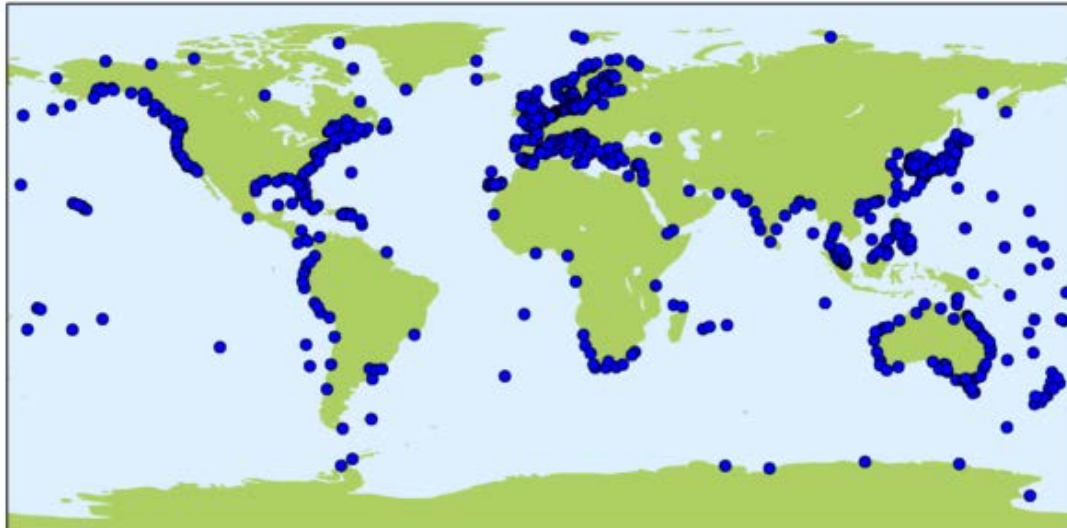


Figure 1: Stations providing new data received between August 2011 and July 2013

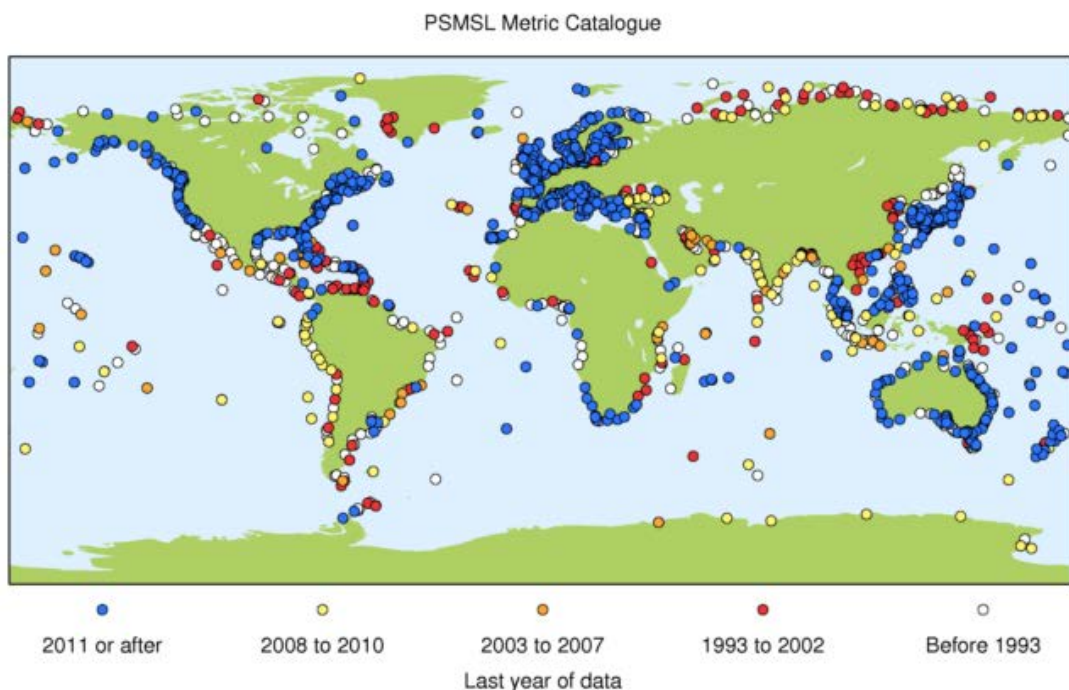


Figure 2: Year of most recent data received by PSMSL

## 5. PSMSL web-site and products

The PSMSL website ([www.psmsl.org](http://www.psmsl.org)) continues to be developed. The dedicated station web pages have been enhanced and now include links to other GLOSS related data streams (e.g. high frequency and real-time tide gauge data and GPS at tide gauges). In order to improve ease of access and exploration of the PSMSL data set, there are now several ways of obtaining the data: files and plots of individual stations can be accessed *via* a map-based explorer or a table, or the entire dataset can be downloaded.

### 5.1 Interactive map showing long-term trends

The relative sea level trends map allows interactive investigation of global mean sea level trends since 1900. A period of at least thirty years must be selected. The map will display the annual sea level trend at each station that has suitable data available over the selected period. The methods page ([www.psmsl.org/products/trends/methods.php](http://www.psmsl.org/products/trends/methods.php)) has further details.

Note that these measured trends are not corrected for local land movement. Furthermore, no attempt has been made to assess the validity of any individual fit, so results should not be treated as a publication quality values suitable for use in planning or policy making.

The map should be used with some care as anomalous trends have many causes:

- land movements (e.g. earthquakes, glacial isostatic adjustment)
- unexplained instrumental datum shifts
- changes in atmospheric pressure
- short records

A more complete account can be found in the geophysical signals section of the PSMSL website (see: [www.psmsl.org/train\\_and\\_info/geo\\_signals/](http://www.psmsl.org/train_and_info/geo_signals/)). A table of long term trends derived from annual mean values of sea level in the PSMSL RLR data set demonstrates the rate of change of sea level at each station.

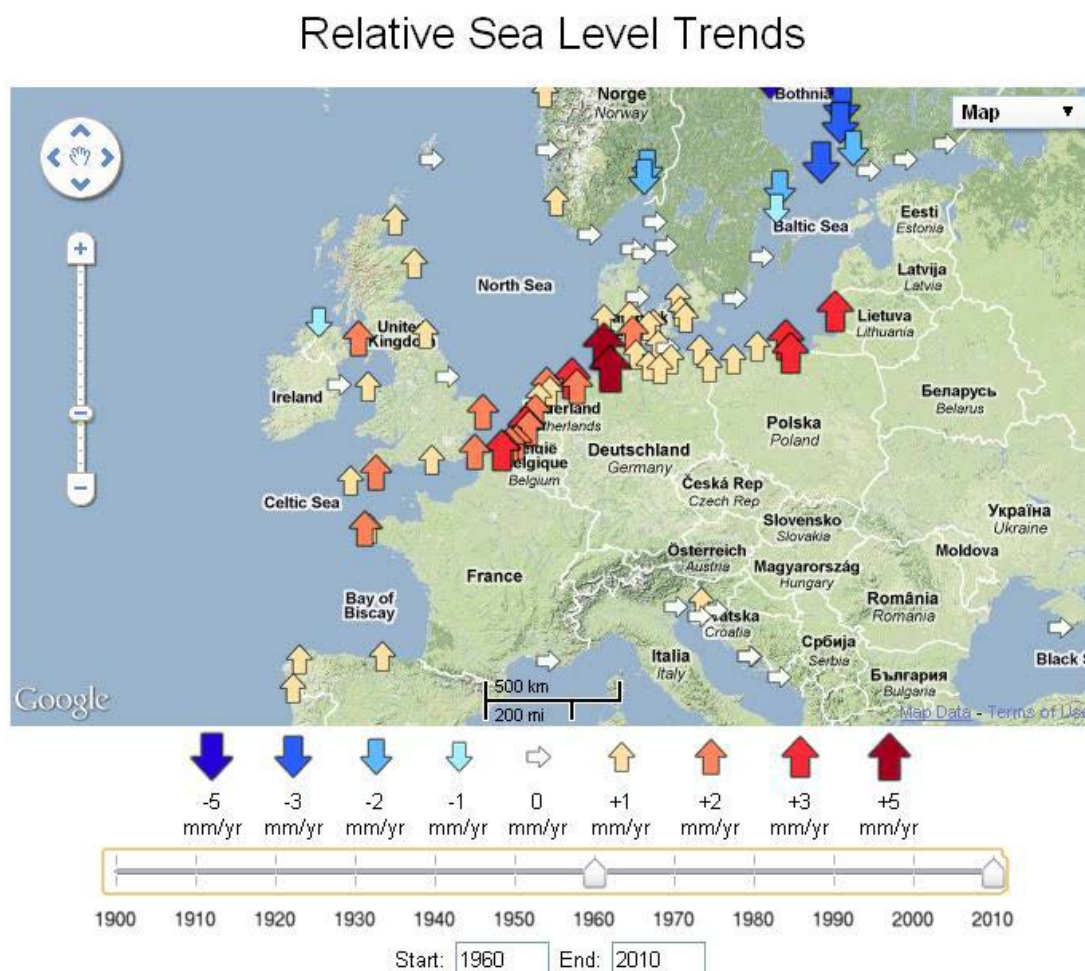


Figure 3: Sample map showing relative sea level trends



### 5.2 Interactive map showing sea level anomalies

Annual mean sea level can vary considerably from year to year in response to various meteorological and oceanographic forcings, typically by hundreds of millimetres. The product allows one to examine the global variations in a year of your choice. The map presents the difference between the annual RLR data for each station (which is quality and datum controlled) compared to that station's long term mean over the baseline period of 1960-1990.

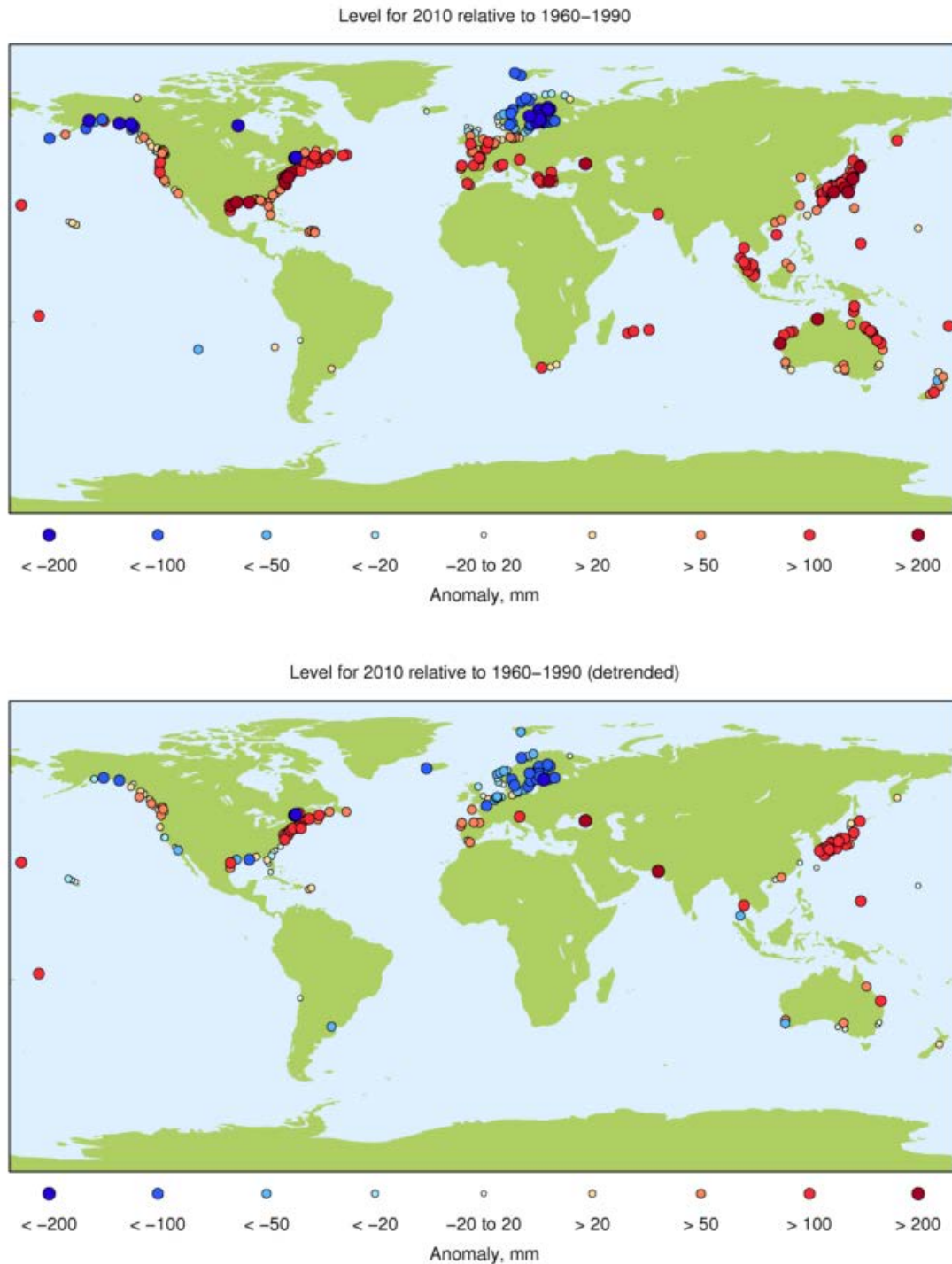


Figure 4: Sea level anomalies for 2010 relative to 1960-1990.  
(Top image: not detrended. Bottom image: detrended)

The long term trend at each station (estimated using the baseline period) can be removed if required. This will prevent results being dominated by long term changes, but will result in the loss of stations for which there is not enough data to calculate a trend. Further information is provided on the methods and derived trends pages of the PSMSL web-site.

## **6. Collection of delayed-mode higher-frequency data from GLOSS Core Network sea level measuring stations**

The PSMSL together with BODC is responsible for an archive of delayed-mode higher-frequency sea level data (e.g. hourly or more frequent values) from the GLOSS network of 289 stations. This activity builds on the earlier work carried out as the Delayed-mode Sea Level Data Assembly Centre (DAC) for the World Ocean Circulation Experiment (WOCE). Between August 2011 and July 2013, new data have been received from Australia, Brazil, Canada, Germany, Iceland, Japan, Korea, UK and USA (NOAA). Further data from UK GLOSS sites have been digitized from the original charts to fill in some gaps in the historical record. These are being added to the high-frequency delayed-mode databank.

In addition, data up to the end of 2012 from the gauges that are part of the ODINAfrica and Indian Ocean network have been downloaded, processed and quality controlled, although not all of the gauges have been operational for the entire period. The data (both 1 minute and 15 minute) are available on the GLOSS web-site. Work has also been underway to set up a European Delayed-Mode Sea Level Data Portal building on the work of the EU funded European Sea Level Service – Research Infrastructure (ESEAS-RI) project. This is undergoing testing and when operational will provide the GLOSS Data Archive with a regular supply of European GLOSS data.

## **7. GLOSS Activities**

### *7.1 GLOSS web-site*

The GLOSS web site ([www.gloss-sealevel.org](http://www.gloss-sealevel.org)) is maintained and updated by the PSMSL and BODC on behalf of GLOSS. New material has been added, the GLOSS Station Handbook and the GLOSS network status has been updated. Following the GE-GLOSS-XII meeting in November 2011, the web-library of GLOSS country reports has been updated, and information extracted from the reports has been used to update the GLOSS Station Handbook. The Handbook has also been updated to reflect the new GLOSS10 definition.

A kml file has been produced to allow exploration of the GLOSS network with links to the appropriate GLOSS Station Handbook page and also to the GLOSS Data Streams (mean sea level data from PSMSL, real-time monitoring from VLIZ, fast-mode from UHSLC, delayed-mode from BODC, nearby GNSS data from SONEL). Examples are shown in the illustrations below.

During the current year, the web-site has been reviewed and a new version designed which will become live towards the end of 2013.

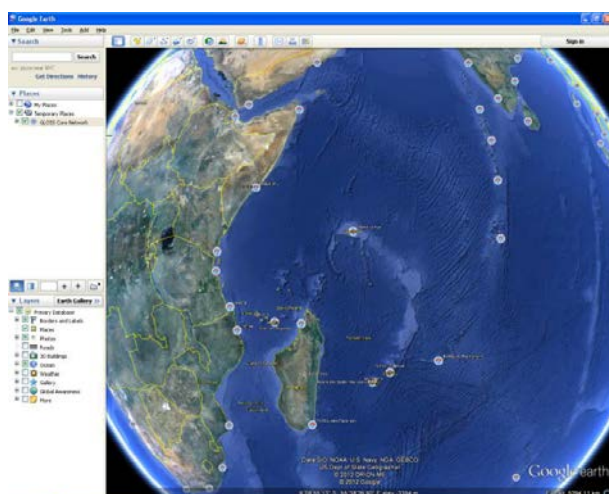
### *7.2 GLOSS Status from a PSMSL Viewpoint (December 2012)*


The PSMSL provides an annual summary of the status of the GLOSS Core Network (GCN) from its viewpoint. An 'operational' station from a PSMSL viewpoint means that recent MSL

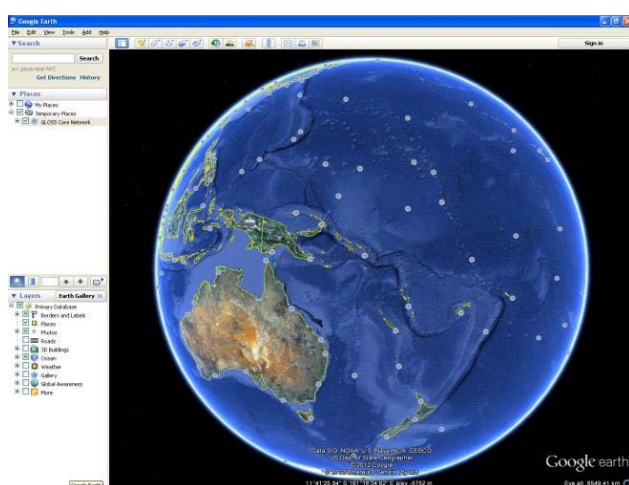
monthly and annual values have been received and checked as far as possible, and have been included in the databank. For each of the GCN stations the year of the last data entered into the databank, if any, is used to place the station into one of four categories:

- Category 1: 'Operational' stations for which the latest data is within the 5 years before the current year;
- Category 2: 'Probably operational' stations for which the latest data is within the period 6 to 15 years before the current year;
- Category 3: 'Historical' stations for which the latest data is earlier than 15 years before the current year;
- Category 4: For which no PSMSL data exist.

During 2010 the latest revision of the GLOSS Core Network was agreed with 289 stations included. Twenty-two new stations have been added and 23 removed. As the new stations are operational and providing data, this has improved the status of the network (64% of the stations are Category 1, having reported their data from 2007 or more recently to PSMSL). However, although improvements to the network will feed through to status improvement in the coming years, further work is still required to develop the network further in order that all stations can be Category 1.



<b>RODRIGUES, PORT MATHURIN MAURITIUS</b> 
GLOSS ID: <a href="#">19</a> Location: 19.683 °S, 63.417 °E
<b>Mean Sea Level Data at PSMSL:</b> <a href="#">1672</a>
<b>Delayed Mode High Frequency Data at BODC:</b> <a href="#">Data</a> , <a href="#">Documentation</a>
<b>Fast Mode High Frequency Data at UHSLC:</b> <a href="#">105</a>
<b>Real Time Data at VLIZ:</b> <a href="#">rodri</a>
<b>Nearby GNSS Data from SONEL:</b> <a href="#">2558</a>




<b>NAURU, GILBERT IS. NAURU</b> 
GLOSS ID: <a href="#">114</a> Location: 0.533 °S, 166.9 °E
<b>Mean Sea Level Data at PSMSL:</b> <a href="#">1374</a> , <a href="#">1844</a>
<b>Delayed Mode High Frequency Data at BODC:</b> <a href="#">Data</a> , <a href="#">Documentation</a> , <a href="#">Documentation</a>
<b>Fast Mode High Frequency Data at UHSLC:</b> <a href="#">4</a>
<b>Real Time Data at VLIZ:</b> <a href="#">naur</a>
<b>Nearby GNSS Data from SONEL:</b> <a href="#">750</a>

Figure 5: GLOSS Stations kml file for Google Earth

### 7.3 GLOSS Training Courses and IOC Indian Ocean Tsunami Warning System fellowships

GLOSS training courses have been held in many countries since the mid-1980s. In the early years these were organised and hosted by PSMSL. More recently (since the 2004 tsunami) individual training courses for technicians have been held at NOC/PSMSL. Two members of staff (Peter Foden and Jeff Pugh) from the Ocean Engineering and Technology Group (OETG) of NOC have worked with local tide gauge operators as necessary on the installation, maintenance and resolution of problems at the African and Indian Ocean tide gauges. In particular, they have continued to provide advice to GLOSS on OTT gauges, data transmission and Broadband Global Area Network (BGAN) systems. Operation of the ODINAfrica gauges is periodically checked the on the VLIZ real-time sea level data monitoring web-site and any problems highlighted when found to the appropriate authority, such as VLIZ, EUMETSAT or local tide gauge personnel.

During the last 2 years specific ongoing support has been provided to the tide gauge operators for the tide gauges in Cameroon, Ghana and Nigeria. In addition training for a technician from Nigeria was undertaken – although unfortunately the Nigerian tide gauge was lost to a storm whilst the technician was being trained. Various training materials (e.g. PowerPoint presentations) are available for trainees who visit NOC Liverpool and PSMSL; these cover installation of tide gauges, calibration, levelling, etc. In addition, material and equipment is available for practical hands-on sessions, which can be tailored to individual trainees needs. Post-training support is available via e-mail and telephone.

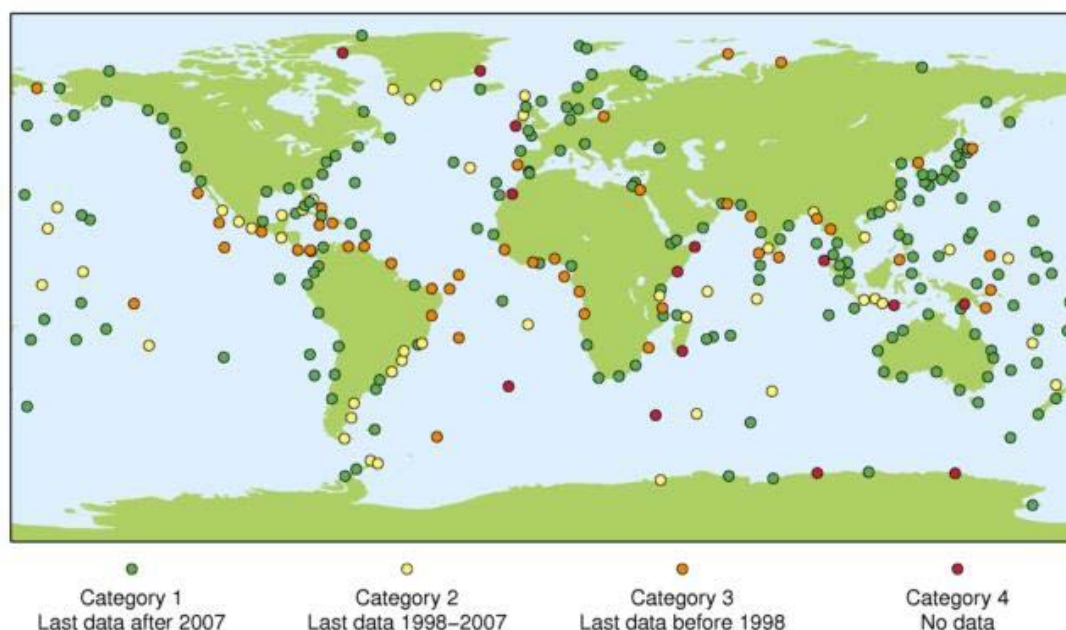


Figure 6: Status of the GLOSS Core Network from a PSMSL perspective (December 2012)

### 7.4 Technology development

#### 7.4.1 Development and design of a second generation sea level measuring station system that requires limited operator intervention.

Following discussion between the GLOSS Technical Secretary, PSMSL and the NOC/OETG staff, it was agreed that it would be beneficial to construct a second generation ODINAfrica

gauge which would be more reliable, less power hungry and require less maintenance. It was noted that a system that does not use pressure sensors (i.e. a radar gauge) would last longer without maintenance visits and a more robust (corrosion-proof) satellite antenna would greatly help reliability. Various different loggers and tide gauges were considered to meet the requirements outlined above (e.g. Waterlog DCP, OTT RLS, Vega, DAA, etc.). Battery replacement would still be an issue, but this is considered the sort of minimal maintenance that can be carried out locally. Following on from this work has been carried out in collaboration with the GLOSS Technical Secretary by the NOC/OETG in constructing two second generation sea level stations from components provided with funding from IOC.

Two Waterlog DCP loggers were supplied to NOCL by IOC, together with two OTT RLS radar sensors and component parts, which were assembled to provide two complete tide gauge systems. The new systems are contained within two separate cabinets instead of the one cabinet used in the existing ODINAfrica installations. This allows a much larger rechargeable battery to be fitted, thus extending the operational life between servicing. This is something that had been a serious issue with the previous ODINAfrica equipment. In addition, alternative battery chargers have been fitted that extend the charging life-time of the battery. These two complete tide gauge systems have been tested and are ready to be deployed in Africa or the Indian Ocean once a suitable location has been agreed.

#### *7.4.2 Development of a facility and methodology for calibration of offsets in the measured range of the radar and for estimation of radar range accuracy, obviating the need for local operators to make dipping measurements.*

Radar gauges generally perform well and are stable, but the determination of their datum has been addressed in the field with the use of complementary measurements with a tide pole, or by dipping measurements in an adjacent stilling well where one exists. However, this has never been a satisfactory situation, and enthusiasm by local operators to make regular tide pole or dipping measurements has never been high. This, together with the availability of a new generation of sensors (in particular the DAA 3611i), has provided motivation for developing a calibration facility.

Measurements were first made in the field, rather than in the laboratory. Three radar gauges (DAA 3611i, OTT RLS and the Vega VegaPuls61) were installed at the Holyhead tide gauge station in Wales, UK. The resulting data was then used to evaluate their performance against the existing onsite reference gauge, the Tide Gauge Inspectorate Bubbler system. The results of the tests with the real sea surface and with the stirrup were consistent. They showed that the DAA 3611i unit performed exceptionally well showing a mean difference (i.e. difference from its nominal reference mark) of approximately 2 mm.

Subsequently, an additional testing phase was carried out at the NOCL Kempston Street facility to see if the above „real world“ figures could be repeated in a laboratory environment. The tests consisted of two sections, one utilising the previously used metal plate as the target and the other, a small water pool. Multiple measurements were made for each sensor, varying the range distance between the sensor and the targets. Overall the RLS and DAA radar gauges agree with the results from the „real world“ experiments. The DAA seemed to mirror the findings in all tests to a very high degree (to within 2 mm).

Of the three radars under study, the DAA performed best and provided sea level data that was compatible with the vertical reference mark on the equipment. However, this good situation cannot be taken for granted with any other DAA sensors, so checks will need to be made with

every new unit. A simple test facility will be maintained at NOCL (either/or the metal and water targets) to check any new purchase, which thereafter can be deployed without the need for tide pole or dipping checks. A short report has been produced and supplied to the GLOSS Technical Secretary describing the tests carried out and the results.

## 8. Publications

Four scientific papers directly using the PSMSL data set were published by NOC scientists partially supported by the PSMSL (listed below). These address global sea-level rise and regional changes, as well as dynamic ocean topography. Perhaps the most notable, in terms of high-level quality control, is the paper by Woodworth et al., “Towards worldwide height system unification using ocean information”. The work on this paper and the continuing research has led to a systematic review of the datum information at the studied tide-gauge sites.

Gehrels, W. R. & Woodworth, P. L., “When did modern rates of sea-level rise start?”, *Global and Planetary Change*, 2013, **100**, 263-277.

Henry, O.; Prandi, P.; Llovel, W.; Cazenave, A.; Jevrejeva, S.; Stammer, D.; Meyssignac, B. & Koldunov, N., “Tide gauge-based sea level variations since 1950 along the Norwegian and Russian coasts of the Arctic Ocean: Contribution of the steric and mass components”, *Journal of Geophysical Research-Oceans*, 2012, **117**, C06023.

Woodworth, P.; Hughes, C.; Bingham, R. & Gruber, T., “Towards worldwide height system unification using ocean information”, *Journal of Geodetic Science*, 2012, **2**, 302-318.

Woodworth, P. L.; Foden, P. R.; Jones, D. S.; Pugh, J.; Holgate, S. J.; Hibbert, A.; Blackman, D. L.; Bellingham, C. R.; Roussenov, V. M. & Williams, R. G., “Sea level changes at Ascension Island in the last half century” *African Journal of Marine Science*, 2012, **34**, 443-452.

One further paper that merits inclusion is an updated overview of PSMSL and its data sets. This paper is now the definitive article for citation of the PSMSL data set:

Holgate, S.J.; Matthews, A.; Woodworth, P.L.; Rickards, L.J.; Tamisiea, M.E.; Bradshaw, E.; Foden, P.R.; Gordon, K.M.; Jevrejeva, S. & Pugh, J., “New Data Systems and Products at the Permanent Service for Mean Sea Level” *Journal of Coastal Research*, 2013, Volume 29, Issue 3: pp. 493 – 504. doi: <http://dx.doi.org/10.2112/JCOASTRES-D-12-00175.1>

In order to assess the wider usage of the PSMSL data set, a search of the scientific literature for the year 2012 was carried out. The result is that 61 papers have been published which have used the PSMSL data set.

PSMSL has also contributed to the IPCC Fifth Assessment Report with Dr Svetlana Jevrejeva a lead author for Working Group I, Prof. Philip Woodworth a review editor and other PSMSL staff also contributing.

## 9. Summary and forward look

It can be seen that PSMSL continues to be active with regard to workshops/conferences and with data acquisition and analysis. The functions provided by the PSMSL are in as much demand as ever and new products continue to be developed. Future plans include:

- Improved integration of the mean sea level data set with higher frequency data and improving the quality of accompanying metadata;
- Keeping contact with data suppliers (the trend being to acquire data from websites rather than direct supply) and ensuring that data made available in real-time are also contributed to PSMSL;
- Inclusion of information on uncertainties/errors in the tide gauge data;

- Addition of bottom pressure record section and data to the PSMSL web-site;
- Redevelopment of capacity building/training material.

Particular thanks as usual go to PSMSL staff and to colleagues at the National Oceanography Centre and British Oceanographic Data Centre who contribute part of their time to PSMSL activities.

# Report on Activities in Developing Countries

*Claudio Brunini (Argentina)*  
*Richard Wonnacott (South Africa)*

## Introduction

This report summarizes the main activities related to the IAG action plans, developed during the 2011 – 2013 in Latin America and the Caribbean (§1), Africa (§2), and Asia (§3). Many persons and institutions have contributed to them; the authors apologize in advance for credits that may have been inadvertently omitted in this report.

### 1. Latin America and the Caribbean

Most of the activities developed in this region can be encompassed in two major areas: reference frames and gravity field: the former have been coordinated by the SC 1.3b (Reference Frames for Central and South America), and are summarized in §1.1; while the later have been coordinated by the SC 2.4b (Geoid and Gravity Field in South America), and are summarized in §1.2. Other activities developed in the region are summarized in §1.3.

#### 1.1. Reference Frames

More than 50 nonprofit institutions in 19 countries contribute to the maintenance and expansion of a continental-wide reference frame, as a densification of the ITRF. The task is performed in two levels: i) continental: through a continuously operational network of GNSS receivers (shortly identified as 'SIRGAS-CON'), which includes ~300 stations (59 of which belong to the IGS); and ii) national: by means of national densifications of SIRGAS-CON, composed by passive and active stations. SIRGAS-CON data are produced, archived and processed in disaggregated manner by 10 data centres, 10 processing centres and 2 combination centres, under the responsibility of the national cartographic agencies of Argentina, Brazil, Colombia, Chile, Ecuador, Mexico, and Uruguay; the universities of Cuyo (Argentina), and El Zulia (Venezuela); and the Deutsches Geodätisches Forschungsinstitut (Germany). Data production, archiving and processing follow the IGS standards; presently the centres are adapting their computation procedures to the new standards released by the IGS for the reprocessing campaign 2.

Efforts have been continued for establishing a gravity field-related vertical reference system in the region, in accordance to the IAG WG0.1.1 on Vertical Datum Standardization. They have been focussed on collecting and validating the levelling, gravity and macrographs database of the different countries (including the transcription of old notebooks to digital records); and on the connection of the levelling networks and tide gauges of the different countries among them and with SIRGAS. A great advance toward the continental adjustment of geopotential numbers have been recently achieved with the realization of the 'SIRGAS Workshop on Vertical Networks Unification', carried out in December 2012, in Río de Janeiro (Brazil), with the local support of the Instituto Brasileiro de Geografia e Estatística (IBGE), and economical support from the IUGG and the PAIGH.

#### 1.2. Geoid and Gravity Field

The coverage of the gravity data over South America was significantly improved, so that  $\sim 10^6$  gravity stations are presently available for computing the geoid. Orthometric heights for the



recent surveys have been derived from geodetic height using EGM2008 restricted to degree and order 150. LaCoste&Romberg and/or CG5 gravity meters and dual-frequency GNSS receivers have been used for establishing: 504 new stations in Argentina; 11,941 in Brazil; 543 in Ecuador; and 771 in Paraguay.

A project for establishing an Earth tide model is being developed under the leadership of the Polytechnic School of the University of São Paulo (Brazil). It aims at establishing 5 well distributed stations in Brazil, one for long term measurements in Manaus, Amazon, and the others for one year operation in different places. The first phase of the project is intended to determine a preliminary model for the Earth tide in São Paulo state. A fundamental gravity network will be established in Brazil with A-10 absolute gravity meter. It will be used as reference for densification measurements, as well as for controlling the drift of the gravity meters.

### *1.3. Other activities*

- During the period 2011-2013 the Fundamental Geodetic Observatory TIGO contributed to the following International Services: IVS, ILRS, IGS, IGFS, IERS, and Time Section of BIPM. Unfortunately the support of the cooperative project by the Chilean main partner Universidad de Concepción stopped by the end of 2011. Since then the operation of TIGO was assured temporarily by an increased funding of Germany. In parallel to the ongoing operation of TIGO a new partner was searched. The Argentina CONICET will be the new partner for TIGO, which will be moved consequently from Concepcion-Chile to La Plata-Argentina during 2014.
- Modelling nonlinear temporal changes in the SIRGAS reference stations;
- Expanding SIRGAS capabilities for real time GNSS positioning;
- Monitoring the ionosphere and troposphere in the CAR/SAM regions with GNSS;
- Exploring the usefulness of GLONASS for the SIRGAS realization;
- Organizing and developing capacity building activities; regarding this topic, it is worth mentioning the IAG-PAIGH-SIRGAS Schools held by the Universidad Nacional of Costa Rica, in 2011; and by the Universidad de Concepción and the IGM of Chile, in 2012; which have been attended by ~100 participants (on average) from almost all Latin American and some Caribbean countries.
- Outreach through focused symposia, conference, lectures and articles; scientists from the region has been active in the following bodies: IAG SC 1.3b, IAG SC 2.4b, IAG ICP 1.2; IAG WG on Dense Regional Velocity Fields; GGOS WG on Vertical Datum Standardization; IAG WG on Deformation Models in Reference Frames, ONU International Committee on GNSS; and SIRGAS WG of the PAIGH Commission of Cartography. In addition, 26 contributions have been presented in international meetings and 20 articles have been published in peer-reviewed literature.

## 2. Africa

IAG related activities in Africa are largely focused on the establishment and maintenance of a uniform reference frame for the continent under SC 1.3d: Africa with little activity taking place under the auspices of SC 2.4d: Gravity and Geoid in Africa.

### 2.1 Reference Frame

The major activity within Africa in relation to the activities of Commission 1 Reference Frames and in particular SC 1.3d Africa is the establishment of a network of permanent GNSS base stations in support of an effort to unify the reference frames in Africa. The project is known as the Africa Reference Frame project (AFREF) and has the support of the United Nations Committee for Development Information, Science and Technology (CODIST).

The three major objectives of AFREF are to:

- Define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF;
- Establish continuous, permanent GPS stations such that each nation or each user has free access to, and is at most 500km from, such stations; and
- Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

In pursuance of these objectives, permanent GNSS base stations are being set-up through most of Africa. Approximately 70 stations have been installed and an Operational Data Centre has been installed to download and archive data from these stations. On average, 40 stations provide data daily albeit not always the same 40.

The stations have been installed by a variety of agencies, organizations and projects such as the Africa Array (seismology), AMMA-GPS (meteorology) and SCINDA (ionosphere) projects.

A two week period was identified in Dec 2012 during which data from an average of 50 stations were downloaded per day. This data, together with a further 50 global stations, was processed by 5 processing centres and combined by the IGN, Paris to provide a set of static co-ordinates based on ITRF to be used for everyday surveying and mapping operations.

The five processing centres were:

- Ardhi Univesity, Tanzania / University of Purdue, USA
- Centre for Geodesy and Geodynamics, Nigeria
- Hartebeesthoek Radio Astronomy Observatory, South Africa
- Surveying and Mapping Division, Ministry of Lands, Tanzania
- University of Beira Interior, Portugal

The second phase will be routine processing of the network to provide a velocity field.

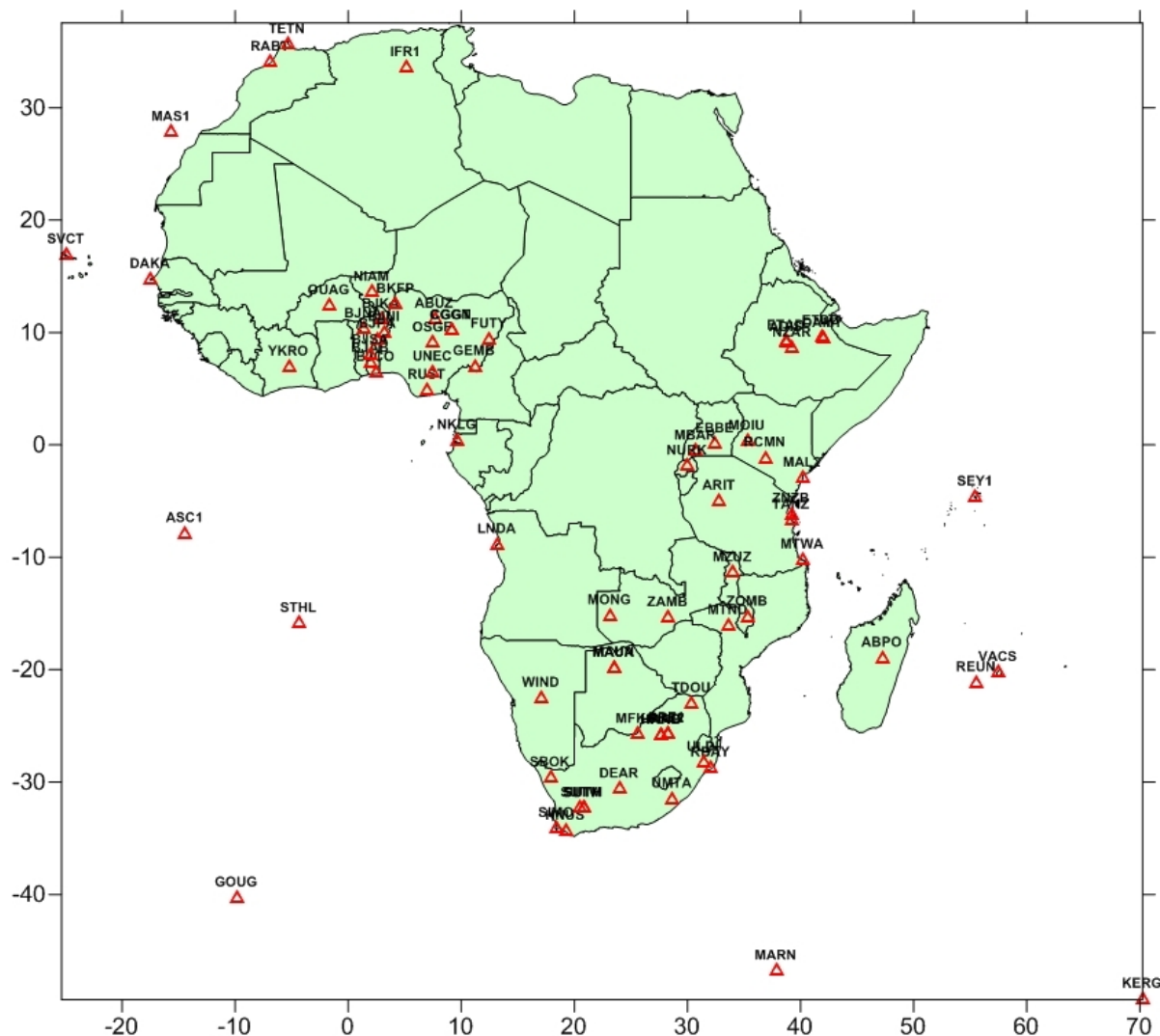


Figure 3. Stations for which data is archived in the AFREF ODC as at 4 January 2013. The lack of freely available CORS data in the area from Angola through Central Africa, Sudan and Sahara and North African countries is of concern.

## 2.2 Geoid and Gravity Field

Estimates of the gravity field and geoid have been undertaken at the national level in Algeria and Khartoum State and Sudan while a Digital Height Model for Egypt has been established using SRTM and ASTER-GDEM data. An update of the South African geoid model SAGEOID 2010 was investigated in 2012 but found not necessary for practical applications.

A two year collaborative project between IAG and IASPEI was accepted by the IUGG which will entail the acquisition of gravity data for Africa in preparation for the computing of an African geoid. Furthermore, investigations of geopotential models at the continental scale have been undertaken by Abd-Elmotaal and others using GRACE/GOCE global potential models, ship borne gravity data and interpolated gravity data in areas of sparse gravity measurements.

More details are available in the Sub-Commission 2.4d: Gravity and Geoid in Africa report.

### 2.3 *Other activities*

Workshops on the establishment and processing of permanent GNSS stations and networks are held annually at the Regional Centre for Mapping of Resources for Development in Nairobi, Kenya. Partially as a result of these workshops, a number of countries have commenced with the establishment of in-country CORS networks.

## 3. **Asia and the Pacific**

(The following report is extracted from a report of WG1: Geodesy Technologies and Applications of the Permanent Committee on Geographic Information System Infrastructure for Asia and the Pacific (PCGIAP) presented at the 19<sup>th</sup> United Nations Regional Cartographic Conference for Asia and the Pacific in November 2012)

The Asia-Pacific region is very active tectonically and is a region in which frequent earthquakes and other geo-activity. The region is susceptible to much gradual to sudden plate motion and deformation very often with fatal results. The region thus creates many challenges for geometrical and physical geodesists.

### 3.1 *Reference Frame.*

In order to address the linear and non-linear effects of plate motions in the region, the Asia-Pacific Reference Frame (APREF) project was set up and a call for participation was released in March 2010 with the following main objectives to:

- Create and maintain an accurate and densely realised geodetic framework based on continuous GNSS data;
- Develop the APREF Permanent Network in close co-operation the IGS as a contribution to the ITRF; and
- Establish a dense velocity field model for the region for scientific applications.

Up to November 2012, GNSS data from a network of approximately 420 CORS, is being contributed by 28 countries and used by three Analysis Centres for processing.

### 3.2 *Other Activities*

WG1 of PCGIAP reported on an analysis of observations and geodetic effects of the two major earthquakes in New Zealand (South Island) 22 February 2011 and Japan (Tohoku-Oki) 11 March 2011.

## Journal of Geodesy (JoG)

<http://link.springer.com/journal/190>

*Editor in Chief: Roland Klees (The Netherlands)*

### Activity Report

Journal of Geodesy (JoG) is an international journal concerned with the science of geodesy and related inter-disciplinary sciences. JoG is the official scientific journal of the IAG and publishes monthly research articles, review papers, and short notes. Springer Heidelberg is the publishing company based on an agreement with IAG. The Editor-in-Chief (EiC) is responsible for the scientific content of the journal. He makes the final decision on whether a manuscript is accepted for publication. He is advised by a Board of Editors. The current Board comprises 15 members from 9 countries:

J Böhm (Austria), P Clarke (UK), A Dermanis (Greece), P Ditmar (the Netherlands), J Freymüller (USA), M Furuya (Japan), R Gross (USA), C Jekeli (USA), W Keller (Germany), K Kotsakis (Greece), J Kouba (Canada), J Kusche (Germany), J C Ries (USA), SDP Williams (UK), P Willis (France).

The JoG uses the Editorial Manager, a web-based peer review system, which allows easy manuscript submission, provides author information and e-mail updates, and helps reducing the turnaround time.

The JoG publishes special issues on high standard contributions physically combined in one issue and all logically related to one clear and general topic of interest to the geodetic community. The most recently published special issues have been on the Continuous geodetic VLBI Campaign 2008 (JoG 85, Issue 7), GOCE (JoG 85, Issue 11), and Ionospheric Modelling (JoG 85, Issue 12).

The JoG would like to encourage authors to i) submit review papers and ii) initiate special issues related to topics of high interest to the geodetic community.

### Impact Factor

The ranking of the JoG has improved steadily; the current (2012) Impact Factor is 2.808 (Thomson Reuters Journal Citation Report 2012). For the last 3 years JoG has seen the following Impact Factor Trend:

Table 1: JoG Impact Factor and total journal article citations for 2012

Year	Impact Factor	Citations
2012	2.808	2,031
2011	2.414	1,413
2010	1.880	1,316

## Submissions

The number of submissions has stabilized at a level of about 150 manuscripts with yearly fluctuations of about 30. The top 5 countries with the highest number of submissions are China, Germany, United States, France, and Australia.

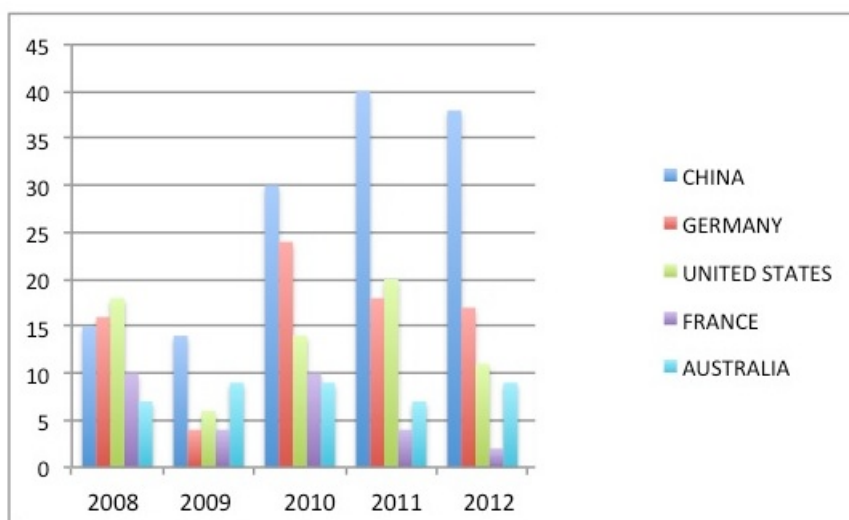


Figure 1: Number of submissions 2008-2012 per country (top 5).

## Review statistics

The JoG knows a nominal review period of 28 days. The number of days to complete a review is stable at a level of 32. Table 2 shows some statistics of the decisions taken by the EiC. There are two notable trends: i) the percentage of original submissions with a minor revision is decreasing and the percentage of major revisions is increasing; the number of outright rejections is fairly stable at a level of about 50%; ii) the percentage of manuscripts which are accepted after revision 1 is decreasing; at the same time, the percentage of manuscripts which are rejected after revision 1 is increasing. The latter is due to the fact that, starting in 2011, a second major revision implies the rejection of the manuscript. The intention of this rule is to stimulate authors to carefully revise the manuscript and to reduce the workload of the Board and the reviewers.

Table 2: EiC decisions

	Accept [%]	Minor revision [%]	Major revision [%]	Reject [%]
Original submission				
2010	-	17	37	46
2011	-	10	39	51
2012	-	8	37	55
First revision				
2010	38	48	10	4
2011	27	50	15	8
2012	27	50	-	23

## Turnaround time

Table 3 provides insight into the turnaround time from the original submission of a manuscript to the publication in the online issue of JoG for the year 2012. According to this table, the time between original submission to the final decision of the EiC is about 8 months; it takes one additional month to get the paper published online first.

Table 3: Turnaround time (days) from original submission to online issue for the year 2012

Submission to online issue	409
Submission to online first	271
Submission to final decision	245
... with reviewers	141
... with authors	63
... with Board/EiC	41

## IAG Symposia Series

<http://www.springer.com/series/1345>

*Editor in Chief: Chris Rizos (Australia)*  
*Assistant Editor: Pascal Willis (France)*

### Overview

The IAG Symposia Series (IAG Symp.) is a book series of peer-reviewed proceedings of selected IAG Symposia organized by the International Association of Geodesy. It deals primarily with topics related to Geodesy as applied to the Earth Sciences and Engineering: terrestrial reference frame, Earth gravity field, geodynamics and Earth rotation, positioning and engineering applications.

Volumes are available online at the Springer web site (<http://www.springer.com/series/1345>), since volume 101 (Global and Regional Geodynamics, 3-5 August 1989), published in 1990. Most recent volumes are also available from the Springer web site as e-Books. It must be noted that articles published in the IAG Symposia Series since 2000 are referenced in the ISI Web of Knowledge, implying that their citations are used in the ISI Web of Science (Thomson SCI). A request was sent to Scopus (Elsevier) to add this book series of peer-reviewed proceedings to their database.

According to the IAG Statutes and By-Laws, the de facto Editor-in-Chief of this series is the IAG President. Following the IUGG General Assembly in Melbourne (July 2011), the new Editor-in-Chief is Chris Rizos for the following four years, replacing Michael G. Sideris who was the Editor-in-Chief for the past four years. In August 2011, Pascal Willis was invited to become Assistant Editor-in-Chief and to organise the peer-review procedure for the IAG Symposia Series. Contacts were made with the publisher of this series (Springer) and the review procedure was significantly changed, starting with volume 139 (Earth on the Edge, Science for a Sustainable Planet, Melbourne, Australia, June 28 – July 1, 2011). A dedicated web site was developed by Springer (<http://www.editorialmanager.com/iags>) to allow full electronic manuscript submission and management of the peer-reviewed process. While Pascal Willis handles this web site on behalf of the Editor-in-Chief, editors are selected for each symposium from the list of convenors, taking into account the number of expected symposium manuscripts. Specifications for authors were developed and are now provided to all authors through the Springer web site. These specifications include the length of article and format description. Written procedures were also provided to all editors to allow a fair and homogeneous review process within all sessions and within all the IAG Symposia. For each manuscript, three independent experts are selected by the editors to review the submitted manuscript. Based on the returned reviewers reports, the editor makes a decision, which needs to be confirmed by the assistant Editor-in-Chief. To improve communication with the authors, monthly reports are sent out by the assistant Editor-in-Chief, anonymously providing some key statistics on the status of manuscripts under review for each symposium. Information emails are also sent out to authors, while papers are handled by Springer Production, until their final publication online and in print.



## Structure and activities

The following paragraphs provide information on the IAG symposia volumes published or under review process in the 2011-2013.

### Volume 136

- Geodesy for Planet Earth Buenos Aires, Argentina, August 31 - September 4, 2009
- Editors: Steve Kenyon, Maria Cristina Pacino, Urs Marti
- Co-editors: Rodrigo Abarca del Rio, Zuheir Altamimi, Mike Bevis, Denizar Blitzkow, Sylvain Bonvalot, Claudio Brunini, Rene Forsberg, Yoichi Fukuda, Richard Gross, Shuanggen Jin, Roland Pail, Hans-Peter Plag, Marcelo Santos, Claudia Tocho, Charles Toth, Tonie van Dam, Sandra Verhagen, Leonid Vitushkin
- Published in 2012, 130 articles, 1046 pages, ISBN: 978-3-642-20338-1

### Volume 137

- VII Hotine-Marussi Symposium on Mathematical Geodesy, June 6-10, 2009, Rome, Italy
- Editors: Nico Sneeuw, Pavel Novak, Mattia Crespi, Fernando Sanso
- Co-editors: Zuheir Altamimi, Athanasios Dermanis, Richard Gross, Wieslaw Kosek, Jürgen Kusche, Hansjörg Kutterer, Torsten Mayer-Gürr, Michael Schmidt, Giorgio Spada, Florian Seitz, Sandra Verhagen, Yanming Wang, Jonathan David Wolfe
- Published in 2012, 36 articles, 407 pages, ISBN: 978-3-642-22078-4

### Volume 138

- References Frames for Applications in Geosciences, Marne-la-Vallée, France, October 4-8, 2010
- Editors: Zuheir Altamimi, Xavier Collilieux
- Co-editors: Claude Boucher, David Coulot, Mike Craymer, Richard S. Gross, Johannes Ihde, Markus Rothacher, Harald Schuh, Michael G. Sideris, Peter Steigenberger, Joao Agria Torres
- Published in 2013, 40 articles, 284 pages, ISBN: 978-3-642-32997-5

### Volume 139

- Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia, June 28 – July 1, 2011
- Editors: Chris Rizos, Pascal Willis
- Co-editors: Jozsef Adam, Zuheir Altamimi, John Dawson, Athanasios Dermanis, Reinhard Dietrich, Xiaoli Ding, Jeff Freymueller, Yoichi Fukuda, Dorota Grejner-Brzezinska, Richard Gross, Urs Hugentobler, Johannes Ihde, Matt King, Hansjörg Kutterer, Frank Lemoine, Mikael Lilje, Ruth Neilan, Markus Rothacher, Laura Sanchez, Marcelo Santos, Harald Schuh, Nico Sneeuw, Oleg Titov, Joao Agria Torres, Sandra Verhagen, Jens Wickert, Herbert Wilmes
- Publication expected in summer 2013

Volume 140

- Gravity, Geoid and Height Systems (GGHS2012), Venice, Italy, October 9-12, 2012
- Editor: Urs Marti
- Co-editors: Oliver Baur, Jianliang Huang, Isabelle Panet, Riccardo Barzaghi, Carla Braitenberg, Shuanggen Jin, Laura Sanchez, Herbert Wilmes
- Publication expected in fall 2013

Volume 141

- Quality of Geodetic Observation and Monitoring Systems (GuGOMS'11), Garching/Munich, Germany, 13-15 April 2011
- Editor: Hamza Alkhatib
- Publication expected in late 2013

**Statistical information**

**Impact Factor**

As such, IAG Symposia Series do not get an Impact factor in ISI, as they are not referenced in ISI Web of Science (scientific journals) but only in ISI Web of Knowledge (as peer-reviewed proceedings). However, it is possible to derive a similar impact factor using the same formula used for ISI Web of Science for journals (number of citations in year / (number of papers published in year-1 and year-2)). The following Table provides an estimate of such an Impact Factor using this simple formula.

Table 1: IAG Symposia (estimated) Impact Factor (as of June 26, 2013)

Year	Citation (Year)	Published papers (Year-1 and Year-2)	Impact Factor
2012	48	91	0.53
2011	84	238	0.35
2010	67	205	0.33

While, the Impact Factor of these proceedings is still well below numbers obtained for journals such as Journal of Geodesy (2.808 in 2012), this number is regularly increasing and should be compared to minor peer-reviewed journals, such as Advances in Space Research (IF of 1.183 in 2012).

## Submissions

The number of submission greatly depends of the number of IAG Symposia per year and also on the number of manuscripts submitted to each meeting.

Table 2: Number of manuscripts submitted to recent IAG Symposia

IAG Symp. volume	IAG Symposium	Location	Date	Number of submissions (articles)
136	IAG Scientific Assembly	Buenos Aires, Argentina	August 31 – September 4, 2009	
137	VII Hotine-Marussi	Rome, Italy	June 6-10, 2009	
138	REFAG	Marne-la-Vallée, France	October 4-8, 2010	
139	IAG General Assembly	Melbourne, Australia	June 28 – July 1, 2011	109
140	GGHS2012	Venice, Italy	October 9-12, 2012	61

The following Table provide the top 8 countries which submitted the largest number of manuscript in 2012 (using the Springer submission Web site):

Table 3: Number of manuscripts submitted per county in 2012

Country	Submitted manuscripts
Germany	26
Australia	10
China	10
New Zealand	9
Canada	7
France	7
Austria	6
Brazil	5

## Review statistics

All numbers below are provided from the Springer submission Web site and only relates to 2012. The nominal delay offered to the reviewers to perform their expertise is 22 days. The average time for the reviewers to confirm their willingness to analyze the manuscript is 4 days. The average time for the reviewers to submit their report is 25 days.

For initial papers submitted in 2012, a major revision was requested for 60%, a minor revision was requested for 25% and a rejection was requested for 15%. At the end of the review process (potential including several revisions), the rejection rate was 24% for the total number of submitted papers. In particular, several papers were rejected before any review because of self-plagiarism, as detected using iThenticate software before assigning any Editor-in-charge.

## Turnaround time

Table 4 provides insight into the turnaround time from the original submission of a manuscript to the publication in the IAG Symposia Series for 2012. On average, it takes less than 1 day for Springer to do the technical check of the papers and less than 1 day for the Editor-in-Chief to assign a manuscript to the proper Editor. It then takes 9 days for the editors to invite the 3 reviewers. According to this table, the time between the original submission to the final decision is about 4 to 5 months.

Table 4: Turnaround time (days) from original submission to online issue for the year 2012

Submission to final decision	137
Submission to first decision	63
... with reviewers	59
... with authors	46
... with Board/EiC	32

## Administrative Activity Report of the IAG

<http://iag.dgfi.badw.de>

*IAG Secretary General: Hermann Drewes (Germany)*

### Administration

#### IAG Council

The IAG Council typically meets during the IUGG General Assembly. In the interim period it is informed by the Secretary General on current activities. The main topics from 2011 to 2013 were the celebration of IAG's 150<sup>th</sup> anniversary in Potsdam, Germany, 1-6 September 2013, and the IAG publications (IAG Symposia series, Journal of Geodesy). The most recent Council meeting was held on 3 September 2013, during the Scientific Assembly in Potsdam.

#### IAG Executive Committee (EC)

The IAG EC held its meetings in December 2011 during the AGU Fall Meeting in San Francisco, in August 2012 on the occasion of the AOGS – AGU (WPGM) Joint Assembly in Singapore, and in April 2013 during the EGU General Assembly 2013 in Vienna, Austria. The most important topics were the reports of all IAG components (Commissions, ICCT, Services, GGOS, COB) and preparatory work on the IAG Scientific Assembly, to be held as the official celebration of IAG's 150<sup>th</sup> anniversary in Potsdam, Germany, 1-6 September 2013. The meeting summaries are published in the IAG Website ([www.iag-aig.org](http://www.iag-aig.org)) and in the IAG Office Homepage (<http://iag.dgfi.badw.de>). The next meeting will be held in Potsdam, 1 September 2013.

#### IAG Bureau

The IAG Bureau held monthly teleconferences to facilitate day-to-day decisions. The IAG President, the Vice-President and the Secretary General represented IAG in various scientific meetings (see below) and gave oral presentations, particularly with regard to the 150<sup>th</sup> anniversary.



Johann Jacob Baeyer, Founder of the IAG



Memorial in Berlin Muggelheim

## Activities

### Scientific Assemblies, Symposia and Meetings

Important meetings of the IAG components and IAG sponsored meetings for the period mid-2011 to 2013:

- International Workshop on “GNSS Remote Sensing for Future Missions and Sciences”, Shanghai, China, August 7-9, 2011.
- Sub-Commission 1.3b “SIRGAS” General Meeting, Heredia, Costa Rica, Aug. 8-10, 2011.
- 3<sup>rd</sup> International Colloquium “Scientific and Fundamental Aspects of the Galileo Programme”, Copenhagen, Denmark, August 31 - September 2, 2011.
- Joint International Symposium on Deformation Monitoring, Hong Kong, China, November 2-4, 2011.
- IGS Workshop on GNSS Biases, Bern, Switzerland, January 18-19, 2012.
- IVS VLBI2010 Workshop on Technical Specifications (TecSpec), Bad Kötzing/Wetzell, Germany, March 1-2, 2012.
- 7th IVS General Meeting “Launching the Next-Generation IVS Network”, Madrid, Spain, March 12-13, 2012.
- Symposium and Workshop on “PPP-RTK and Open Standards”, Frankfurt am Main, Germany, March 12-14, 2012.
- IERS Global Geophysical Fluids Center (GGFC) Workshop, Vienna, Austria, April 20, 2012.
- DORIS Analysis Working Group Meeting, Prague, Czech Republic, May 31 – June 1, 2012.
- Sub-Commission 1.3a “EUREF” 2012 Symposium, Saint Mandé, France, June 6-8, 2012.
- IGS Analysis Center Workshop, Olsztyn, Poland, July 23-27, 2012.
- IAG Symposium at the AOGS-AGU (WPGM) Joint Assembly, Singapore, August 13-17, 2012.
- International Symposium on “Space Geodesy and Earth System (SGES2012)”, Shanghai, China, August 19-20, 2012.
- WEGENER 2012 Symposium, Strasbourg, France, September 17-20, 2012.
- 17th International Symposium on “Earth Tides and Earth Rotation (ETS 2012)”, Cairo, Egypt, September 24-28, 2012.
- 20 Years of Progress in Radar Altimetry, Venice, Italy, September 24-29, 2012.
- IDS Workshop, Venice, Italy, September 25-26, 2012.
- 7th IAG-IHO ABLOS Conference, Salle du Ponant, Monaco, October 3-5, 2012.
- European VLBI Network (EVN) Symposium, Bordeaux, France, October 9-12, 2012.
- International Symposium on “Gravity, Geoid and Height Systems (GGHS 2012)”, Venice, Italy, October 10-12, 2012.
- Sub-Commission 1.3b “SIRGAS” Meeting 2012, Concepción, Chile, October 20-31, 2012.
- International VLBI Technology Workshop, Westford, Massachusetts, USA, October 22-24, 2012.
- ILRS International Technical Laser Workshop “Satellite, Lunar, and Planetary Laser Ranging: Characterizing the Space Segment”, Frascati, Italy, November 5-9, 2012.
- 21st European VLBI for Geodesy and Astrometry (EVGA) Working Meeting, Helsinki, Finland, March 6-8, 2013.
- IDS Analysis Working Group Meeting, Toulouse, France, April 4-5, 2013.
- 17th International Symposium on Earth Tides “Understand the Earth (ETS 2013)”, Warsaw, Poland, April 15-19, 2013.
- International Symposium on “Mobile Mapping Technology”, Tainan, Taiwan, April 30 - May 2, 2013.
- Seventh IVS Technical Operations Workshop, Westford, Massachusetts, USA, May 6-9, 2013.
- IERS Workshop on Local Ties and Co-locations, Paris, France, May 21-22, 2013.
- Sub-Commission 1.3a “EUREF” Symposium 2013, Budapest, Hungary, May 29-31, 2013.
- International Symposium on “Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change”, Ilulissat, Greenland, May 30 – June 2, 2013.
- GNSS PPP Workshop, Ottawa, Canada, June 12-14, 2013.
- VIII Hotine-Marussi Symposium, Rome, Italy, June 17-21, 2013.

- International Conference on “Earth Observations and Societal Impacts (ICEO-SI 2013)”, Tainan, Taiwan, June 23-25, 2013.
- International Symposium on Planetary Sciences (IAPS2013), Shanghai, China, July 1-4, 2013.
- IAG Scientific Assembly, Potsdam, Germany, September 1-6, 2013.
- 2nd Joint International Symposium on Deformation Monitoring (JISDM), Nottingham, UK, September 9-11, 2013.
- IAG Third Symposium on “Terrestrial Gravimetry: Static and Mobile Measurements (TGSM-2013)”, St Petersburg, Russian Federation, September 11-20, 2013.
- Scientific Developments From Highly Accurate Space-Time Reference Systems, Observatoire de Paris, Paris, France, September 16-18, 2013.
- ITU/BIPM Workshop on “The Future of the International Time Scale”, Geneva, Switzerland, September 19-20, 2013.

### **Schools organised by the IAG**

- SIRGAS School on Geodetic Reference Frames, Heredia, Costa Rica, August 3-5, 2011.
- GNSS School, Hong Kong, China, May 14-15, 2012.
- International Summer School on Space Geodesy and Earth System, Shanghai, China, August 21-25, 2012.
- SIRGAS School on Real Time GNSS Positioning, Concepción, Chile, Oct., 24-26, 2012.
- EGU-IVS Training School for the Next Generation Geodetic and Astrometric VLBI, Helsinki, Finland, March 2-5, 2013.

### **IAG Office**

The main activities of the IAG Office were the publication of the Geodesist's Handbook and preparations for the IAG's 150<sup>th</sup> anniversary at the 2013 Scientific Assembly. Travel grants were awarded to young scientists for participation in several symposia. The individual IAG membership was regularly updated. IAG Council and EC meetings were organised, including detailed minutes for the participants and meeting summaries for publication in the IAG webpages and in the IAG Newsletters.

### **Communication and Outreach Branch (COB)**

The publication of the Geodesist's Handbook, the monthly Newsletters (online and in print, in the Journal of Geodesy), and the maintenance of the IAG Homepage were the main activities of the COB. The IAG Newsletter is sent to the IAG members, to the Presidents and Secretaries General of the IUGG Associations, and to the members of the Joint Board of Geospatial Information Societies (JBGIS). A meeting of the COB Steering Committee was held in Budapest, Hungary, 19-20 November 2013.

### **Commissions and Inter-Commission Committee**

The four IAG Commissions and the Inter-Commission Committee on Theory (ICCT) maintain their individual Webpages (all accessible via the IAG Homepages). Several sub-components (Sub-Commissions, Working and Study Groups) held their own symposia and workshops (see above, e.g. SIRGAS, EUREF, SGES, WEGENER, ETS, GGHS).

### **Services**

The fifteen IAG Services maintain their own Webpages (all accessible via the IAG Homepages) and data servers. They held their regular administrative meetings (Coordinating Board, Directing Board or Governing Board) and organised their own symposia and workshops (see above, e.g. IGS, IVS, ILRS, IERS, IDS, IGFS).

## **Global Geodetic Observing System (GGOS)**

GGOS established in 2012 its new structure including the Consortium composed by representatives of the Commissions and Services, the Coordinating Board as the decision-making body, the Executive Committee, and the Science Panel. The outreach is done by the GGOS Portal, Webpages ([www.ggos.org](http://www.ggos.org)), brochures and books. GGOS is representing IAG in the Group on Earth Observation (GEO) and contributes to the GEO Work Plan and GEO System of Systems (GEOSS). A strategic retreat was held in Frankfurt, Germany, 26-28 June 2012, and meetings of the GGOS Consortium and the Coordinating Board, respectively, took place on 3 December 2011 in San Francisco, 27 April 2012 in Vienna, 1 December 2012 in San Francisco, 6 April 2013 in Vienna.

## **Cooperation with other Organisations**

Close cooperation of the IAG is maintained with several organisations outside IUGG. There were meetings with the Advisory Board on the Law of the Sea (ABLOS, together with IHO), Group on Earth Observation (GEO, with IAG as a participating organisation), International Standards Organisation (ISO, with IAG represented in TC211 Geographic Information / Geomatics), Joint Board of Geospatial Information Societies (JBGIS), United Nations Office for Outer Space Affairs (UNOOSA, with participation in Space-based Information for Disaster Management and Emergency Response, UN-SPIDER, and International Committee on Global Navigation Satellite Systems, ICG).

## **Publications**

The monthly issues of the Journal of Geodesy, the proceedings of the IAG Assembly “Geodesy for Planet Earth” (IAG Symposia Series Vol. 136), the VII Hotine-Marussi Symposium on Mathematical Geodesy (IAG Symposia Series Vol. 137), and the Symposium “Reference Frames for Applications in Geosciences” (IAG Symposia Series Vol. 138) were the main publications in 2012-2013.

## **Awards, Anniversaries, Obituaries**

Travel awards were granted to young scientists (not older than 35 years) for participation in several symposia: 6 after the General Assembly in Melbourne in 2011; 11 in 2012; and 23 in 2013 (including the IAG Scientific Assembly).

The IAG Young Author award was granted for excellent publications in the Journal of Geodesy; in 2011 to Thomas Arzt (Germany); and in 2012 to Manuela Seitz (Germany).

Obituaries were written and published in the IAG Newsletters for former IAG officers Andrey M. Finkelstein, Russia (1942-2011), Soren Werner Henriksen, USA (1916-2011), and IAG Past President Klaus-Peter Schwarz, Canada (1938-2012).

## **Planned and Future Activities**

The most important activity for the next year is the consolidation of the IAG's Global Geodetic Observing System. The three themes, namely the Unified Height System, Geohazards Monitoring, and Sea Level Change, will be the focus of scientific work based on the input from Commissions and Services. The IAG Services will continue to provide their products for use in science and practice, and for the benefit of society in general. The IAG Commissions and Services will organise their own, and actively participate in IUGG and other interdisciplinary symposia and meetings.

IAG will continue its close cooperation with other international scientific bodies, e.g. the Joint Board of Geospatial Information Societies (JBGIS) and its members, the International Astronomical Union (IAU), the International Hydrographic Organisation (IHO), the International Standards Organisation (ISO), the United Nations Office of Outer Space Affairs (UNOOSA) and Initiative on Global Geospatial Information Management (GGIM), the Committee on Space Research (COSPAR), the Group on Earth Observation (GEO), the American Geophysical Union (AGU), the Asia Oceania Geosciences Society (AOGS), and the European Geosciences Union (EGU).