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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 mid-term 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 37 contains the reports of all IAG components for the period 2007 to 2011 and is presented at the IAG General Assembly in Melbourne/Australia, in June/July 2011 in conjunction with the General Assembly of the International Union of Geodesy and Geophysics (IUGG). In addition, the quadrennial report of the IAG Secretary General is included, and links to the meetings summaries of the IAG Executive Committee are provided. Thereby a complete overview of the activities of the past four year period is presented.

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)

Hermann Drewes
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Commission 1 - Reference Frames

http://iag.ensg.ign.fr

President: Zuheir Altamimi (France)
Vice President: Mike Craymer (USA)

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Introduction

Commission 1 activities and objectives are to deal with theoretical aspects of reference systems and the practical applications for their realizations as well as applied researches. 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.
- Promote the definition and establishment of vertical reference systems at global level, considering the advances in the regional sub-commissions.

Overview of the main activities of Commission 1

The main activities of Commission 1 during the period 2007-2011 are the following:

- A dedicated web site was established immediately after the IUGG General Assembly in Perugia 2007, where the new Commission members were approved by the IAG Executive Committee. The Web site (http://iag.ensg.ign.fr) 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 presidents of sub-commissions and sub-components to reflect changes and continuous activities of all commission entities.
- Steering Committee meetings were held
  - in Vienna, April 16, 2008 were 7 participants from the commission sub-components attended. The meeting was devoted to discussion on the main structure and activities of the commission. A few reports and presentations were provided, e.g. SC 1.3 (Regional Reference Frames), SIRGAS with a complete informative presentation, and IC-P1.2. The main highlights of the meeting were twofold: the IAG should give more emphasis to the activities of SC-1.3 and from the research side, the participants indicated the need for some theoretical work on Nutation under the lead of SC-1.4 in cooperation with Commission 3.
  - in Buenos Aires during the IAG General Assembly 2009 where most of Commission 1 members were attended. Reports from all the sub-commissions and most of the working groups were presented
  - in conjunction with Commission 1 Symposium – REFAG (see below) held in Marne la Vallée 4-8 October. This SC meeting was devoted to review the main sub-component activities, but also the review process of the REFAG papers and the preparation of the Proceedings.

  An additional SC meeting is foreseen during the IUGG2011 General Assembly in July in Melbourne, Australia.
- Participation in COSPAR GA held in Montreal, July 2008 and in Hotine Marussi symposium in Rome, July 2009.
- Commission 1 Symposium: Reference Frames for Applications in Geosciences (REFAG), held in Marne la Vallée, October 4-8. A dedicated website is set up, containing all the symposium related information: http://iag.ign.fr/index.php?id=140.

  Six sessions were organized as follows:

  1. Theory and realization of global terrestrial reference systems. Conveners Claude Boucher & David Coulot
  2. Strenghts, weaknesses, modelling standards and processing strategies of space geodetic techniques. Conveners: Markus Rothacher & Peter Steinberger
  3. Definition, establishment, maintenance and integration of regional reference Frames. Conveners: Joao Torres & Mike Craymer
  4. Interaction between the celestial and the terrestrial reference frame. Conveners: Harald Schuh, Chopo Ma
  5. Definition and establishment of vertical reference systems. Conveners: Michael Sideris and Johannes Ihde

6. Usage and applications of reference frames in Geosciences. Conveners: Richard Gross and Frank Lemoine

All the session summaries are available at the Symposium WEB site, together with all oral and some poster presentations.

About 150 participants were attended the symposium which was sponsored by IGN, CNES, NASA and Leica.

The REFAG Proceedings will be published in the symposia IAG series by Springer where about 40 papers will be published.

– As a joint effort between the ICCT Study Group IC-SG1 and Commission 1 a first IAG School on Reference Frames was held on June 7-12 2010. The School was hosted by the Department of Geography of the Aegean University in Mytilene, Lesvos Island, Greece. The School was attended by 58 students from 19 countries. More details about the school are available in the ICCT Report of this Volume.
– The main activities of Commission 1 were obviously undertaken by the commission sub-components as presented in the rest of this final report and highlighted hereafter.

Main highlights of the activities of Commission 1' sub-components

Sub-commission 1.1: Coordination of Space Techniques.

The main activities of SC-1.1 are the development of GGOS-D project and the experimental combination of the observation data from CHAMP and the GRACE satellites.

Sub-commission 1.2: Global Reference Frames

The main activities of SC-1.2 are: summary report on terminology related to reference systems and frames, contribution to the updates of IERS Conventions and in particular, Chapter 4 dealing with the terrestrial reference system and the establishment of working group on an ITRS standardization for the benefit of GGOS.

Sub-commission 1.3: Regional Reference Frames

The activities of each of the regional Sub-Commissions and the WG Regional Dense Velocity Fields show that all the components of the structure are developing according to the main objectives of the SC 1.3.

It must also be emphasized that during the 4-year period covered by this report there was a strong increase of activity in the less developed regions, as it is demonstrated by the results achieved. Some general aspects deserve to be referred:

– The activities are contributing to the scientific and technical development in several topics such as GNSS analysis and processing, precise reference frame establishment, among others.
– The organizational aspects play a more and more important role and are crucial for the efficient achievement of results.
– There is a great effort to bring together different types of institutions (R&D structures, National Mapping Agencies, political and economic agencies, etc.) to support the realiza-

tion of international campaigns (GNSS and other space techniques) and the installation of continuously observing GNSS sites.

- The products delivered are used not only by the scientific community but are also being used to define world-wide national reference frames related to the ITRF.
- There is a concern to develop education and training events, especially in less developed regions and countries. This effort must be continued and supported by the IAG.
- It is recognized the role of the WG Regional Dense Velocity Fields to detect some problems that were not evident in each of the regional Sub-commissions, due to the fact that the data are processed in limited areas.

Last but not least, the reports of all the components of SC 1.3 show the importance to keep and develop this kind of 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 1.4: Interaction of Celestial and Terrestrial Reference Frames

Main objective of IAG Sub-Commission 1.4 is the study of the interaction of the celestial and the terrestrial reference frames. In particular, SC 1.4 is focusing on the consistency between the frames. Sub-Commission 1.4 has established three Working Groups.

IC Project 1.2: Vertical Reference Frames

The main IC-P1.2 is the realization of a global vertical reference system (GVRS) based on the classical and modern observations and a consistent modeling of both, geometric and gravimetric parameters. At present, there are some hundred physical height systems realized worldwide.
The realization of a unified global reference surface for physical height systems, the relation of individual tide gauge records with respect to this reference surface, the separation of sea level changes and vertical crustal movements at tide gauges, and the connection with the terrestrial reference system are to at large unsolved problems. To proceed towards a unified physical height system we need at the centimetre accuracy level:

- a unified global height datum,
- consistent parameters, models and processing procedures for the Terrestrial Reference Frame (TRF) and gravity field,
- a closed theory for the combination of parameters (space techniques, gravity),
- consideration of time dependency, and
- a rigorous concept for the realization.

The definition and realization of a World Height System (WHS) is a fundamental requirement of GGOS (Global Geodetic Observing System). In the same way as the ITRS/ITRF provides a high precision geometrical reference frame, the WHS shall provide the corresponding high precision physical reference frame for studying the system Earth.

ICP 1.2 is a common project of IAG Commission 1 and 2. From beginning of 2010 the activities of ICP1.2 were integrated in GGOS as Theme 1.

IC Working Gr. 1.1: Environment Loading: Modelling for Reference Frame and Positioning

The principal objective of the scientific work of Working Group 1.1 is to investigate optimal methods to mitigate loading effects in ITRF frame parameters and site coordinates. The main activities of the members of this working group are represented in papers published or in preparation, as well as oral and poster presentations at the Fall Meetings of the American Geophysical Union (San Francisco, CA, USA), General Assemblies of the European Geosciences Union (Vienna, Austria), and occasional other special and topical meetings. Based on the WG research findings, the WG recommendation is that displacements due to non-tidal geophysical loadings not be included in the a priori modeled station positions for reasons detailed in the WG full report.

IC Working Gr. 1.2: Precise Orbit Determination and Reference Frame Definition

The members of the working group have agreed to focus on the effects of non-conservative force model error in precision orbit determination and how it aliases into POD solutions. Progresses have also been made to mitigate the radiation pressure modelling on DORIS TRF geocenter estimates.

IC Working Gr. 1.3: Concepts and Terminology Related to Geodetic Reference Systems

The WG has established a detailed report on recommended nomenclature related to Geodetic Reference Systems.

IC Working Gr. 1.4: Site Survey and Co-locations

The WG held meetings in conjunction with EGU and AGU. A particular emphasis was placed on attempting to establish a new challenging methodology for monitoring collocation vectors in near real time.

Sub-Commission 1.1: Coordination of Space Techniques

President: Markus Rothacher (Switzerland)

Objectives

Sub-Commission 1.1 coordinates efforts that are common to more than one space geodetic technique. It studies combination methods and approaches concerning the links between techniques co-located onboard satellites, common modeling and parameterization standards, and performs analyses from the combination of a single parameter type up to a rigorous combination on the normal equation (or variance-covariance matrices) or even the observation level. The list of parameters includes site coordinates (e.g. time series of positions), Earth orientation parameters, satellite orbits, atmospheric refraction (troposphere and ionosphere), gravity field coefficients (primarily the low-degree harmonic coefficients), geocenter coordinates, etc.

The work of Sub-Commission 1.1 is done in close cooperation with the IAG Services, namely the International Earth Rotation and Reference Systems Service (IERS), its Working Groups on Combination and on Site Co-locations, the International GNSS Service (IGS), the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry, the International DORIS Service (IDS), the IAG project "Global Geodetic Observing System" (GGOS), and with COSPAR.

For more details see the Sub-Commission description at http://www.iag-aig.org.

General Remarks

Within Sub-Commission 1.1 three working groups have been established and continued their work also in this second phase, i.e., after the IUGG General Assembly in Perugia 2007, in order to make progress towards the goals described above:

- SC1.1-WG1 on "Comparison and combination of precise orbits derived from different space geodetic techniques"
- SC1.1-WG2 on "Interactions and consistency between Terrestrial Reference Frame, Earth rotation, and gravity field"
- SC1.1-WG3 on "Comparison and combination of atmospheric information derived from different space geodetic techniques"

The three working groups are very important as steps towards GGOS, the Global Geodetic Observing System of the IAG. They have the task to (1) compare and combine precise orbits, to (2) study the interactions between the three pillars of geodesy, namely the Earth's geometry, Earth rotation and the Earth's gravity field as well as the temporal variations of these three parts, and to (3) compare and combine the atmospheric information derived from different space geodetic techniques.

Considerable progress has been made in some of the field addressed by IAG Sub-Commission 1.1. Let us just name a few:

- As part of the GGOS-D project consistent long-term series of SINEX solutions have been generated for GPS, VLBI and SLR including not only station coordinates and Earth Rotation Parameters (ERPs) but also troposphere zenith delays and gradients, quasar coordinates and low-degree coefficients of the Earth's gravity field. Not all the common parameters have yet been combined in one large multi-year solution, but many studies have already been performed with these very valuable SINEX data sets.

- Quite some experience has been gained with the combination of the observation data from CHAMP and the GRACE satellites with the observations (GPS and SLR) of the ground networks, an important step to combine geometry and gravity more extensively. Also, co-location of GPS and SLR onboard LEOs has been investigated and has led to the insight that the correction for the antenna phase center variations of the GPS antenna on the LEOs are crucial for gravity field determination.
- JPL is studying a satellite project specifically dedicated to the co-location of the space geodetic techniques onboard a new satellite, called GRASP. An initial study, but with a different concept, i.e. a low-cost nano-satellite with co-location, is also running at present with GFZ, ETH Zurich, TU Berlin and space industry. Both these missions, if realized, will be complementary to the co-location efforts on the ground.
- An new IERS Working Group has been formed (Chair: Richard Biancale) to make progress in the combination of the space geodetic techniques on the observation level.

The activities of the three working groups of Sub-Commission 1.1 during the last few years are summarized below.

Report on Working Group 1 (SC1.1-WG1):

Chair: Henno Boomkamp (Germany)

Long-term strategy

The Working Group is involved in an ambitious scheme of three related projects that were conceived and planned several years ago and are now gradually being implemented. The projects are called DIGGER, DANCER and DART and will be briefly revisited here (various other publications are available for further details).

The DIGGER project is the most relevant in terms of the WG charter, and the overall objectives of the IAG Reference Frame commission. It aims at coherent reprocessing of all different space geodetic datasets in the form of a cloud computing scheme on the internet. Current reprocessing activities of the IAG services are very useful, but not well coordinated between the techniques. Simultaneous estimation processes that include e.g. GPS, VLBI and SLR simultaneously can ensure much better consistency of common model parameters, but no individual Analysis Centre is currently performing such analyses. The key problems are typically a lack of processing capacity, and a lack of adequate knowledge of multiple tracking techniques at a single centre. The cloud computing approach on internet will eliminate the processing capacity problems, while process description databases can be derived from reprocessing activities of the separate services, even by non-experts. A functional prototype of DIGGER was developed by late 2006 around the grid computing software from Berkeley University. This showed that the concept was feasible, but no estimation software that could be freely distributed was available at that time. This is why the DANCER project will have to be completed first.

The DANCER project aims at computing GPS reference frame time series for an unlimited number of receivers. This solves the problem that at present only a very small percentage of permanent GPS sites have formal ITRF coordinates, and that many receivers cannot release their observation data for ITRF analysis by third parties. DANCER splits a typical GPS orbit estimation process into as many identical sub-tasks as there are receivers, and implements this task in the form of a scalable peer-to-peer process on the internet so that one task can run on one computer. Most naturally, this computer would be collocated with the GPS site, and can in the future even be fully embedded on the receiver itself (a so called "smart receiver" that immediately generates precise estimation products). This allows solutions for a virtually unlimited number of reference frame receivers at zero operational cost. The DANCER project is in an advanced state of implementation and will therefore be discussed in more detail in the next section.

The DART project (DAncer Real-Time-kinematic) aims to implement a web interface to the DANCER reference frame realization software in such a way that RTK users can establish accurate position coordinates in the DANCER ITRF realization. To this purpose, a DART user downloads the most recent global solution (and prediction) for GPS orbits, clocks and polar motion from any DANCER computer in the area, and interacts with other near-by DART users for ambiguity resolution in a short-baseline network. Today, the DART project only exists as a concept: not even a prototype has been constructed. The DANCER project has implemented a complete orbit estimation process that currently only processes GPS data. Some other geodetic datasets – notably VLBI, for observing absolute UT1 – might be added in the future. The intention is to use the same estimation module in DIGGER, and to construct DART by reusing existing RTK software. The main effort in terms of implementation of the three projects is therefore to produce the DANCER system.

Status of the DANCER project

Because the current WG activities focus on the DANCER project, its status will be discussed in some more detail. DANCER is implemented as a JAVA application around the JXTA peer-to-peer protocol, and uses the JXSE implementation of JXTA that is freely available from SUN Microsystems. This means that the entire peer-to-peer layer, including facilities for e.g. firewall transversal or network discovery, are readily available, and do not need to be implemented by the project. The application layer is nonetheless fairly complicated, in particular because it needs a high "network volatility robustness", i.e. high tolerance against processes that may go off-line at arbitrary moments.

The software implementation stage covered a series of around 16 milestones, each representing relatively independent tasks so that relatively small sub-tasks could be handled by different volunteers. Implementation started in the summer of 2009, and the last milestone was achieved in October 2010. For a project that has a budget of zero, this is a major achievement.

The present stage is one of the most complicated of the project, and is therefore progressing slowly (…but steadily). This is the first of four system test phases, in which the two main components of DANCER - the network communication module, and the parameter estimation module - are tested and stabilized separately. The first two stages perform all system testing off-line, i.e. not on the public internet. Once that off-line processing is entirely stable, both system test stages will be repeated on the real internet, using real GPS receivers. If this also works to satisfaction, the system can be declared operational. On-line testing of the communication layer can be done in parallel to the off-line testing of the estimation module (see Figure 1). At present, the off-line testing of the network is almost completed, so that the project is close to going on-line for the first time. This involves the installation of a first JXTA "relay-peer" with a public IP address.

It is remarkable that a complex system like DANCER can apparently be implemented in the form of a voluntary project at a budget of zero. The advantage is that there are no political dependencies on agencies or other entities, so that free distribution of the software can be ensured. The disadvantage is of course that progress is difficult to predict, as it depends entirely on availability of some very specific people.

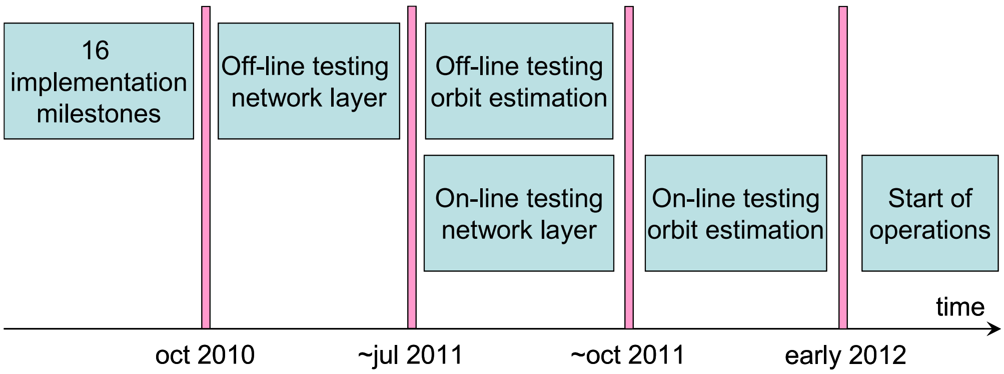

Figure 1: Implementation schedule of the DANCER project

Nonetheless, it seems reasonable to aim for the following remaining target dates in this project

- Start of on-line testing of network module: before IUGG 2011 Melbourne
- Start of on-line testing of estimation run: before AGU Fall meeting 2011
- Start of operations: before IGS Workshop 2012

During the IGS Workshop in Newcastle, a splinter meeting was dedicated to the DANCER project. Posters and papers on the Dancer project have been presented in e.g. Advances in Space Research and the REFAG2010 Symposium in Paris. Further details can be found on the project website www.GPSdancer.com.

Working Group issues

Membership of the Working Group is not very well-defined, partially because the WG was initially a merger between two earlier Working Groups, and partially because the actual project implementation requires significant assistance from people of very different fields, notably experienced JXSE users from other JXTA-based projects. However, it never seems very meaningful to remove people from a list of Working Group members, nor does it really happen that new members are formally added. Strict membership could create an illusion of exclusiveness that is only counterproductive, and the current situation does not really cause problems. However, in a future revision of IAG structures or WG structures it may be realistic to think of a different term than "Working Groups". In practice, most IAG Working Groups seem to consist of one or two active members who can fall back on a large network of experts – not just formal WG members - for occasional assistance. This concept works quite well in practice, but is probably not what most people would call a Working Group.

Mid and long term perspective

From the above it should be clear that the WG has a coherent strategy to reach its objectives, and that the planned projects are progressing in a satisfactory way. If the DANCER system succeeds in starting on-line operations around early 2012, this represents a major accomplishment of an IAG Working Group, and shows that much can be done even without any real resources. The implementation of the DIGGER and DART systems will still require a substantial additional effort, but good progress in the DANCER project gives reason to be optimistic. Together, these three systems will ultimately offer the following improvements

1. DANCER: coherent reference frame time series for *all* GPS reference receivers
2. DIGGER: consistency of reference frame of other techniques with GPS DANCER
3. DART: real-time access to this reference frame for all geodetic GPS users

Report on Working Group 2 (SC1.1-WG2):

Chair: Detlef Angermann (Germany)

Objectives

This working group is a joint WG together with Commission 2, Commission 3, and GGOS. The long-term objective of WG2 is to investigate the interaction between the terrestrial reference frame, Earth rotation and the gravity field and to develop methods for a consistent determination of the relevant parameters of these three fields by combining all contributing space geodetic observation techniques.

The main research topics are:

- Study the theoretical and practical interactions/relationships between parameters and models describing the terrestrial reference frame (station positions and their variations), Earth rotation (pole coordinates, UT1, nutation, …) and the gravity field (e.g., low-degree spherical harmonic coefficients).
- Analyses of the sensitivity of the different space geodetic observations for the determination of the relevant parameters and the correlations between them, and assess systematic biases between different space techniques.
- Assess and study the consistency of the products of these three fields.
- Develop improved methods to integrate and combine these three fields by using different space geodetic techniques (VLBI, SLR, GNSS, DORIS) and by including Low Earth Orbiting (LEO) satellites.

Working Group activities

Within this working group various activities related to the integration of geometry, Earth rotation and gravity, and the interactions between these three fields were carried out during the period of this report. A major focus was on the assessment and study of systematic biases between different space techniques, improvements regarding the unification of standards for the modeling and parameterization of the different observations, as well as the development of improved methods for a consistent estimation of products of the three fields geometry, Earth rotation and gravity. A significant progress has been achieved in these fields during the last four years. In the following, two projects that address various issues of WG2, are exemplarily mentioned:

- The project "Integration of Earth rotation, gravity field and geometry using space geodetic observations" within the DFG Research Unit „Earth Rotation and Global Dynamic Processes" is closely related to the objectives of WG2. The project has been started in 2006 and is now in the second funding period (2009 - 2012). Refined combination procedures have been developed to estimate consistently station positions, Earth Orientation Parameters (EOP), satellite orbit parameters together with the spherical harmonics of low degree and order of the Earth gravity field. SLR is the primary space technique to estimate all these parameters in a common adjustment. However, there are high correlations between several parameters (e.g., LOD, C_{20} and the empirical accelerations estimated once per revolution for the satellite orbits). Methods for a decorrelation of these parameters by using multi-satellite constellations were studied. Another issue was to investigate the benefits of a combination of SLR with GPS and VLBI. Since the SLR observation stations are not homogeneously distributed over the Earth, in particular the stable GPS network contributes significantly to stabilize the SLR network. In this context, the integration of the technique-specific networks via co-location sites is a key issue. An example for the results of the present activities is given below.
- The second project that shall be explicitly mentioned in context with the working group activities is the GGOS-D project. The project has been carried out from 2005 to 2008 with the major goal to investigate optimal possibilities for the integration of the various space-geodetic observations, thus fitting perfectly into the framework of GGOS (Rothacher et al., 2011). The members of the group belonged to Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum (GFZ), Deutsches Geodätisches Forschungsinstitut (DGFI), Institut für Geodäsie und Geoinformation, Universität Bonn (IGG) und Bundesamt für Kartographie und Geodäsie, Frankfurt am Main (BKG). With the project GGOS-D an important contribution could be made to GGOS in that it performed the first steps of an integration of the geometric and gravimetric space geodetic techniques. The major activities may be summarized as follows: (1) Definition and implementation of standards, models and parameterizations for a consistent processing of VLBI, GPS, and radar altimetry observations and for the representation of the products (Steigenberger et al., 2010); (2) Generation of a consistent reference frame for the computation and provision of all parameters of the global observing system (Angermann et al., 2010); (3) Development of methods for the computation of consistent time series of the most important parameters such as station coordinates, EOP, quasar coordinates, low-degree coefficients of the Earth gravity field, troposphere parameters (Nothnagel et al., 2010; Tesmer et al., 2009); (4) Investigation of relationships and correlations between time series of parameters and the comparison and validation of the geodetic results with external geophysical data.

As an example for the working group activities some results are given, that were obtained from the project "Integration of Earth rotation, gravity field and geometry using space geodetic observations" within the DFG Research Unit „Earth Rotation and Global Dynamic Processes". Figure 2 shows the time series of the low-degree spherical harmonic coefficients (C_{21}, S_{21} and C_{20}) that were computed at DGFI from SLR data to Lageos 1 and 2 (Bloßfeld et al., 2011). The results were obtained from a consistent estimation of station positions, EOP and orbit parameters of the satellites together with the spherical harmonic coefficients of the Earth gravity field. The results with an arc length of 7-days were compared with those of 28 days. An external comparison with the monthly solutions of the Center of Space Research (CSR), USA shows a very good agreement.

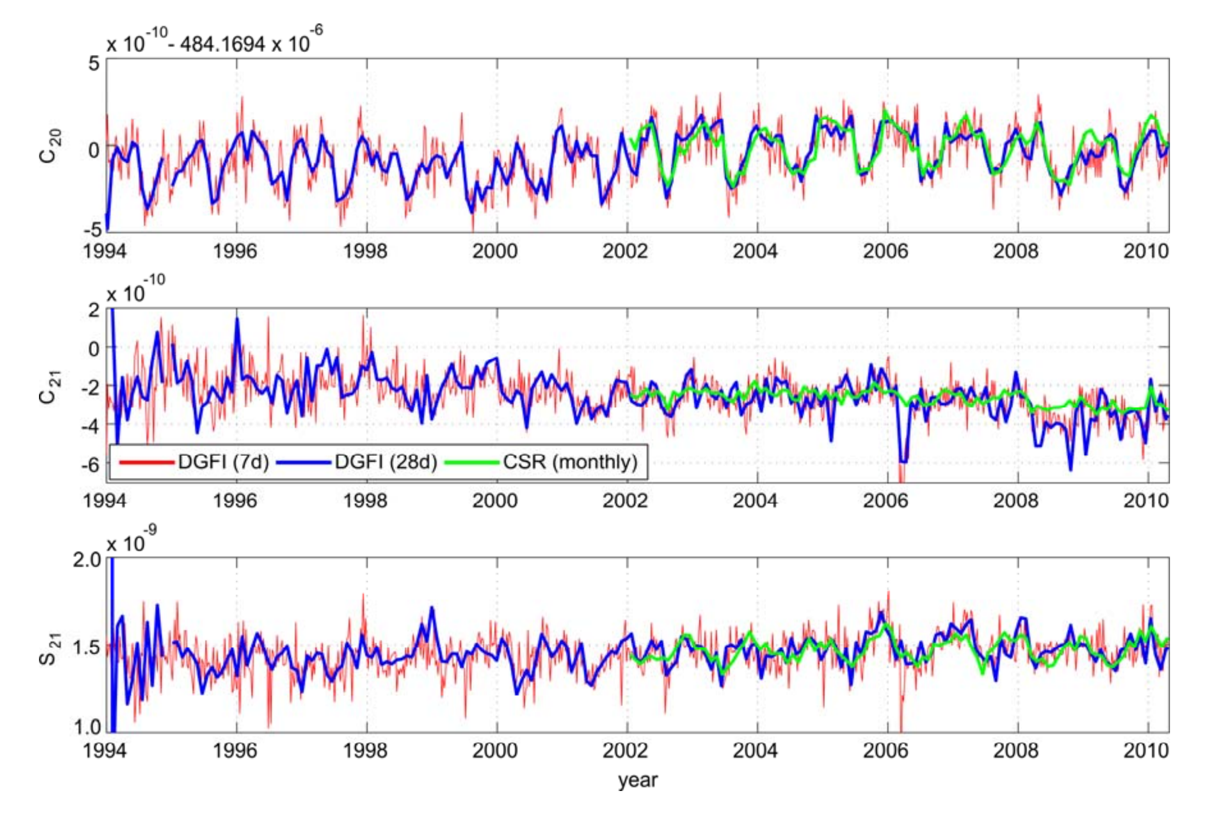

Figure 2: Estimated normalized low-degree harmonic coefficients C21, S21 and C20 of the Earth gravity field. The DGFI solutions (arc lengths of 7 days and 28 days) contain only data from Lageos 1 and 2, whereas the CSR solution includes in addition data from Stella, Starlette and Ajisai.

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Report of Working Group 3 (SC1.1-WG3):

Chair: Johannes Böhm (Austria)

The main task of Working Group 3 is the comparison and combination of atmospheric information derived from different space geodetic techniques, such as GPS, VLBI, DORIS, or altimetry. Major research topics are the investigation of differences between the troposphere delay parameters and the Total Electron Content (TEC) values with the assessment of systematic biases between the techniques in particular. The Global Geodetic Observing System (GGOS) with the goal to integrate all observations of geometry, rotation and gravity field of the Earth, is requiring the accurate, consistent, and bias-free modelling of delays in the neutral atmosphere ('troposphere') as well as in the ionosphere over all techniques.

Prerequisite for the comparison and combination of troposphere parameters is the application of consistent models and parameters, i.e., hydrostatic, wet, and gradient mapping functions, as well as a priori zenith delays and a priori gradients. (Read below for more details on this issue.) Also critical in the analysis of space geodetic observations and consequently for the comparison of TEC values (and also troposphere parameters) is the use of higher-order ionospheric terms, as e.g. discussed by Petrie et al. (2010) for GPS.

As replacement or extension to present-day troposphere delay modelling, direct ray-tracing through numerical weather models for the individual observations will become more and more important in the analysis of space geodetic observations. As a consequence, a *Workshop on Ray-Tracing for Space Geodetic Techniques* was held in Vienna in April 2010 within SC1.1-WG3 which was devoted to technical and physical details of ray-tracing, to the development of models from the ray-traced delays, and to their application in the analysis of space geodetic techniques. As an outcome of the workshop, a comparison campaign of various software packages for ray-tracing was initiated, and the results were described by Nafisi et al. (2011). High-resolution data from the operational analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) were provided to the five participating institutions for the stations Tsukuba (Japan) and Wettzell (Germany). In general, Nafisi et al. (2011) found good agreement among the submissions with standard deviations and biases at the 1 cm level (or significantly better for some combinations) between the ray-traced slant factors (azimuth-dependent mapping functions multiplied with a nominal zenith delay) from the different solutions at 5 degrees elevation if determined from the same pressure level data of the ECMWF (see Figure 3).

Many investigations have been carried out to compare the troposphere parameters derived from GPS, VLBI, and DORIS with observations from water vapour radiometers (WVR) and values from numerical weather models, e.g. Krügel et al. (2007) for the 15-days continuous VLBI campaign CONT02 or recently Teke et al. (2011) for CONT08. Furthermore, Steigenberger et al. (2007) and Heinkelmann et al. (2007) compared long time series from VLBI and GPS. From 2005 to 2008, a common research project by several German institutions dealt with the *Integration of Space Geodetic Techniques as the Basis for a Global Geodetic-Geophysical Observing System* (GGOS-D, Rothacher et al., 2010). More information about this project is available at the webpage *http://www.ggos-d.de*.

Some Ph.d. theses (partly in German) were finished in the last four years which also deal with the comparison and combination of atmosphere delay parameters derived from space geodetic techniques, e.g. Thaller (2008), Heinkelmann (2008), and Schmid (2009) for the troposphere or Todorova (2009) for the ionosphere. Those theses contain detailed and very important information for this working group.

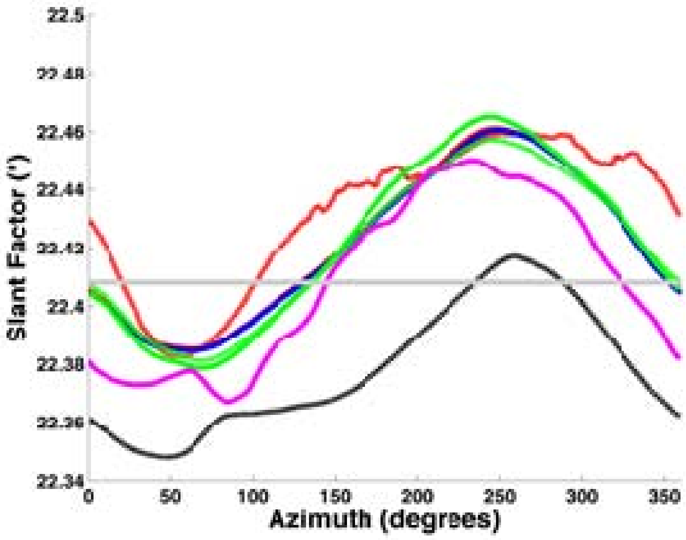

Figure 3: (from Nafisi et al., 2011). Ray-traced slant factors in m at 5 degrees elevation at Wettzell (Germany) on 1 January 2008 at 0 UT as determined with different programs and/or approaches from data of the ECMWF. Mind that two group used model level instead of pressure level data (magenta and black lines). More discussion of the results can be found in (Nafisi et al., 2011).

Troposphere delay comparisons

Teke et al. (2011) compared troposphere parameters for CONT08, a 15-days campaign of continuous VLBI observations in the second half of August 2008. In their study, VLBI estimates of troposphere zenith total delays and gradients were compared with those derived from observations with the GPS, DORIS, and water vapour radiometers (WVR) co-located with the VLBI radio telescopes. Similar geophysical models were used for the analysis of the space geodetic data, whereas the parameterization for the least-squares adjustment was optimized for each technique. In addition to space geodetic techniques and WVR, zenith delays and gradients from various global and regional numerical weather models were used for comparison. The best inter space geodetic agreement of zenith delays during CONT08 is found between the combined IVS and the IGS solutions with a mean standard deviation of about 6 mm over all CONT08 sites, whereas the agreement with numerical weather models is between 6 and 20 mm. The standard deviations are generally larger at low latitude sites because of higher humidity, and the latter is also the reason why the standard deviations are larger at northern hemisphere sites during CONT08 in comparison to CONT02 which was observed in October 2002 (Snajdrova et al., 2005). This finding also confirms Thaller et al. (2008) who found that the standard deviations between zenith delays from GPS and VLBI are correlated with the size of the zenith wet delays. Figure 4 is from Teke et al. (2011), and it shows the various zenith delays at Wettzell (Germany) during CONT08 which were used in the comparison.

Furthermore, it is described by Schmid et al. (2005) and Schmid (2009) that the biases between the techniques decrease when using absolute phase center patterns for GPS. However, there remains a significant influence on the zenith delays at those GPS antennas covered by a radome.

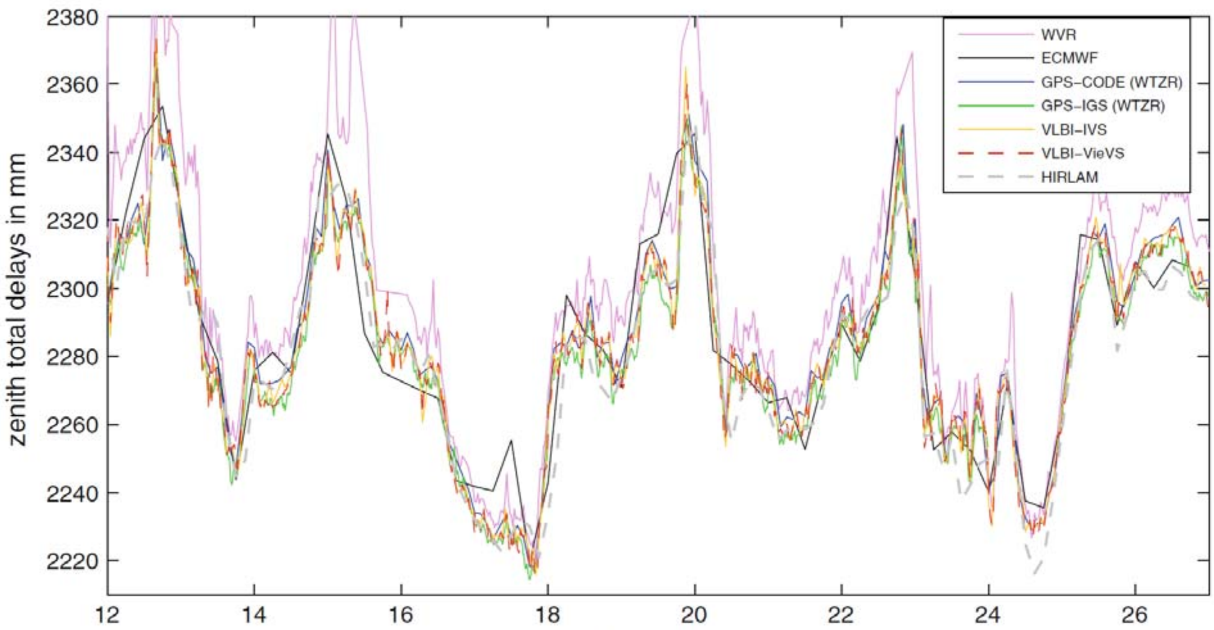

Figure 4: (from Teke et al., 2011). Zenith total delays at site Wettzell (Germany) vs. day in August 2008 from space geodetic techniques (VLBI, GPS), numerical weather models (ECMWF, HIRLAM) and WVR.

The assessment of troposphere gradients from the different techniques is not as clear because of different time intervals, different estimation properties, or different observables (Teke et al., 2011). However, the best inter-technique agreement for CONT08 is found between the IVS combined gradients and the GPS solutions with standard deviations between 0.2 and 0.7 mm. Nothnagel et al. (2009) compared mean gradients as derived from GPS and VLBI analysis, and they found that GPS gradients are generally larger (in absolute sense) than those determined with VLBI. Moreover, Böhm et al. (2011) described recently that mean GPS gradients are larger than those derived from numerical weather models. However, more investigations need to be carried out to explain these differences.

Important for the comparison and in particular for the combination is the use of identical geophysical models for the determination of the a priori troposphere delays. The a priori hydrostatic zenith delays are usually determined from pressure values at the site, which can be measured locally, extracted from a numerical weather model or - with minor precision - determined from empirical equations like the GPT model (Böhm et al., 2007). The same holds for the selection of the hydrostatic mapping function: mapping functions based on data from numerical weather models like the VMF1 (Böhm et al., 2006a) are more accurate, but empirical mapping functions like GMF (Böhm et al., 2006b) are easier to be implemented and yield also consistent values across the techniques. However, geodetic analysis should certainly go for the most accurate models as e.g. shown by Steigenberger et al. (2009), requiring that special care is taken to derive consistent values for the different techniques.

Combination of troposphere delays

It is essential to apply very accurate measures for the local ties between the various antennas at a site, because the differences in the station coordinates also correspond to differences in the hydrostatic and wet zenith delays. This is important for the combination of space geodetic observations: Any technique observing at microwave frequencies at a site is sensitive to the same troposphere delays; thus, if the local ties and the troposphere ties (!) are accounted for properly, the geodetic results (e.g. station coordinates but also troposphere parameters) benefit from the combination because more observations are contributing to the estimation of the same parameters. So far, routine combinations at the normal equation level do not include troposphere parameters, but future combinations should definitely take them into account. As another step towards its realization, there are also plans within the *IERS Working Group on the Combination at the Observation Level* to combine troposphere parameters.

Thaller (2008) concludes in her Ph.D. thesis that the inclusion of the troposphere parameters into the combination yields time series of zenith delay and horizontal gradients for the GPS and VLBI sites that are fully consistent with the common reference frame. The consistency is especially important as the time series based on the independent single-technique solutions' reference frames differ from those time series based on a common reference frame by up to 2 mm at mean. Thaller (2008) states that a combination of the zenith delays can stabilize the determination of the height coordinate, although this stabilization has not been seen for all co-locations. But she has demonstrated that a stabilization of the height component by combining the zenith delay is achieved if the local tie for the corresponding co-location is missing. The combination of the zenith delay acts only indirectly on the stability of the station height, thus, the combination of the zenith delay cannot fully replace the information that is given by introducing the local tie directly. However, as the problems concerning local tie values are manifold, the combination of the troposphere parameters might be an alternative to the application of local tie values that are questionable.

Thaller (2008) also summarizes that a stabilization of the solution similar to the effect seen for the combination of the troposphere zenith delay could not be shown for the combination of the troposphere gradients, neither with horizontal local ties additionally introduced nor without applying the local ties. However, it could be demonstrated that the common treatment of troposphere gradients together with the TRF can give valuable information about the discrepancy between the local tie and the coordinate differences derived from the space-geodetic techniques.

Comparison and combination of ionosphere delays

The ionosphere (from approximately 50 km to 1000 km) is dispersive for microwaves, and therefore the ionospheric delays (or phase advances, respectively) can be mostly eliminated by observing at two frequencies. However, the ionospheric delays, which are different for all techniques, are caused by similar Total Electron Content (TEC) values. Thus, all dual-frequency techniques should determine similar TEC values at the same line of sight or Vertical (VTEC) values above a point on the Earth surface.

IGS Ionosphere Working Group comparisons of TEC values were carried out between those values determined from IGS TEC maps and TEC values from altimeter observations (e.g. JASON, TOPEX, ENVISAT) (Hernández-Pajares et. al, 2009). These comparisons, which are only possible over the oceans and thus provide a lower boundary for the GPS TEC performance, yielded a mean bias of about zero and a mean standard deviation over all latitudes of about 5 TECU, but comparisons near the coast (with close GPS stations) implied that standard deviations can be as low as 2 TECU.

Within the IGS Analysis Centers (AC) the classical input data for the development of Global Ionosphere Maps (GIM) of VTEC are obtained from dual-frequency observations carried out at GNSS ground stations. However, GNSS stations are inhomogeneously distributed around the world, with large gaps particularly over the oceans; this fact reduces the precision of the GIM over these areas. On the other hand, dual-frequency satellite altimetry missions such as

TOPEX/Poseidon (T/P) and Jason-1 provide information about the ionosphere precisely above the oceans; and furthermore Low Earth Orbiting (LEO) satellites, such as Formosat-3/COSMIC (F-3/C) provide well-distributed information of the ionosphere globally. The combined GIMs connect the advantages of the different techniques and, thus, provide more homogeneous global coverage and higher reliability. Todorova et al. (2007) performed the combination of GNSS observations and satellite altimetry measurements for global modeling of the VTEC. Their studies showed that the combined GIMs from GNSS and satellite altimetry increased the precision of GIMs over the oceans. In the recent studies carried out by Alizadeh et al. (2011) VTEC values calculated from transformed F-3/C radio occultation measurements were also included in the combination procedure. Within their study it was shown that the combined VTEC maps of GNSS, Jason-1, and F-3/C have a higher accuracy and reliability compared to the GNSS-only maps (see Figure 5). They found a mean VTEC bias (combined minus GNSS) of -0.7 TECU through a whole day and a mean RMS difference (combined minus GNSS) of -0.2 TECU, which verified an improvement of 0.2 TECU in the accuracy of VTEC maps after combination. Dettmering et al. (2010) performed the combination of several space geodetic techniques for a regional modeling of VTEC. Their approach used the International Reference Ionosphere (IRI) as a background model. The GPS observations were included in the model in combination with radio occultation data from LEOs, dual-frequency radar altimetry measurements, and data obtained from VLBI. It was shown in their study that a combination of different observation techniques for ionospheric modeling could provide reliable VTEC maps with high resolution and accuracies better than 2 TECU.

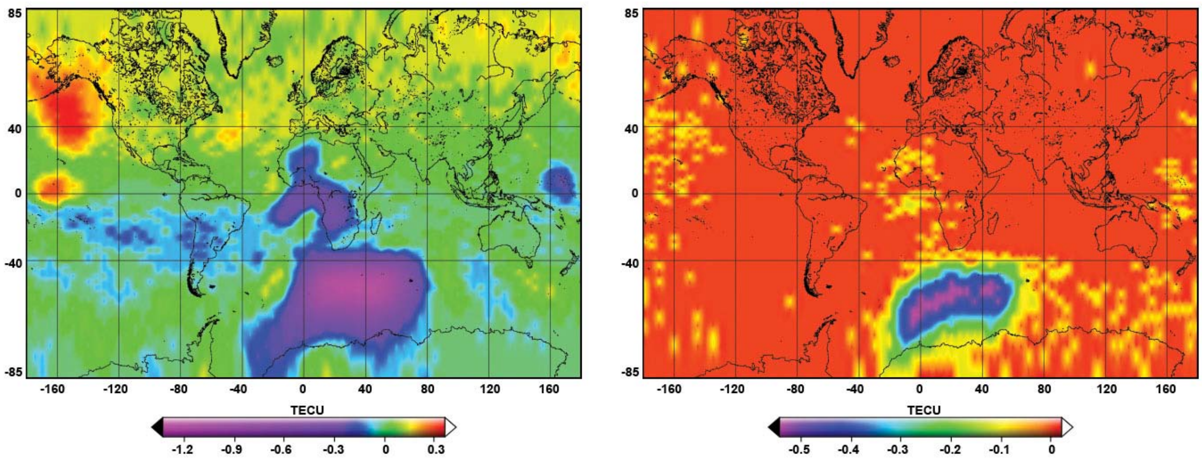

Figure 5: (from Alizadeh et al., 2011) (a) VTEC map of GNSS, satellite altimetry and COSMIC combined <minus> GNSS, satellite altimetry combined solution (global RMS 0.37 TECU), and (b) RMS map of GNSS, satellite altimetry and COSMIC combined <minus> GNSS, satellite altimetry combined solution (global RMS 0.89 TECU), day 202, 2007 – 9:00UT.

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Outlook

Considerable progress has been made in some of the combination issues that are addressed by IAG Sub-Commission 1.1. However, in order to reach a rigorous combination of all common parameters present in the solutions of the individual space geodetic technique much has still to be achieved. The next steps should be:

- The terrestrial reference frame, the Earth Orientation Parameters (EOPs) and the celestial reference frame should be linked in a consistent way. Therefore, the quasar coordinate estimates (derived from VLBI data) should be included in the normal equations systems or variance-covariance matrices to be combined. The VLBI community is working in this direction.
- Daily solutions should be generated from GPS, DORIS and VLBI that contain not only station coordinates and Earth Rotation Parameters (ERPs) but also troposphere zenith delays and gradients. The combination of troposphere zenith delays and gradients is important to improve the consistency of the solutions and to detect technique-specific biases.
- Low-degree coefficients of the Earth's gravity field and range biases should be included in the SLR weekly solutions and should become part of the combined intra-technique solutions produced by the ILRS combination centers.
- Low Earth Orbiters with more than one observation technique onboard should be analyzed to benefit from the co-location of instruments in space. The inclusion of LEOs like CHAMP, GRACE, and GOCE into the global solutions based on the ground networks (GPS and SLR) would also help to link geometry and the gravity field.

We see from the few items above, that large deficits still exist and a lot of work is still ahead of IAG Sub-Commission 1.1. The long-term goal of Sub-Commission 1.1 is still the development of a much better understanding of the interactions between the parameters describing geometry, Earth rotation, and the gravity field, as well as the study of methods to validate the combination results, e.g., by comparing them with independent geophysical information.

Sub-Commission 1.2: Global Reference Frames

President: Claude Boucher (France)

The IAG Sub-Commission 1.2 was created in 2003 as a part of the new structure of the International Association of Geodesy (IAG). The present missions were fixed by the charter for the period 2007-2010. This report provides only summaries of activities. More details or references can be found in the web pages hosted by the IAG Commission 1 website.

Structure

The sub-commission has an open membership. Several Study Groups and Working Groups are linked to SC1.2 :

- IC-SG1: Theory, implementation and quality assessment of geodetic reference frames (jointly with ICCT)
- IC-WG1-3: Concepts and terminology related to Geodetic Reference Systems
- IC-WG1-4: Site Survey and Co-location (jointly with IERS)

Please refer to their own activity reports.

In order to stimulate some specific research topics, two task forces were established within the Sub-commission:

- External Evaluation of Terrestrial Reference Frames Chairman : Xavier Collilieux (France)
- Global Geodetic Observatories Chairman: Perguido Sarti (Italy)

Terminology

The IC-WG1-3 was specifically devoted to this subject. Please refer to its report

Site survey and co-locations

The IC-WG1-4 has reactivated its involvement into research topics, and therefore its close link with the SC activities, thanks to Perguido Sarti who is now chairing this group. See its report.

International Terrestrial Reference System (ITRS)

At the IUGG/IAG General Assembly of Perugia, an IUGG resolution was approved about ITRS, related to its definition and adoption by the geoscience community. The definition is consistent with the recent IAU resolutions. More details can be found in the new version of the IERS Conventions.

It is worthwhile to mention numerous efforts to promote the adoption of ITRS and its realizations as unique preferred system among the various communities. Several actions have started within GGOS, specifically:

- Establishment of a working group on an ITRS standard
- Leading a sub-task in the frame of GEO on these issues

Within the GNSS community, a Task force on Geodetic references has been recently (dec 2008) established by the International Committee for GNSS (ICG)

Within the metrological community, the Consultative Committee on Time and Frequencies (CCTF) took a resolution to adopt ITRS, submitted to the International Conference for Weights and Measurements (CGPM), the relevant inter-governmental organization.

Concerning ITRS itself, some discussions were raised about the possible refinement of its present definition, in particular about its origin and scale. The present situation did not show a clear need to modify the current definition.

International Terrestrial Reference Frame (ITRF)

Numerous research activities are developed related to ITRF, either as the methodological level or on quality assessment. More details can be found in the various reports by IERS, in particular related to ITRF2005 and the new solution, ITRF2008, released end of May 2010.

We can mention the relevant chapters of the new GGOS 2020 document , and the organization by Sakis Dermanis of a session during the Hotine-Marussi symposium in July 2009.

External Evaluation of Terrestrial Reference Frames

Considering the importance of the external evaluation of ITRF, a task force has been recently created by the SC. Its main objectives are:

- To investigate various activities in which the adopted Terrestrial Reference Frame (TRF) has a quantitative influence on the results of this activity, such as
  - Precise Orbit Determination (POD)
  - Data reduction of satellite radar altimetry
  - Correction of vertical motions at tide gauges
  - Antenna Phase Center Offsets/Variations calibration for GNSS (on board and ground)
  - Geophysical models (plate motions, post-glacial rebound…)
  - Geophysical Fluid Mass inversions
  - ….
- To discuss for each identified activity whether there is a preferred numerical effect in view of a priori expectations
- To inverse the relation to evaluate TRF datum and derive possible external constraints on TRF datum fixation, related to its origin, scale or orientation and their time evolutions

Although TRF in general are under consideration, a major impact of these activities is clearly for ITRF.

Global Geodetic Observatories

In order to satisfy the need to activate work on Global Geodetic Observatories (GGO) which is in the SC charter , a task force was recently established, which is just starting. Items to be considered:

- GGO as fundamental station for geodetic networks of various types (space techniques, gravimetric, clocks, tide gauges…)
- Metrological aspects
- Co-locations of instruments : tie issues, colocated sensors, other geophysical sensors (seismometers, magnetometers, atmospheric sensors…)
- Operational and logistic issues
- Network design and coordination of network deployments

Sub-Commission 1.3: Regional Reference Frames

President: 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 organizations.

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, the Working Group on Regional Dense Velocity Fields was created within SC 1.3. This WG aims at joining the efforts of the regional sub-commissions together with the groups processing local/regional CORS or repeated GNSS campaigns in order to compute a dense velocity field referenced in a unique global frame.

Overview

The activities of each of the regional Sub-Commissions and the WG Regional Dense Velocity Fields are reported hereafter.

A summary of those activities and the main results achieved, are summarized as follows.

Sub-Commission 1.3 a: Europe

- The number of permanent GNSS tracking sites in Europe has grown considerably; more than 244 EPN stations are operated the end of 2010 by national European institutions. The number of sites which record GLONASS data simultaneously to GPS data and which stream real time data is steadily increasing (59 % and 49 % resp.). Also a new Local Analysis Centre joined the group of EPN analysis centres, increasing the total number to 17.
- The majority of the EPN Local Analysis Centres (LAC) participate in the EUREF Special Project "EPN Reprocessing". The complete EPN is re-analysed using the data from 1996 until 2006. The first results of EPN REPRO1 campaign are expected soon. Another re-analysis of the entire EPN is foreseen using the ITRF08.
- The number of regional broadcasters for real-time GNSS data increased to 3. One of them started to broadcast satellite orbits in the ETRS89 (realization ETRF2000). Using these orbits, users can directly derive in real-time coordinates in the ETRS89.
- The continuation of the promotion of the ETRS89 (European Terrestrial Reference System) and the EVRS (European Vertical Reference System), following the adoption by INSPIRE of these systems as the basis for georeferencing in Europe.
- The computation of transformation parameters between national height systems and EVRS (EVRF2007) and its delivery in April 2010. Additionally the online-transformation for heights of single points was implemented.
- The continuation of the ECGN (European Combined Geodetic Network). The ECGN is considered as a European contribution to the IAG Project Global Geodetic Observation System (GGOS).
- The realization of symposia in 2008 (Brussels), in 2009 (Florence), 2010 (Gävle) and 2011 (Chisinau) (in preparation).

Sub-Commission 1.3 b: South and Central America

- The implementation of the SIRGAS-CON network, which replaces the former realizations and allows a permanent monitoring of the reference frame. The SIRGAS-CON network was extended to 270 continuously operating GNSS stations. 48 stations are integrated in the IGS global network, and 72 receivers are able to track GLONASS. The data are weekly processed by 9 analysis centres.
- The new strategy used to realize the SIRGAS datum, in order to reduce network deformations due to the effect of seasonal variations in the datum realization, with the alignment of the weekly solutions of the SIRGAS-CON frame to the ITRF using the IGS weekly coordinates.
- The reprocessing of the entire SIRGAS-CON network applying the reprocessed IGS products (IG1), allowing the improvement of the reliability and accuracy of station positions and velocities computed within multi-year solutions.
- The availability of a Velocity Model for SIRGAS (VEMOS), consisting on horizontal velocities in those regions which are not covered by SIRGAS-CON.
- The systematic adoption of official geodetic reference system at national level based on SIRGAS in 16 of the 18 SIRGAS member countries.

- The development of actions for capacity building and the promotion of SIRGAS in the member countries, in particular the support to the establishment of new experimental associated analysis centres and the organization of the SIRGAS School on Reference System, under the sponsorship of the IAG and PAIGH.
- The Executive Committee met in Bogotá (2007), in Montevideo (2008), in Buenos Aires (2009) and Lima (2010).

Sub-Commission 1.3 c: North America

- The realization of densifications of the ITRF and IGS global networks by weekly combinations of seven different regional weekly solutions using different GPS processing software, including for the first time a solution from Mexico.
- The generation of the last cumulative solutions (coordinates and velocities) based on the weekly NAREF combinations to produce new solutions on an annual basis.
- The reprocessing of regional solutions prior to GPS Week 1400 using the new IGS procedures and absolute antenna phase center variation models is underway. A solution has been realized at one processing center for 2,264 CORS stations based on weekly reprocessed solutions from 1994 to 2010.5 with absolute antenna calibrations and global sites for alignment to IGS08.
- The progress towards a new realization of NAD (North America Datum). This new realization will be truly geocentric, fixed to North America and fully consistent with the ITRS.
- The continuation of the activities related to the definition and maintenance of the relationships between international and North American reference frames/datums. The transformation between NAD83 and ITRF2008 was determined for use in Canada and the US, and other activities have focused on education and outreach efforts.
- The re-activation of the working group related to the maintenance of the vertical datum for the management of the Great Lakes water system, taking also into consideration the need to update the International Great Lakes Datum by 2015.

Sub-Commission 1.3 d: Africa

- The Steering Committee met several times. The most significant was a series of joint meetings held in June 2008 in Johannesburg, June 2010 in Washington and November 2010 in Johannesburg which brought together representatives from the fields of seismology, meteorology, space weather, geophysics and geodesy.
- Progress has been made with the installation of permanent GNSS reference stations in Africa. These have been installed by National Mapping Agencies, Universities and research groups.
- An Operational Data Centre (ODC) for AFREF with an open data policy, became operational in June 2010 and is currently archiving data from approximately 45 permanent continuous GNSS base stations.
- Four annual training courses were held between 2007 and 2010 at the Regional Centre for Mapping of Resources for Development (RCMRD), covering the concepts of AFREF, permanent GNSS reference stations, reference frames and the processing of GNSS data. The first two courses were more theoretical in nature while the latter two placed greater emphasis on the practical aspects of the project.

- A Call for Participation in the processing of GNSS data in support of the AFREF project has been prepared and will be distributed shortly.

Sub-Commission 1.3 e: Asia-Pacific

- The resolution of the 18th United Nations Regional Cartographic Conference (UNRCC) for Asia and the Pacific to mandate APREF, also endorsed by the International Global Navigation Satellite System Service (IGS), the United Nations Office for Outer Space Affairs (UNOOSA) and the Federation of International Surveyors (FIG).
- The APREF initiative to realize a high-standard regional reference frame by processing the GNSS data of the network in different Analysis Centres (ACs).
- The availability since 2010 of a weekly solution containing weekly estimates of the coordinates of the participating Asia-Pacific GNSS tracking stations and their covariance information. This product gives a reliable time-series of a regional reference frame in the ITRF and a quality assessment of the performance of the GNSS CORS stations included in the network. The APREF combined solution will be also a contribution to the IAG Regional Dense Velocity Field Working Group.
- The realization of an annual geodetic observation campaign in order to densify the ITRF in the Asia-Pacific Region and to provide an opportunity to connect to national geodetic networks and to determine site velocities. These campaigns have focused on GPS observations but incorporated also other geodetic techniques, SLR and VLBI.
- The large activity in the Asia-Pacific area in order to upgrade and extend the geodetic infrastructure, by the installation of GNSS and VLBI stations, and the launch of projects for crustal monitoring.
- The contribution to enhance the regional geodetic infrastructure, to encourage the transfer of GPS technology and sharing of analysis techniques to nations in need.
- The meetings held in Seoul (2007), Kuala Lumpur (2008), Bangkok (2009), Singapore (2010). The next meeting is planned for Ulaanbaatar in July 2011.

Sub-Commission 1.3 f: Antarctica

- The realization of SCAR GPS Campaigns in 2008 and 2009. The data of 34 Antarctic sites are collected in the SCAR GPS database beginning with the year 1995.
- The continuation of data analyses and presentation of the results at the XXX SCAR Meeting (2008) and at the EGU Meeting (2009).
- The meeting that took place during the XXX SCAR Meeting, resulting in the working plan of the SCAR Group of Experts on Geodetic Infrastructure in Antarctica (GIANT) for the years 2008-2010.
- The active participation in the project POLENET (Polar Earth Observing Network), in the frame of the International Polar Year 2007/2008.

Working Group on Regional Dense Velocity Field

- The WG appointed for each region a region coordinator to gather velocity solutions for their region (in accordance with the WG requirements) to produce one regional combined velocity solution. The cumulative velocity solutions submitted in 2009 showed that they could not be rigorously combined.

- The investigations are being carried out in order to verify the agreement between regional and global GNSS solutions and on the best possible procedures to reduce network effects.
- The latest tests are being carried out with one new global solution and 4 new regional solutions, all of them based on a reprocessing and using absolute antenna models, in about 400 densification sites to the ITRF2008.
- The WG is concentrated on identifying the sources of disagreements between the solutions submitted to the WG and the ITRF2008 before using any site as a frame-attachment site.
- The WG met in Miami Beach (2008), San Francisco (2008), Vienna (2009), Buenos Aires (2009) and Paris (2010). A website has been set up providing a gateway to the WG activities.

Conclusion

The activities of each of the regional Sub-Commissions and the WG Regional Dense Velocity Fields show that all the components of the structure are developing according to the main objectives of the SC 1.3.

It must also be emphasized that during the 4-year period covered by this report there was a strong increase of activity in the less developed regions, as it is demonstrated by the results achieved.

Some general aspects deserve to be referred:

- The activities are contributing to the scientific and technical development in several topics such as GNSS analysis and processing, precise reference frame establishment, among others.
- The organizational aspects play a more and more important role and are crucial for the efficient achievement of results.
- There is a great effort to bring together different types of institutions (R&D structures, National Mapping Agencies, political and economic agencies, etc.) to support the realization of international campaigns (GNSS and other space techniques) and the installation of continuously observing GNSS sites.
- The products delivered are used not only by the scientific community but are also being used to define world-wide national reference frames related to the ITRF.
- There is a concern to develop education and training events, especially in less developed regions and countries. This effort must be continued and supported by the IAG.
- It is recognized the role of the WG Regional Dense Velocity Fields to detect some problems that were not evident in each of the regional Sub-commissions, due to the fact that the data are processed in limited areas.

Last but not least, the reports of all the components of SC 1.3 show the importance to keep and develop this kind of 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 proceeding from EUREF support the use of the European Reference Systems in all scientific and practical activities related to precise geo-referencing and navigation, Earth sciences research and multidisciplinary applications. EUREF makes use of the most accurate and reliable terrestrial and space-borne techniques available, and develops the necessary scientific background and methodology. Its activities are focused on a continuous innovation and on the changing user needs, as well as on the maintenance of an active network of people and organizations, and may be summarized as follows:

- to maintain the ETRS89 (European Terrestrial Reference System) and the EVRS (European Vertical Reference System) and upgrade the respective realizations;
- to refine the EUREF Permanent Network (EPN) in close cooperation with the IGS;
- to improve the European Vertical Reference System (EVRS);
- to contribute 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 Technical Working Group (TWG) Meetings 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 countries in Europe and other continents, representing universities, research centers and the NMCA (National Mapping and Cadastre Agencies). It's an open forum, and may be attended by any person interested in the work of the Sub-Commission. The organization of the EUREF Symposia has been and will be supported by EuroGeographics, the consortium of the European National Mapping and Cadastral Agencies, reflecting the importance of the EUREF work for practical purposes. This involvement is consolidated since 2007 by a formal liaison between EUREF and EuroGeographics. The latest EUREF symposia took place in Brussels, Belgium (2008), in Florence, Italy (2009), in Gävle, Sweden (2010), the 2011 symposium will be held in Chisinau, Moldova.

To achieve these activities, EUREF works closely together with EuroGeographics. A Memorandum of Understanding between EUREF and EuroGeographics guarantees on one hand that the developments made by EUREF are absorbed and implemented by the NMCA; and on the other hand, to involve EUREF in the NMCA concerns and problems on geodetic issues that must be solved in a European and global perspective

EUREF is an associated member of the International Committee on Global Navigation Satellite Systems (ICG) since 2009. Goals of the annual meetings are to review and to discuss developments in GNSS and to allow ICG members, associate members and observers to consider matters of interest. ICG also addressed GNSS technology in the era of multi-systems receivers and the impact of GNSS interoperability on timing and other user applications.

Conventional frame ETRF2000

The ETRS89 is linked to the International Terrestrial Reference System (ITRS) and up to the release of the ITRF2005, each new realization of the ITRS (i.e. ITRFyy) was followed by a new realization of the ETRS89 (i.e. ETRFyy). However, from ITRF2005 on, the TWG decided to continue using the ETRF2000 as the ETRS89 realization and it adopted the ETRF2000 as the conventional realization of the ETRS89. The ETRF2000 will thus also be the ETRS89 frame adopted in conjunction with the latest release of the ITRS, ITRF2008 (release May 2010, for more information see http://itrf.ign.fr/ITRF_solutions/2008/).

The mathematical transformation from ITRFyy to ETRF2000 can be done in a two-step approach using two successive Helmert transformations (ITRFyy → ITRF2000 followed by ITRF2000 → ETRF2000), or can be done by one single 14-parameter transformation (directly from ITRFyy → ETRF2000), (Altamimi, 2009). The parameters of all these transformations are available from the Memo by Boucher and Altamimi (2008) which was updated on Nov. 24, 2008 and which will soon be updated again to include the transformation formula to and from the ITRF2008. To help users to perform the necessary transformations, an on-line transformation tool, which allows transforming between any ITRS/ITRS, ITRS/ETRS89 and ETRS89/ETRS89 realization has been put on-line at http://epncb.oma.be/_dataproducts/coord_trans/.

EUREF Permanent GNSS Network (EPN)

The EPN is a permanent GNSS network created by the IAG Sub-Commission for Europe (EUREF). Its primary objective is to maintain and provide access to the ETRS89. The EUREF Technical Working Group (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 centers, local and regional data centers, local analysis centers, a combination centre and a central bureau. The EPN is the European densification of the network operated by the International GPS Service (IGS). Therefore, the EPN uses the same standards and exchange formats as the IGS. In 2010, a new Local Analysis Centre (Military University of Technology (MUT, Poland)) joined the group of EPN analysis centres, increasing the total number to 17.

Two workshops of the Local Analysis Centres (LAC) were held in Frankfurt, Germany (2008) and Warsaw, Poland (2010). The scope of such workshops is to verify the current and future direction of the EPN analysis activities and to continue in improving the processing strategy and options. The initiation of the EPN re-processing activities and encouragement of the Analysis Centres to step towards GNSS (GPS, GLONASS, Galileo) was one of the outcomes of the mentioned workshops.

Special Projects are set up by the EPN Coordination Group in order to introduce new applications into the EPN or study special aspects of the permanent network. The different EPN components (such as the tracking stations, data centers and analysis centers) follow specific guidelines. Candidate EPN stations can also find the necessary instructions for becoming an EPN station in http://www.epncb.oma.be. The number of permanent GNSS tracking sites in Europe has grown considerably; more than 244 EPN stations are operated the end of 2010 by national European institutions. The number of sites which record GLONASS data simultaneously to GPS data and which stream real time data is steadily increasing (59 % and 49 % resp.).

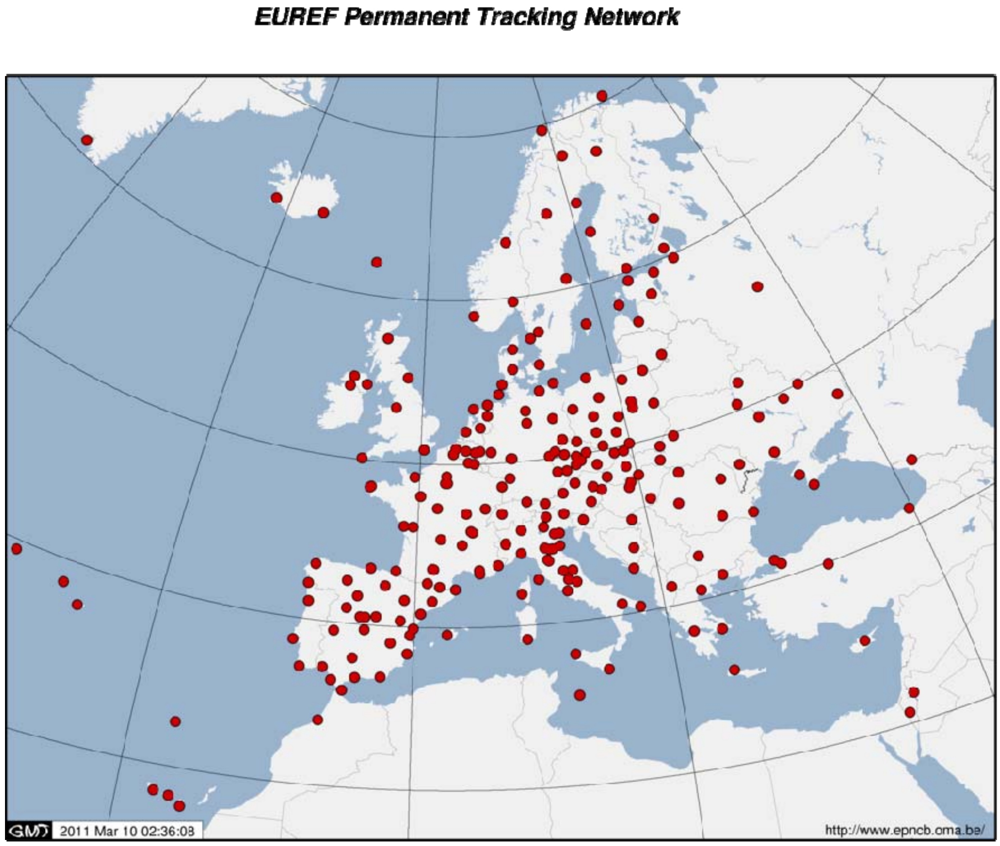

Figure 1: EUREF Permanent GNSS Network EPN

EUREF Densification of the ITRF

Even while 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 ITRS realizations.

The latest realization of the ITRS, the ITRF2005, is based on observations from space geodetic techniques (GNSS, DORIS, VLBI, and SLR) up to December 2005 and does not take into account any of the IGS/EPN data gathered after Jan 1st, 2006. Consequently it cannot reflect the most recent status of the EPN (e.g. antenna changes). The limited number of stations and the lack of frequent updates limit therefore the use of the ITRF for EUREF densifications.

To take full advantage of the EPN and its most recent GNSS observation data, 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 at all epochs of the time span of the used observations
- 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", only Class A EPN stations can be used for densifications of the ETRS89.

EPN re-processing activities

During the past years it has been realized that the analysis of the global as well as the regional GNSS networks are affected by different factors causing systematic biases like the reference system realization, correction models, analysis strategies and software packages. Inconsistencies in the coordinates and long time series are therefore very frequent. The TWG has therefore decided to define a new EPN project "EPN Reprocessing". The aim of the EPN reprocessing project is to obtain improved and consistent coordinates, position time series and troposphere parameters for each of the EPN sites. Most of the EPN Local Analysis Centres (LAC) participate in this project. Different software packages like BERNESE, GIPSY/OASIS and GAMIT are used for the analysis of the data. Within the so called *Pilot Phase* the data of 2006 have been re-analysed with different models and strategies in order to select the best common strategy for the complete re-analysis of the EPN data. The first results of the reprocessing have been presented and discussed at the EPN Local Analysis Centres workshop hosted in Warsaw from Nov. 18-19, 2010. At present, the LACs have analysed a benchmark campaign in order to compare the results of the individual LACs and to tune the setup. Currently the complete EPN is re-analysed using the data from 1996 until 2006 using the reprocessed orbits and ERPs of the IGS reprocessing campaign. Data from 2007 until present are already computed in the most recent realization of the ITRS (currently ITRF2005) and will be used together with the reprocessed solutions to derive consistent coordinates and velocities for the EPN that will support the realization of the ETRS and shall be made available to the community.

The first results of EPN REPRO1 campaign are expected before the summer of 2011. It is quite clear that the new realization of the ITRS, the ITRF08, will cause another re-analysis of the entire EPN applying again the most recent models, strategies and standards, as long as new reprocessed products based on the ITRF08 for a global network will be made available by the IGS community. More information the EPN reprocessing is available from http://epn-repro.bek.badw.de/.

EPN Real-time Analysis Project

The EPN Project on "Real-time 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 (http://www.euref-ip.net) is broadcasting satellite orbits in the ETRS89 (realization ETRF2000). Using these orbits, users can directly derive in real-time coordinates in the ETRS89.

One aim of the project is to increase the reliability of the EPN real-time data flow and to minimize the possibility of regional broadcaster's 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 (Royal Observatory of Belgium, http://www.euref-ip.be/). based on the existence of three regional broadcasters, several stations started uploading their data in parallel to all of the broadcasters. By this strategy dependency on one broadcaster will be avoided and the real-time data flow become more consistent. More information of the EPN "Real-time Analysis" Special Project is available from http://www.epncb.oma.be/_organisation/projects/RT_analysis.

The new broadcaster which has been set up at BKG (http://products.igs-ip.net) allows access to several real-time product (orbit and clock correction) streams. These streams are uploaded by various institutions participating to the IGS Real-time pilot project.

Promotion of Adoption of the ETRS89

Since 1989, many European countries have defined their national reference frames in (or closely aligned to) ETRS89 by calculating national ETRS89 coordinates following the EUREF guidelines. The national ETRS89 coordinates, adopted by the different countries, can differ from each other due to differences in datum definition: they are often based on different ETRFyy frames and each of them refers to different observation periods.

The difference between the ETRS89 adopted in each of the different countries with respect to the most recent estimates of the ETRS89 coordinates of the EPN stations is now monitored on a regular basis by EUREF. The results of the comparison show an agreement of a few cm (see Figure 2).

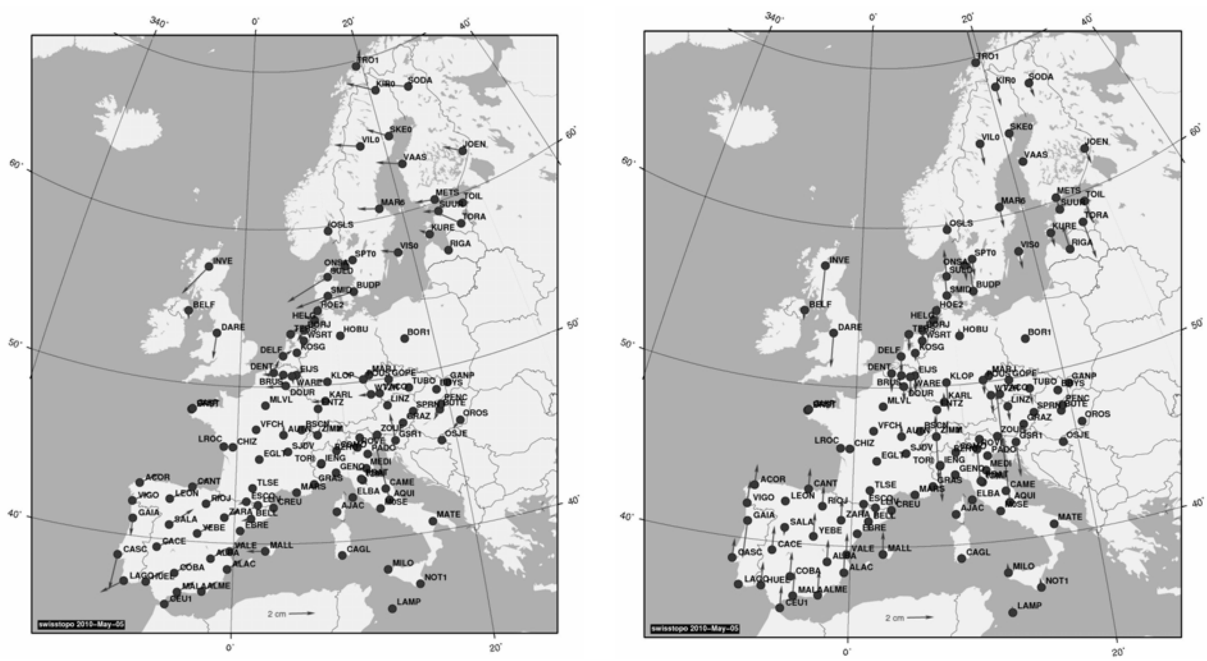

Figure 2: Difference between ETRS89 coordinates adopted in the different countries and the latest EPN cumulative coordinate solution.

In addition, the EUREF TWG also decided to update its information concerning the usage of ETRS89 in the different countries. The goal of this activity is to issue a new questionnaire to be distributed among the National Mapping and Cartographic Agencies. This questionnaire will be the follow up of the questionnaire distributed in 2005.

European Vertical Reference System (EVRS)

Since 1994 the IAG Sub-commission for Europe (EUREF) have enhanced the Unified European Leveling Network (UELN) and defined a European Vertical Reference System (EVRS). About 50 % of the participating countries provided new national leveling data to the UELN data centre after the release of the last solution EVRF2000. 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 over the stable part of Europe. The measurements have been reduced to the common epoch 2000 using the land up-lift model of 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 adopted proposing to the European Commission to adopt the EVRF2007 as the mandatory vertical reference for pan-European geo-information.

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

After providing the EVRF2007 results the development of the UELN will be continued.

In 2009 the measurements of the 1. Order Leveling Network of the European part of Russia were handed over to the UELN data center. These additional data finally allow to close the loop around the Baltic Sea. Moreover, Belarus and Ukraine have decided to participate in the UELN project. As both countries report, the preparation of their leveling data is in progress.

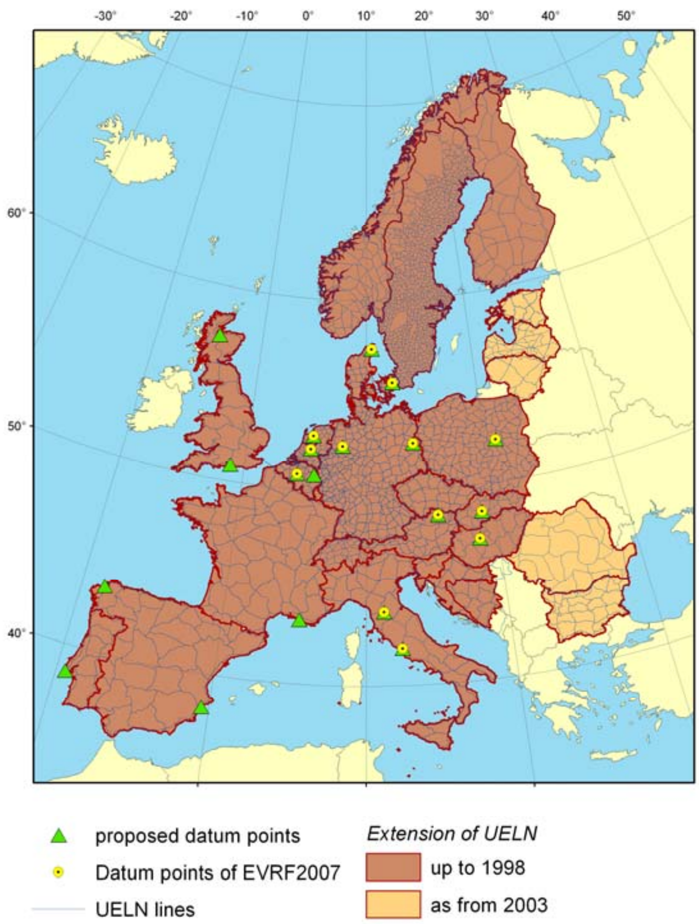

Figure 3: EVRF2007

The delivery of the new leveling network of Spain has been announced for about 2009. Besides that, a partial re-measurement of the French leveling network (NIREF) has been performed.

ECGN continuation

The ECGN combines the integration of time series of spatial/geometric observations by GNSS technique, and physical quantities by gravity field related observations and parameters including precise levelling, tide gauge records, gravity observations, as well as earth and ocean tides. The objective of ECGN as an integrated European Reference System for Spatial Reference and Gravity is the maintenance of the terrestrial reference system with long-term stability for Europe.

The objectives of ECGN can be summarized as follows:

- Monitoring the long term stability of the terrestrial "3D+1" reference system for Europe with an accuracy of 10^{-9}, including 3D geometric parameters together with the gravity related height component
- In-situ combination of geometric positioning (C-GNSS time series) with physical height (UELN) and repeated gravity measurements on 1 cm accuracy level or better
- To contribute to the maintenance and improvement of precise geoid models
- To provide connection to the sea level and sea level changes via tide gauges in the area concerned
- To maintain databases (via existing components, such as EPN) and a metadata base for access to the data and products of the ECGN

ECGN, 2011. http://www.bkg.bund.de/nn_165056/geodIS/ECGN/EN/Home/homepage__node.html__nnn=true (30.1.2011)

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

Chair:	*Claudio Brunini (Argentina)*
Vice-chair:	*Laura Sánchez (Germany)*
SC1.3b-WG1 (Reference Frame) chair:	*current: Virginia Mackern (Argentina)*
	former: Sonia Costa (Brazil)
SC1.3b-WG2 (Geocentric Datum) chair:	*current: William Martínez (Colombia)*
	former: Tomas Marino (Costa Rica)
SC1.3b-WG3 (Vertical Datum) chair:	*current: Roberto Luz (Brazil);*
	former: William Martínez (Colombia)

Sub-commission 1.3b (Latin America and Caribbean) encompasses the activities developed by the "Geocentric Reference System for the Americas" (SIRGAS) initiative, whose main objective is the definition and realization of a unified and globally consistent geometrical reference frame for the region (SC1.3.b – WG1). Besides, SIRGAS promotes the establishment of national densifications of the continental frame (SC1.3b – WG2), and the definition and realization of a unified and globally consistent vertical reference system for the region supporting physical and geometrical heights (SC1.3b – WG3).

The SC1.3b Executive Committee met in four opportunities for evaluating the ongoing and planning the forthcoming activities. The meetings were:

- in Bogotá (Colombia), on June 7 – 8, 2007 (reported in SIRGAS Newsletter No 12);
- in Montevideo (Uruguay), on May 28 – 30, 2008 (reported in SIRGAS Newsletter 13);
- in Buenos Aires (Argentina), in the frame of the Scientific Assembly "Geodesy for Planet Earth" of the International Association of Geodesy (IAG), August 31 – September 4, 2009, (reported in SIRGAS Newsletter 14); and
- in Lima (Peru), on November 11 – 12, 2010, (reported in SIRGAS Newsletter 15) .

The main achievements of SIRGAS in this period can be summarized as follows:

- Continuous monitoring of the Reference Frame: the first SIRGAS realizations were established by means of two GPS campaigns: the first one in May 1995 including 58 stations, and the second one in 2000 with 184 stations. At present, SIRGAS is realized by a network of continuously operating stations. This so-called SIRGAS-CON network replaces the former realizations and allows a permanent monitoring of the reference frame.
- Geographical densification of the reference stations: the SIRGAS-CON network was extended from 163 continuously operating GNSS stations in June 2007, to 270 in February 2011. Forty eight stations are integrated in the IGS global network, and 72 receivers are able to track GLONASS.
- Redundancy in the analysis of the reference frame: in June 2007, the SIRGAS-CON network was processed by one processing centre in a common block adjustment. Today, the analysis strategy is based on the combination of individual solutions of different clusters of stations, guaranteeing that each station is included in three individual solutions. These clusters are weekly processed by 9 analysis centres, namely: CEPGE (Ecuador), CIMA (Argentina), CPAGS-LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGN (Argentina), INEGI (Mexico), SGM (Uruguay), and DGFI (Germany). The last one continues acting as the IGS RNAAC for SIRGAS. The combination of the different solutions is performed by DGFI and IBGE.

- GLONASS processing: Until now, the SIRGAS Analysis Centres process GPS data only. Since the number of GLONASS stations is increasing in the SIRGAS region, the SC1.3b - WGI initiates the routine processing of GLONASS observations on a weekly basis. All GLONASS stations will be analysed as an individual network, loosely constrained solutions of which will be combined with the similar solutions generated for the other SIRGAS-CON sub-networks.
- Datum definition strategy and availability of weekly reference coordinates: after a carefully study devoted to reduce network deformations due to the effect of seasonal variations in the datum realization, SIRGAS changed the strategy used to realize its datum. Currently, the weekly solutions of the SIRGAS-CON frame are aligned to the ITRF using the IGS weekly coordinates (igsyyPwwww.snx), instead of applying epoch positions and constant velocities. The geodetic datum is defined by constraining the coordinates of the IGS reference stations. The applied constrains guarantee that the positions of the IGS reference stations do not change more than 1,5 mm within the SIRGAS-CON adjustment.
- Reprocessing of the entire SIRGAS-CON network applying the reprocessed IGS products (IG1): weekly solutions from January 2000 (GPS week 1043) to November 2006 (GPS week 1399), formerly computed with relative antenna phase centre corrections and referring to previous ITRF solutions, have been reprocessed based on absolute phase centre corrections provided by the IGS and the IGS05 as reference frame. This reprocessing allows improving the reliability and accuracy of station positions and velocities computed within multi-year solutions.
- Kinematics of the SIRGAS reference frame: every year, a cumulative solution containing all available weekly normal equations delivered by the SIRGAS analysis centres is computed. The latest one is called SIR10P01 and covers the period between January 2, 2000 (GPS week 1043) and June 5, 2010 (GPS week 1586). It refers to the ITRF2008 at epoch 2005,0 and provides positions and velocities for 183 SIRGAS-CON stations. Its precision was estimated to be ~±0,5 mm (horizontal) and ~±0,9 mm (vertical) for the station positions at the reference epoch, and ~±0,2 mm/a (horizontal) and ~±0,4 mm/a (vertical) for the constant velocities. A loosely constrained version of this solution was delivered to the IAG SC1.3 Working Group on Regional Dense Velocity Fields as the SIRGAS contribution.
- Velocity Model for SIRGAS (VEMOS): the availability of horizontal velocities in those regions which are not covered by SIRGAS-CON stations is strongly improved through the new Velocity Model for SIRGAS (VEMOS 2009), which represents the continuous present-day deformation of the Earth crust in the SIRGAS region. It is based on nearly 500 velocity stations observed in 13 GPS projects. The overall precision of the point velocities is better than ±1 mm/a in South-North and ±1,5 mm/a in West-East direction.
- Long-term stability of the SIRGAS reference frame: the former SIRGAS realizations of 1995 and 2000 and the computed multi-year solutions were compared with the new ITRF2008 frame. Results show a very good consistency between the different SIRGAS solutions. The largest discrepancies (~2 cm) were detected for the SIRGAS realizations referring to ITRF94 and ITRF97. Realizations referring to ITRF2000 and IGS05 have an agreement better than ±5 mm. This reflects the expected improvement of the reference frame as consequence of longer time series of station positions and the better new models, standards, and analysis strategies applied today. However, special care shall be given to the deformations caused by seismic events.
- Reference frame deformations caused by seismic events: the western part of the SIRGAS region is an extremely active seismic area because it is located in the plate boundary zone of six tectonic plates. The frequent occurrence of earthquakes causes episodic station

movements, which affect the long-term stability of the SIRGAS reference frame. For instance, in the last three years, three big earthquakes caused displacements of about 2,5 cm in Costa Rica, between 2 cm and 3 m in Chile and Argentina, and 26 cm in Baja California, Mexico. To mitigate the impact of these events on the reference frame, SIRGAS is developing a strategy oriented to measure and model the generated deformations as soon as possible after any strong seism.

- Applicability of SIRGAS as reference frame: 16 of the 18 SIRGAS member countries adopted SIRGAS as official reference frame, i.e. the SIRGAS continental network is extended through national densification networks. Today, users of precise GNSS positioning refer to SIRGAS (or their densifications) by: i) introducing weekly station positions of the SIRGAS-CON stations as reference coordinates to process GNSS surveying; and ii) applying the velocities provided by the multi-year solutions to reduce new station positions to the conventional reference epoch defining the official reference frame.
- Extension of the SIRGAS reference frame at national level: the national reference frames of El Salvador and Bolivia were integrated into SIRGAS. The frame of El Salvador (SIRGAS-ES2007.8) is composed by 35 stations observed in a GPS-campaign in 2007. Adjusted station positions refer to the IGS05, epoch 2007.8. The reference frame of Bolivia (Referencia Geodésico Nacional, MARGEN) comprises 17 GPS stations, 8 of them are those continuously observing stations. The final coordinates are given in IGS05, epoch 2010.2.
- Capacity building within SIRGAS: In order to divulge and promote the adequate use of SIRGAS as reference frame in the different countries of the region, the SC1.3b-WG2 (in charge of the SIRGAS activities at national level) coordinates a capacity building activity oriented to strengthen the fundamental concepts associated with the Geodesy of Reference. This activity is sponsored by the International Association of Geodesy (IAG) and the Pan American Institute of Geography and History (PAIGH), and therefore, it is called IAG-PAIGH-SIRGAS School on Reference Systems. The first School was held in Bogotá (Colombia), between 13 and 17 July 2009. It was hosted by the Instituto Geográfico Agustín Codazzi and attended by 120 participants from 12 Latin American and Caribbean countries. The second IAG-PAIGH-SIRGAS School was carried out in Lima (Peru), between 8 and 10 November 2010. It was hosted by the Instituto Geográfico Nacional of Peru and was attended by 112 participants from 13 countries.
- IAG Inter Commission Project 1.2: SC1.3b-WG3 activities are integrated in the IAG Inter Commission Project 1.2, "Vertical Reference Frames", and were focused on two major issues: i) determination of a reliable geopotential value W_0 within a global realization; and ii) evaluation of levelling data combined with gravimetric measurements, including the direct connection of the first levelling networks between neighboring countries and to SIRGAS2000 realization. These activities are complemented by the formulation of a combined system of observation equations based on spirit levelling, GNSS positioning, and geoid determination. It includes the common analysis of tide gauge registrations, satellite altimetry observations, and GNSS positioning at those tide gauges which serve as vertical datum in the classical height systems. This analysis is carried out in the frame of the IGS TIGA project.
- SIRGAS in Real Time: the SIRGAS Real Time (SIRGAS-RT) project was established in the SIRGAS 2008 General Meeting (May 2008). Its main objective is to evaluate the possibility of providing near real time corrections for GNSS positioning based on the SIRGAS-CON stations. After two years, Argentina, Brazil, Uruguay, and Venezuela, who are applying the NTRIP tool, show significant advances in the implementation and use of this technique. The SC1.3b-WG2 will continue promoting the development of similar

studies in other SIRGAS countries. The planned activities include a capacitation course of two weeks to provide expertise in the implementation and adequate use of the NTRIP protocol in the SIRGAS countries. This course will be partially supported by the Agencia Española de Cooperación Internacional together with the Instituto Geográfico Nacional de España.

– Ionospheric analysis within SIRGAS: the routine production of vTEC maps for South America by the Universidad Nacional de la Plata (Argentina) as SIRGAS Ionosphere Analysis Centre provides control and improvement for different kind of projects such as the International Reference Ionosphere (IRI) over South America, positioning with single-frequency GPS receivers, and the feasibility of computing ionosphere corrections for a satellite based augmentation system (SBAS) for the region.

During the four years, the SC1.3b was represented in the following meetings:

– III Seminario de Geomática, Sociedad Colombiana de Ingenieros. Bogota, Colombia. October 27 - 29, 2010.
– IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010). Marne-la-Vallée, France. October 4 - 8, 2010.
– 20th UN/IAF Workshop on GNSS Applications for Human Benefit and Development. Prague, Czech Republic. September 24 - 25, 2010.
– XI Congreso internacional de Geomática: Geodesia, Topografía y Catastro en tiempo real. San José, Costa Rica. September 16 - 18, 2010.
– AGU 2010, The Meeting of the Americas. Foz do Iguaçu, Brazil. August 8–12, 2010.
– European Geosciences Union, General Assembly 2010 (EGU 2010). Vienna, Austria. May 02 – 07, 2010.
– II Convención de las Ingenierías de las Geociencias y la Química - V Congreso de agrimensura. La Habana, Cuba. March 2 - 5, 2010.
– 20th Technical Consultative Meeting on Cartography, Pan American Institute for Geography and History (PAIGH). Quito, Ecuador. November 26-27, 2009.
– United Nations/Azerbaijan/European Space Agency/United States of America Workshop on the Applications of Global Navigation Satellite Systems. Baku, Azerbaijan. May 11-15, 2009.
– European Geosciences Union, General Assembly 2009 (EGU 2009). Vienna, Austria. April 19 - 24, 2009.
– Reunión Científica 24 de la Asociación Argentina de Geodesia y Geofísica (AAGG). Mendoza, Argentina. April 14 - 17, 2009.
– Semana Geomática Internacional. Barcelona, Spain. March 3 - 5, 2009.
– Third Meeting of the International Committee on Global Navigation Satellite Systems (ICG). Pasadena, California, USA. December 8 - 12, 2008.
– International Symposium on Global Navigation Satellite Systems, Space-based and Ground-based Augmentation Systems and Applications. Berlin, Germany. November 11 - 14, 2008.
– IAG International Symposium on Gravity, Geoid and Earth Observation. Chania, Crete, Greece. June 23 - 27, 2008.

– United Nations/Colombia/United States of America Workshop on the Applications of Global Navigation Satellite Systems. Medellin, Colombia. June 23 - 27, 2008.
– AGU 2008 Joint Assembly. Fort Lauderdale, Florida, USA. May 27 - 30, 2008.
– AGU Fall Meeting. San Francisco, USA. December 10 - 14, 2007.
– 6th FIG Regional Conference. San Jose, Costa Rica. November 12 - 15, 2007.
– SDI Americas Symposium: Concepts, Practices, and Projects. IGAC-IPGH-GSDI. Bogota, Colombia. November 7 - 8, 2007.

The most relevant information regarding SC1.3b, related newsletter, presentations and papers, as well access to its main products can be found in the web at www.sirgas.org.

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

Co-Chairs: Michael Craymer (Canada), Richard Snay/Jake Griffiths (USA)

Introduction

The objective of the NAREF 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). Some of these issues include:

- Densification of the ITRF reference frame network in North America and promotion of its use.
- Maintenance and future evolution of vertical datums (ellipsoidal and orthometric), including NAVD88 and the International Great Lakes Datum.
- Collocation of different measurement techniques such as VLBI, SLR, DORIS, GPS, etc.
- Effects of crustal motion, including tectonic motions along, e.g., the western coast of N.A. and in the Caribbean, and post-glacial rebound.
- Standards for the accuracy of geodetic positions.
- Outreach to the general public through focused symposia, articles, workshops and lectures and technology transfer to other groups, particularly in N.A.

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

- SC1.3c-WG1: North American Reference Frame (NAREF)
- SC1.3c-WG2: Stable North American Reference Frame (SNARF)
- SC1.3c-WG3: Reference Frame Transformations
- SC1.3c-WG4: International Great Lakes Datum (IGLD)

The following summarizes the activities of each WG. For more information see www.naref.org. Note the U.S. co-chair, Dr. Richard Snay, retired from the U.S. National Geodetic Survey in 2010 and was succeeded by Dr. Jake Griffiths from the same agency.

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

Most of the effort of the Sub-Commission is focused on this WG with the aim of densifying the ITRF and IGS global networks in the North American region. Until GPS week 1399, the densification consisted of weekly combinations of six different weekly regional solutions spanning the continent and using four different GPS processing software packages. These NAREF contributors and some details of their solutions are given in the table and figures below.

A number of sites have been omitted from the combination of submitted contributions due mainly to problems with antenna heights. Investigations are being conducted to resolve these issues during the reprocessing phase described below. Many other stations have been removed from the MIT and Scripps solutions because of current software limitations and the very high density of sites in southern California and some local areas of the PBO network. Presently, only those stations in the U.S. common with the NGS CORS solution are being included in the current weekly combinations.

Table 1.3c-1: NAREF weekly regional coordinate solution contributions up to GPS Week 1399.

Contributor	Software	Region	No. Stations (total/used)
NGS	PAGES	US & territories (CORS network)	820/762
Scripps	GAMIT	North America	700/140
MIT	GIPSY & Bernese Combo	Western North America	670/183
NRCan/GSD	Bernese	Canada & border areas of US & Greenland	112/112
NRCan/GSD	GIPSY	Canada	43/43
NRCan/PGC	Bernese	Western Canada Deformation Array (WCDA)	55/55

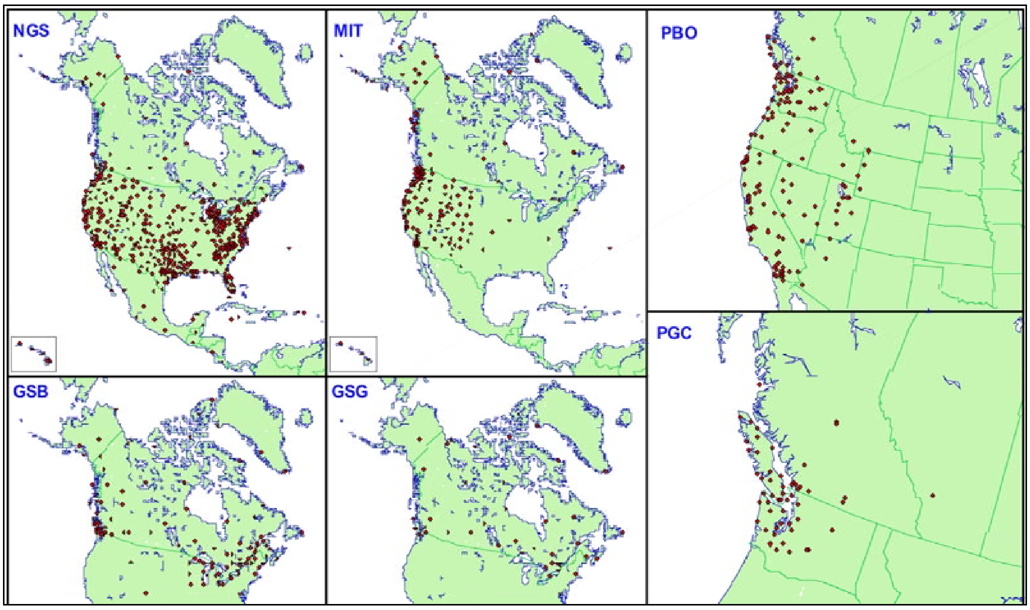

Figure 1.3c-1: NAREF regional contributions for GPS week 1399.

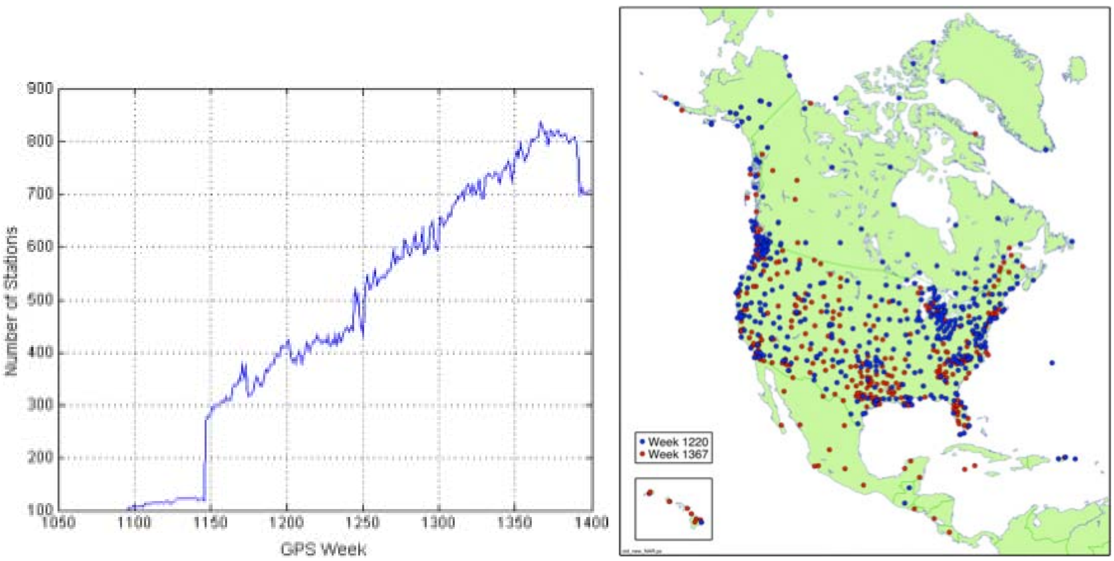

Figure 1.3c-2: NAREF network growth until GPS week 1399.

Since GPS week 1400, a number of changes have been made to the regional solutions. First and foremost was the implementation of the new IGS procedures and absolute antenna calibrations. In addition, many more stations were included not only in the regional solution being submitted but also in the number of stations used in the weekly combinations. These additional stations increased the number of sites in more than one solution, thereby improving redundancy. The table below summarizes the number of sites used in each of the regional submissions since GPS week 1400 and the figure show the increase in total number of stations since week 1399. New regional submissions were also obtained from the Mexican National Institute of Statistics and Geography (INEG) beginning with week 1563.

All of the solutions also included a subset of IGS global reference frames sites to better align the NAREF combinations to ITRF. The exception was that from NRCan/PGC (it being a local solution by design). The following figure illustrates the distribution of sites for a recent week.

Table 1.3c-2: NAREF weekly regional coordinate solution contributions since GPS week 1400.

Contributor	Software	Region	No. Stations (approx.)
NGS	PAGES	US & territories & Mexico (CORS network)	1200+
Scripps	GAMIT	North America	1100+ (~625 used)
MIT	GIPSY & Bernese Combo	Western North America	1100+ (~520+ used)
NRCan/GSD	Bernese	Canada & border areas of US & Greenland	200
NRCan/GSD	GIPSY	Canada	45
NRCan/PGC	Bernese	Western Canada Deformation Array (WCDA)	75
INEGI	GAMIT	Mexico	30 (since 1563)

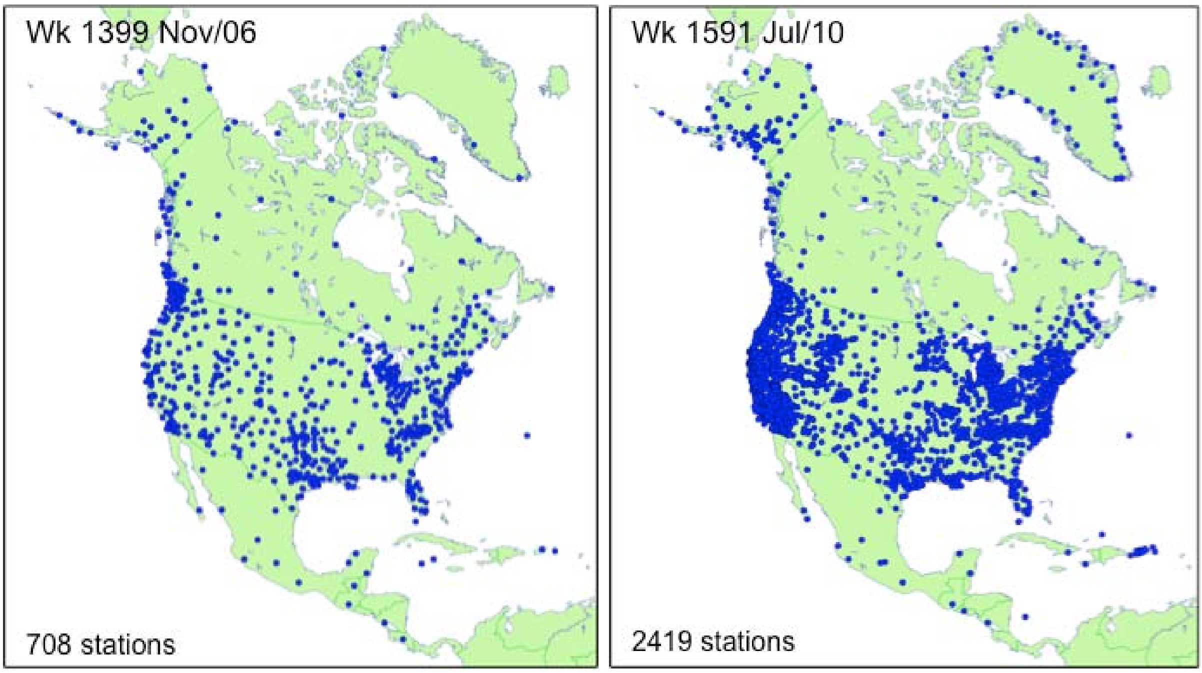

Figure 1.3c-3: Increase in number of NAREF stations since GPS Week 1399.

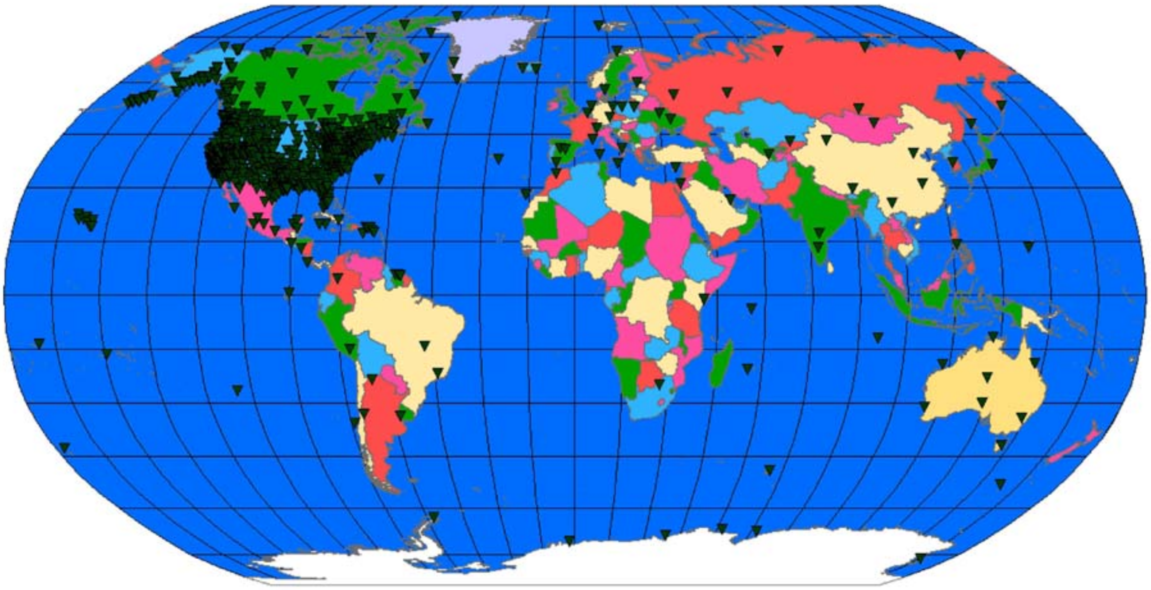

Figure 1.3c-4: NAREF network since GPS Week 1400 with global sites used to align with ITRF.

The submitted weekly regional solutions, NAREF weekly combinations and the current cumulative solution are available from the NAREF FTP archive (see www.naref.org). The NAREF weekly combinations are also submitted to the IGS data archive at CDDIS.

Unfortunately, no combinations have been possible after GPS week 1513 due to the total number of stations in the combination (2000+) exceeding the capabilities of the SINEX combination software. NRCan/GSD is presently enhancing the SINEX combination software to handle many more sites and to increase its processing speed. In the interim, NGS is implementing a weekly combination procedure based on the CATREF software.

A major reprocessing effort of regional solutions prior to GPS Week 1400 has been completed by NGS, NRCan/GSD and Scripps using the new IGS procedures and absolute antenna calibrations. For Scripps and NGS, the regional solutions have essentially been a densification of their global reprocessing efforts for the IGS. On the other hand, NRCan/GSD uses fixed IGS orbits in their solutions and had to wait for the completion of the IGS repro1 project to obtain the new orbits before they could begin their reprocessing. They are just now completing that effort after which all reprocessed solutions will be combined into new NAREF weekly combinations that will be compatible with current solutions.

Absent from this reprocessing effort were MIT and NRCan/PGC, who also use fixed IGS orbits in their processing. They are instead planning to reprocess with the new IGS08.atx antenna calibrations later in 2011. Also absent from the reprocessing effort was the NRCan/GSD GIPSY solution. NRCan/GSD plans to eventually replace this with one based on their Precise Point Positioning (PPP) software. INEGI does not have plans to reprocess.

Although the intention is to eventually produce updated NAREF cumulative solutions along with the weekly NAREF combinations each week, this has not yet been possible. A NAREF cumulative solution (coordinates and velocities) has been generated based only on the weekly NAREF combinations up to week 1399. The following figures show the horizontal and vertical velocity fields from this solution. Weekly solutions after this were not included because of the change from relative to absolute antenna calibrations, which would have produced a discontinuity in the positional time series for all sites. Once solutions before week 1400 are reprocessed with the new absolute antenna calibrations and IGS repro1 orbits, a new cumulative solution will be generated with all weeks to date. This solution will then be updated weekly with each new NAREF weekly solution.

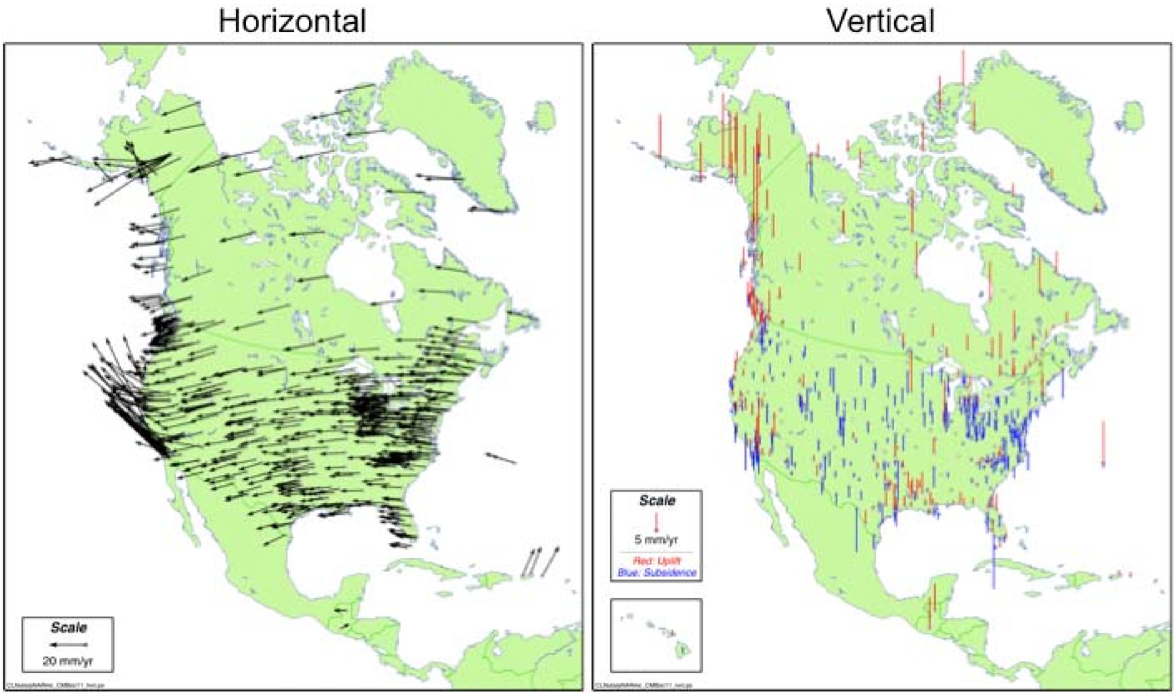

Figure 1.3c-5: NAREF velocity field aligned to ITRF2005 using weekly solutions up to GPS week 1399.

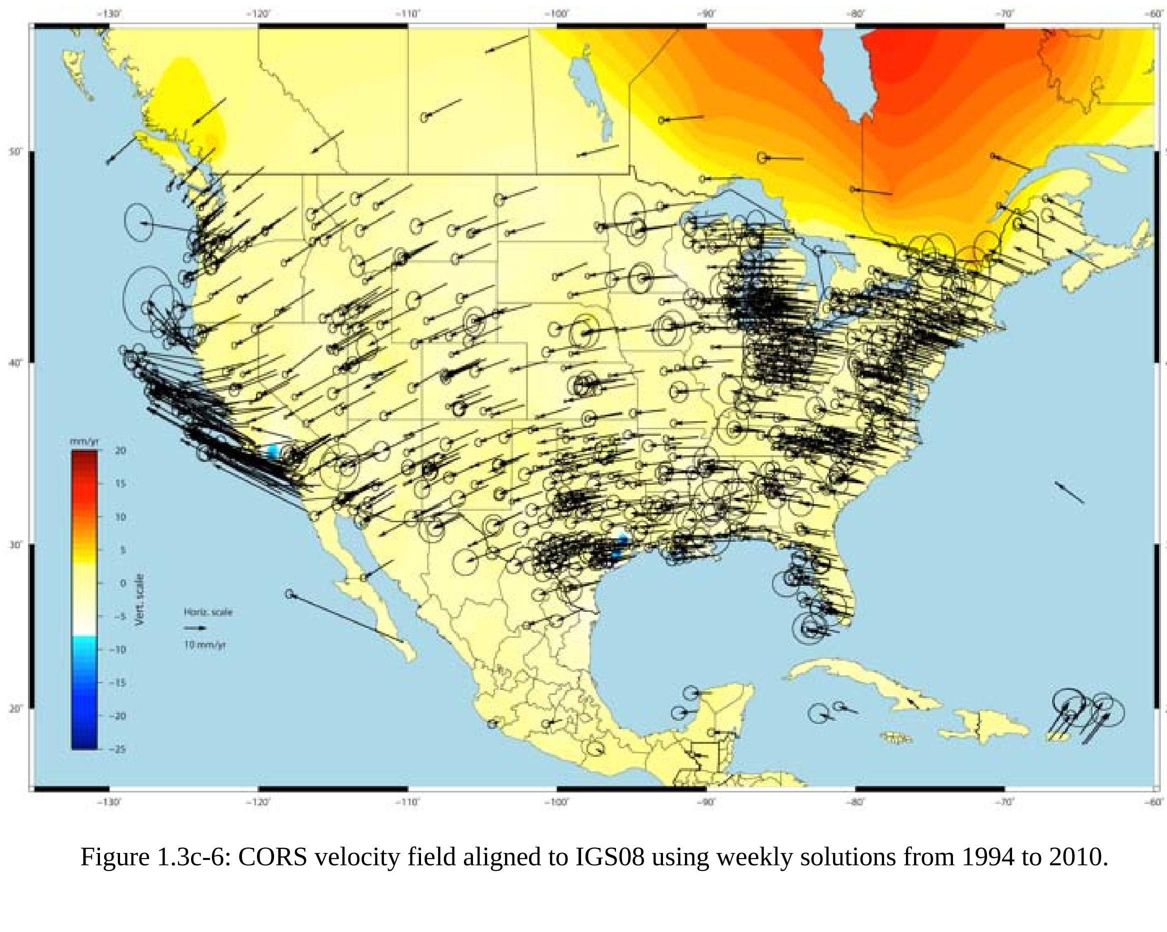

Figure 1.3c-6: CORS velocity field aligned to IGS08 using weekly solutions from 1994 to 2010.

Although no recent NAREF cumulative solution is available using reprocessed results, NGS has generated a solution using the CATREF software for 2,264 CORS stations based on their own weekly reprocessed solutions from 1994 to 2010.5 with absolute antenna calibrations and global sites for alignment to IGS08. The above figure displays the horizontal velocity field for this solution.

SC1.3c-WG2: Stable North American Reference Frame (SNARF)

This WG is joint with UNAVCO, Inc. in support of the EarthScope project. The goal of the WG is to define a plate-fixed regional reference frame for North America, stable at the sub-mm level, in order to provide a standardized and consistent reference frame in support of geodynamics studies throughout the continent. Nine workshops to define the reference frame have been held since 2004, including two during this reporting period. All of the workshops were funded by UNAVCO.

The SNARF frame is being defined via a no-net-rotation condition for a set of stable frame sites with respect to the ITRF. A novel technique has been used to assimilate GPS velocity solutions together with a geophysical model of glacial isostatic adjustment to model both horizontal and vertical intra-plate motions. The first version of the reference frame was released at the UNAVCO Annual Meeting in June 2005.

An updated version of the frame was begun in 2007 using several improved velocity solutions from the members of the WG, including the last NAREF cumulative solution up to GPS week 1399. Unfortunately, the SNARF workshop funding contract with UNAVCO expired before the new SNARF frame could be completed and the working group has since become inactive.

It is now expected that this WG will evolve into one on defining a replacement for NAD83 that is truly geocentric, fixed to North America and fully consistent with the ITRS (i.e., SNARF-like). Progress towards such a new realization of NAD began with the first "Federal Geospatial Summit on Replacing NAD83 and NAVD88" held in Washington on May 11-12, 2010.

SC1.3c-WG3: Reference Frame Transformations

This sub-commission is concerned with the definition and maintenance of the relationships between international and North American reference frames/datums. This 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 (Craymer et al., 2000). 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. In 2006, the transformation was updated with the introduction of ITRF2005.

In late 2010, ITRF2008, a new realization of the International Terrestrial Reference System was publically released and the transformation between NAD83 and ITRF2008 was determined for use in Canada and the US. The new transformation was derived from the NAD83-ITRF2005 transformation by incrementally adding the ITRF2005-ITRF2008 transformation published by the IERS.

SC1.3c-WG4: International Great Lakes Datum

The purpose of this working group is to consider problems related to the maintenance of the vertical datum for the management of the Great Lakes water system, including post-glacial rebound, the use of GPS/geoid techniques, lake level transfers through hydrodynamic models, comparisons with NAVD88 and the implementation of a revised height system by 2015.

Until 2010, this sub-commission has been inactive since the inception of the NAREF sub-commission. However, with recent plans for height modernization in both Canada and the U.S., and the need to update the International Great Lakes Datum by 2015 due mainly to the effects of glacial isostatic adjustment, the WG has been re-activated in collaboration with the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. It is expected that a new IGLD datum will be defined by a geoid-based datum similar to height modernization plans in the Canada and the U.S.

NAREF-Related Publications & Presentations

The following are a list of papers and presentations related to NAREF activities since 2007.

Craymer, M.R., M. Piraszewski, J.A. Henton. The North American Reference Frame (NAREF) project to densify the ITRF in North America. Proceedings of ION GNSS 2007, Fort Worth, Texas, September 25-28, 2007.

Craymer, M., G. Sella. Making Sense of Evolving Reference Frames for North America. Eos Transactions, AGU, 88(23), Joint Assembly Supplement, Abstract G32A-01 Invited, 2007.

Craymer, M., R. Snay. Regional Reference Frames for North America: Status and Future Plans of Sub-commission 1.3c. IUGG XXIV General Assembly, Perugia, Italy, July 2-13, 2007.

Craymer, M.R., J.A. Henton, M. Piraszewski. Predicting Present-Day Rates of Glacial Isostatic Adjustment Using a Smoothed GPS-Based Velocity Field for the Reconciliation of NAD83 Reference Frames in Canada. Eos Transactions, AGU, 89(53), Fall Meeting Supplement, Abstract G31A-0638, 2008.

Craymer, M.R., J.A. Henton, M. Piraszewski. Transforming PPP results to different realizations of the NAD83 reference frame in Canada. Eos Transactions, AGU, 90(52), Fall Meeting Supplement, Abstract G11C-0659, 2009.

Craymer, M., R. Ferland, J. Henton, E. Lapelle, M. Piraszewski. IGS, NAREF & CBN Velocity Fields for Monitoring GIA in Canada. COST ES0701 Working Group Meeting: Inter-comparison of GIA Estimates from GPS, Dresden, March 29-30, 2010.

Craymer, M.R., J. Henton, E. Lapelle, M. Piraszewski. Preliminary results of an updated North American GPS velocity field. Eos Transactions, AGU, 91(51), Fall Meeting Supplement, Abstract G23B-0825, 2010.

Craymer, M., R. Snay. Regional Reference Frames for North America: Current Status & Future Plans of Regional Sub-commission SC1.3c. IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), Marne-La-Vallée, France, October 4-8, 2010.

Griffiths, J., J.R. Rohde, J. Ray, M. Cline, W.H. Dillinger, R.L. Dulaney, S. Hilla, W.G. Kass, J. Ray. Reanalysis of CORS and Global GPS Data at the National Geodetic Survey. Eos Transactions, AGU, 89(53), Fall Meeting Supplement, Abstract G33B-0686, 2008.

Griffiths, J., J. Ray, J.R. Rohde, W.G. Kass, R.L. Dulaney, M. Cline, S. Hilla, R.A. Snay, An assessment of the NGS's contribution to the reprocessed IGS products. Eos Transactions, AGU, 90(52), Fall Meeting Supplement, Abstract G11B-0631, 2009.

Griffiths, J., J.R. Rohde, M. Cline, R.L. Dulaney, S. Hilla, W.G. Kass, J. Ray, G. Sella, R. Snay and T. Soler. Reanalyis of GPS data for a large and dense regional network tied to a global frame. IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), Marne-La-Vallée, France, October 4-8, 2010.

Herring, T., M. Craymer, G. Sella, R. Snay, G. Blewitt, D. Argus, Y. Bock, E. Calais, J. Davis, M. Tamisiea. SNARF 2.0: A Regional Reference Frame for North America. Eos Transactions, AGU, 89(23), Joint Assembly Supplement, Abstract G31B-01, 2008.

Henton, J., M. Craymer, E. Lapelle, M. Piraszewski. Contributions of the North American Reference Frame Working Group to the next realization of the Stable North American Reference Frame (SNARF). Eos Transactions, AGU, 88(52), Fall Meeting Supplement, Abstract G21B-0498, 2007.

Kass, W.G., R.L. Dulaney, J. Griffiths, S. Hilla, J. Ray, J. Rohde. Global GPS data analysis at the National Geodetic Survey. J. Geod., Vol. 83, pp. 289-295, doi: 10.1007/s00190-008-0255-4.

Mtamakaya, J., M.C. Santos, M. Craymer. Harmonic analysis of IGS stations time series. Eos Transactions, AGU, 90(52), Fall Meeting Supplement, Abstract G11B-0634, 2009.

Mtamakaya, J.D., M.C. Santos, M.R. Craymer. In search of periodic signatures in IGS REPRO1 solution. Eos Transactions, AGU, 91(51), Fall Meeting Supplement, Abstract G51B-0665, 2010.

Rohde, J.R., J. Griffiths, M. Cline, R.L. Dulaney, S. Hilla, W.G. Kass, J. Ray, G. Sella, R.A. Snay. NGS2008-beta: A preliminary estimate of an update to the North America CORS velocity field. Eos Transactions, AGU, 90(52), Fall Meeting Supplement, Abstract G11C-0660, 2009.

Sella, G.F., S. Stein, T.H. Dixon, M. Craymer, T.S. James, S. Mazzotti, and R.K. Dokka, Observation of glacial isostatic adjustment in "stable" North America with GPS, Geophys. Res. Lett., Vol. 34, L02306, doi:10.1029/2006GL027081, 2007.

Sella, G., S. Stein, T. Dixon, M. Craymer, T. James, S. Mazzotti, R.K. Dokka. Constraints on Glacial Isostatic Adjustment (GIA) Motion in North American Using GPS. IUGG XXIV General Assembly, Perugia, Italy, July 2-13, 2007.

Zilkoski, D.B., J.D. D'Onofrio, S.J. Frakes. Guidelines for Establishing GPS-derived Orthometric Heights (Standards: 2 cm and 5 cm). NOAA TM NOS NGS-59 (http://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf), March 26, 2008.

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Craymer, M.R., R. Ferland and R. Snay. Realization and Unification of NAD83 in Canada and the US via the ITRF. In R. Rummel, H. Drewes, W. Bosch, H. Hornik (eds.), "Towards an Integrated Global Geodetic Observing System (IGGOS)", IAG Section II Symposium, Munich, October 5-9, 1998, International Association of Geodesy Symposia Volume 120, Springer-Verlag, Berlin, 2000.

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

Chair: Richard Wonnacott (South Africa)

Introduction

IAG Sub-Commission 1.3d (Africa) of Commission 1 Reference Networks was established with the objective:

- To establish a continental reference system for Africa consistent and homogeneous with the global reference frame of the ITRF as a basis for national 3-d reference networks;
- To realize a unified vertical datum and to support efforts to establish a precise African geoid;
- To establish continuous, permanent GPS base stations at a spacing such that users will be within 1000km of a base station and that data is freely available to all nations;
- To provide a sustainable development environment for technology transfer so that these activities will enhance the national networks and other applications;
- To understand the necessary geodetic requirements of participating national and international agencies; To determine the relationship between the existing national reference frames and the ITRF to preserve legacy information based on existing frames; andTo assist in establishing in-country expertise for implementation, operation, processing and analysis of modern geodetic techniques, primarily GNSS.

While AFREF is an African project which is to be designed, managed and executed by African countries, these objectives are to be carried out with the technical assistance and in collaboration with the IAG community and its service organization, the IGS, together with the National and Regional Mapping Organizations of Africa. Although many of these objectives have not been met during the review period, progress has been made with the installation of permanent GNSS reference stations and a number of the other objectives such as the transfer of technology through training programmes and to broaden the understand the geodetic and GNSS requirements of a number agencies and projects engaged in disciplines other than geodesy.

Installation of Permanent GNSS Stations

Since July 2007, the number of permanent GNSS reference station installations has increased throughout Africa. These have been installed by National Mapping Agencies, Universities and research groups. In spite of the number of installations increasing, there remains a difficulty in knowing where stations have been installed, who has installed them, what standards have been used and where data is being archived. Networks of permanent GNSS base stations in a few countries in Africa but because of data policies of some of these countries, free and open access to the data has been denied for all but a few of these stations.

At a recent AFREF Steering Committee meeting in Addis Ababa in April 2009, the Chief Directorate: National Geospatial Information in South Africa offered to establish an Operational Data Centre (ODC) for AFREF. This ODC became operational in June 2010 and has created a single data base for permanent GNSS stations in Africa and the AFREF project which has an open data policy. Data will be mirrored to the Regional Data Centre at the Hartebeesthoek Radio Astronomy Observatory. Data for approximately 45 permanent stations is currently being archived on ODC.

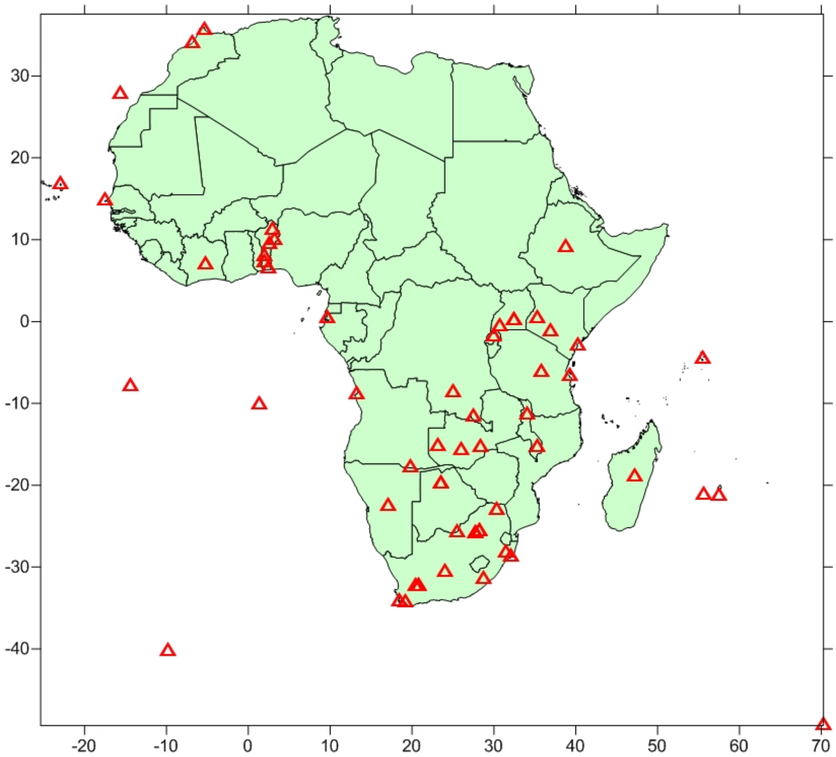

Figure 2 Permanent GNSS base stations for which continuous data is being archived at the AFREF Operational Data Centre as at February 2011. Although some campaign style data is also available, this has not been shown here.

Meetings and Training Courses

A number of Steering Committee meetings were held during the reporting period but perhaps the most significant has been a series of joint meetings held in June 2008 in Johannesburg, June 2010 in Washington and Johannesburg in November 2010. These meetings brought together representatives from the fields of seismology, meteorology, space weather, geophysics and geodesy. The groups that met were

- AFREF (geodesy)
- Africa Array (seismology and geophysics)
- AMMA-GPS (meteorology)
- SCINDA/ IHY (space weather)
- Universities (geophysics)

All these groups have a common interest in and requirement for GNSS data and it is felt that with a common understanding and by working in a collegial environment, the groups should be able to share resources and expertise.

Four training courses were held between 2007 and 2011. The courses were held in August each year between 2007 and 2010 at the Regional Centre for Mapping of Resources for Development (RCMRD). The courses covered the concepts of AFREF permanent GNSS reference stations, reference frames and the processing of GNSS data. The courses were run by RCMRD in conjunction with Hartebeesthoek Radio Astronomy Observatory and the University of Beira in Portugal.

Processing of GNSS Data for AFREF

A Call for Participation in the processing of GNSS data from the permanent stations has been prepared and will be distributed before the IUGG General Assembly in July 2011. The call has both practical processing and capacity building aspects to it.

Funding for AFREF

Finding remains one of the main stumbling blocks to significant progress being made with AFREF. An application for funding was submitted to the African Union Commission (AUC) and European Union (EU) for inclusion within the EU/ AU Lighthouse Projects. The application was not successful. Apart from this application, there are a few other direct or indirect sources of support for the project such as the Millennium Challenge Corporation funding granted to selected low or low middle income countries for various development projects or the donation of equipment and software from receiver manufacturers.

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

Co-Chairs: Shigeru Matsuzaka (Japan), John Dawson (Australia)

Overview and Organization

The Sub-Commission 1.3e continues to maintain a close working relationship with the Regional Geodesy Working Group of the Permanent Committee for GIS Infrastructure in the Asia and the Pacific region (PCGIAP) and the Asia Pacific Space Geodynamics project (APSG). The activities of this Sub-Commission are principally carried out by the members of national surveying and mapping organisations, in the region, through the PCGIAP, which operates under the purview of the United Nations Regional Cartographic Conference for Asia and the Pacific (UNRCC-AP), and through the scientific members of the APSG.

The efforts of the Sub-Commission have provided a regional focus for cooperation in the definition, realisation and densification of the International Terrestrial Reference Frame (ITRF). More specifically, the Sub-Commission has sought to:

- Enhance the regional geodetic infrastructure by contributing to monitoring, warning and post-event reconstructions through the cooperative observation of crustal deformation and plate motion, and information exchange, including tide gauge networks and placement of new GPS key sites;
- Encourage the transfer of GNSS technology to nations in need through annual campaign observations, and the development and sharing of analysis techniques;
- Promote the application of new geodetic adjustment techniques and datum transformation parameters for regional spatial data integration and for geo-referencing cadastral information;
- Interact with IAG commissions 1 and 2 on the status of the regional geodetic reference frames and geoid determination using absolute gravity, satellite, airborne and terrestrial gravity; and
- Support the densification of continuous GNSS installations in areas of earthquake and tsunami hazard and strongly encourage nations to make their geodetic data readily available.

Outputs

Asia Pacific Reference Frame (APREF)

The Asia-Pacific Reference Frame (APREF) project is an initiative that recognizes the importance of improving the regional geodetic framework in the Asia-Pacific region. A substantial number of state-of-the-art GNSS networks, operated by national mapping agencies and private sector organizations, are available in the region.

In the APREF initiative these networks are combined to realize a high-standard regional reference frame. The GNSS data of the network is processed by different Analysis Centres (ACs). The contributions of the different ACs are combined into a weekly solution by the APREF Central Bureau. This weekly solution is the core product of the APREF; it contains weekly estimates of the coordinates of the participating Asia-Pacific GNSS tracking stations and their covariance information.

The APREF product, which is available since the first quarter of 2010, gives a reliable time-series of a regional reference frame in the International Terrestrial Reference Frame and a quality assessment of the performance of the GNSS CORS stations included in the network.

APREF is mandated by Resolution 1 (Regional Geodesy) of the 18th United Nations Regional Cartographic Conference (UNRCC) for Asia and the Pacific, 26 – 29 October 2009, Bangkok, Thailand. Demonstrating a broad community desire to improve the reference frame it is also endorsed by the International Global Navigation Satellite System Service (IGS), the United Nations Office for Outer Space Affairs (UNOOSA) and the Federation of International Surveyors (FIG).

APREF is a voluntary, collegial, non-commercial endeavor, and has to date encouraged wide participation from government agencies, research institutes and the private sector. There is no central funding source and each participating organization is contributing their resources. APREF is encouraging the sharing of GNSS data from Continuously Operated Reference Stations (CORS) in the region while also developing an authoritative source of coordinates, and their respective velocities, for geodetic stations in the Asia-Pacific region. The APREF combined solution will be contributed to the IAG Regional Dense Velocity Field Working Group.

In response to the March 2010 Call for Participation (CfP) a large number of agencies have agreed to participate in APREF, Table 1 summarizes their commitments. 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).

Country/Locality	Responding Agency	Proposed Contribution		
		Analysis	Archive	Stations
Afghanistan	National Geodetic Survey (USA)			2
Alaska, USA	National Geodetic Survey (USA)			90
American Samoa	National Geodetic Survey (USA)			1
Australia	Geoscience Australia	✓	✓	50
Australia	Curtin University of Technology	✓		1
Australia	University of New South Wales	✓		
Australia	Department of Environment and Resource Management, Queensland			8
Australia	Department of Sustainability and Environment, Victoria	✓		55
Australia	Department of Lands and Planning, Northern Territory			5
Australia	Department of Primary Industries, Parks, Water & Environment, Tasmania			2
Australia	Land and Property Management Authority, New South Wales			52
Cook Islands	Geoscience Australia			1
Cook Islands	Geospatial Information Authority of Japan			1
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			19
Hong Kong, China	Survey and Mapping Office			6
Indonesia	Bakosurtanal			4
Iran	National Cartographic Center, Iran			5
Iraq	National Geodetic Survey (USA)			6
Japan	Geospatial Information Authority of Japan	✓	✓	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
Marshall Islands	Geoscience Australia			1
Micronesia	Geoscience Australia			1
Nauru	Geoscience Australia			1
New Zealand	Land Information New Zealand	✓	✓	38
Northern Mariana Islands	National Geodetic Survey (USA)			1
Papua New Guinea	Geoscience Australia			1
Philippines	Department of Environment and Natural Resources, National Mapping and Resource Information Authority	✓	✓	4
Samoa	Geoscience Australia			1
Solomon Islands	Geoscience Australia			1
Tonga	Geoscience Australia			1
Tuvalu	Geoscience Australia			1
Vanuatu	Geoscience Australia			1

Table 1: Responses to the APREF CfP. Responding agencies have indicated whether they would undertake analysis, provide archive and product distribution or supply data from GNSS stations. Geoscience Australia has agreed to act as the Central Bureau coordinating the overall activities of APREF.

Asia Pacific Regional Geodetic Project (APRGP)

In order to densify the ITRF in the Asia-Pacific Region an annual geodetic observation campaign has been held to provide an opportunity to connect to national geodetic networks and to determine site velocities. While these campaigns have focused on GPS observations, coordinated through the PCGIAP, they also incorporated other geodetic techniques, including: Satellite Laser Ranging (SLR), coordinated through cooperation with International Laser Ranging Service (ILRS) and Western Pacific Laser Tracking Network (WPLTN); and Very Long baseline Interferometry (VLBI), coordinated through the APSG and International VLBI Service (IVS).

APRGP campaigns were coordinated by Geoscience Australia (GA) and the campaign data (1997 – 2010) were collated by Geoscience Australia, and subsequently made available, on request, to participating countries for analysis. The data from these GPS surveys are available, from Geoscience Australia, for both scientific research and local applications.

Other Activity

Other activities associated with the regional reference frame development include:

- The 13th PCGIAP meeting was held in Seoul, Korea in June 2007.
- The 14th PCGIAP meeting was held in Kuala Lumpur, Malaysia in August 2008.
- The 15th PCGIAP meeting was be held in Bangkok, Thailand in October, 2009.
- The 16th PCGIAP meeting was be held in Singapore in October, 2010.
- The 17th PCGIAP meeting will be held in Ulaanbaatar, Mongolia in July 2011.
- China, Japan, Korea and Australia are densifying their GNSS networks;
- Indonesia and the Philippines are planning to build and/or densify their continuous GPS networks;
- Australia, under the AuScope Initiative, has completed the construction of 3 new VLBI stations and new IGS standard GNSS stations;
- New Zealand has constructed a new geodetic VLBI station;
- Korea has engaged in a construction of a new geodetic VLBI observatory, 2008-2011;
- GSI, Japan, has launched a new project: Asia-pacific Crustal Monitoring Project;
- South Pacific Sea Level Monitoring Project (SPSLMP) installation phase complete, 12 CGPS stations have been collocated with tide gauges. GPS data is publicly available from Geoscience Australia; and
- Japan has upgraded its South Pacific (Plume) sites.

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

Chair: Reinhard Dietrich (Germany)

Observation Campaigns

The SCAR GPS Campaigns 2008, 2009, 2010 and 2011 were carried out in the austral summers 2008 to 2011. All together, the data of 34 Antarctic sites are now collected in the SCAR GPS database beginning with the year 1995.

Data Analysis

The data analyses continued. All data analyses were carried out with the Bernese GPS Software, version 5.0. The results were presented at the XXX SCAR Meeting in St. Petersburg/Russia in July 2008 and at the EGU Meeting 2009 in Vienna. New results will be presented at the IUGG Meeting 2011.

Meetings

During the XXX SCAR Meeting in St. Petersburg 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 2008-2010. R. Dietrich (Germany) was confirmed as the coordinator of the SCAR GPS Campaigns. The members of GIANT represent the SC1.3f.

The International Polar Year 2007/2008

The International Polar Year (IPY) 2007/2008 started at 1st of March 2007 and ended at 28th of February 2009. It was organized jointly by ICSU and WMO, and provided the frame for a broad range of coordinated, international projects. The SC1.3f actively participated in the frame of the IPY project POLENET (Polar Earth Observing Network). Results of POLENET were presented at the IPY Conference in Oslo in June 2010.

Working Group: Regional Dense Velocity Fields

Chair: Carnie Brunini

Activities

The long-term goal of the IAG Working Group "Regional Dense Velocity Fields" is to provide a globally referenced dense velocity field, based on GNSS observations, and to be used as a densification of the International Terrestrial Reference Frame. The Working Group (WG) closely links its activities with the regional reference frame sub-commissions, and regional coordinators have been appointed from the WG members. Their expertise, coordination role for their region, and their capability to generate a unique and unified cumulative GNSS-based position and velocity solution for their region, including velocity solutions from third parties (even campaigns), is a key element for the WG.

In reply to a first call for participation issued at the end of 2008, regional coordinators and analysts of global networks submitted in 2009, cumulative velocity solutions to the WG. Several of the regional solutions were a combination of cumulative velocity solutions based on the permanent GNSS network operated by the regional sub-commissions themselves and third party velocity solutions. A first test combination of the individual solutions (Bruyninx et al., in press) showed that the solutions could not be rigorously combined due to:

- inconsistent discontinuity epochs and solution numbers for the frame-attachment sites (mostly ITRF2005 sites) entailing large discrepancies at the common sites,
- inconsistent station naming and DOMES numbering,
- numerical instabilities caused by velocity constraints at sites with coordinate offsets.

In addition, using a European case study, Legrand et al. (2010, in press) showed that positions and velocities obtained from a regional GNSS network tied to the ITRF2005 using minimal constraints, can differ (up to 2 mm in the horizontal and 8 mm in the vertical for the positions and up to 0.5 mm/yr in the horizontal and 2 mm/yr in the vertical for the velocities) w.r.t. a global solution. When considering the residual velocity fields after removing the rigid block rotation, the velocity differences are considerably reduced but can still reach up to 0.8 mm/year in horizontal component. The disagreement between regional and global positions and velocities is caused by the so-called "network effect" and it is amplified when the reference stations used in the regional solution cover a smaller geographical area or the different solutions to be combined exhibit large discrepancies at common sites. This means that sites showing different discontinuities, time spans or large non-linear signals should be treated with extreme care. The network effect, of course, challenges the provision of a consistent dense velocity field partly based on regional position/velocity solutions.

Upon the release of the ITRF2008 (Altamimi et al., 2011), the investigation done in Legrand et al. (2010, in press), verifying the agreement between regional and global GNSS solutions, was repeated using the ITRF2008 reference frame. The tests showed that the disagreement between the global and regional position/velocity solutions is now reduced. It can nevertheless still reach 1 mm/yr in the vertical and 0.5 mm/yr in the horizontal. The investigation demonstrated that in order to reduce network effects, it is essential:

- to have the best possible agreement between the solutions we want to combine (by e.g. using similar data span, outlier rejection and discontinuity epochs for the common stations as well as a similar analysis strategy),

- to increase as much as possible the coverage of each of the solutions we want to combine (best is global),
- to increase to a maximum extend the redundancy between regional and global solutions in order to mitigate individual problems at the common stations.

With the goal to generate a high-quality solution for a core network, several newly reprocessed global and regional cumulative position and velocity solutions were submitted to the Working Group in the summer of 2010. In order to find a consensus on discontinuity epochs for stations common to several networks (an issue which was problematic in previous submissions) and reduce problems with the DOMES numbering and station naming, the new submissions were restricted to contain only the core networks over which the analyst has full control so that ITRF2008 discontinuities could be applied.

One new global solution was provided and 4 new regional solutions (Asia & Pacific, Africa, Europe, Latin America and Caribbean). All of these solutions are based on a reprocessing, using absolute antenna models (igs05.atx), and the stacking was done using the CATREF software (Altamimi et al., 2007) applying, as much as possible, the ITRF2008 discontinuity list. One exception is the African solution, where the site velocities have been computed using a linear regression through daily-estimated site positions expressed in the ITRF2008. For the North America region, no new solution has been made available.

In total, about 400 densification sites to the ITRF2008 were provided.

The 3D-RMS of the agreement of the new solutions with the ITRF2008 (after outlier rejection) varies between 0.6 and 1.1 mm/yr; it is extremely good for some solutions, while others still require more iteration to reach the required level of agreement. A part of these disagreements has been identified and often originates in the use of different data time spans within the ITRF2008 and submitted solution. Some cases were also identified where the residual position time series from the ITRF2008 significantly underperformed compared to the time series from a regional solution (see Bruyninx et al., submitted). This raises the need for more interaction between the regional reference frame sub-commissions and the IGS and/or the ITRF product center in order to prevent from facing a similar situation in the next release of the ITRF.

It was demonstrated that a careful inspection and comparison of both ITRF2008 and regional residual position time series is mandatory before using any site as a frame-attachment site. This adds as additional task for the WG which will need to verify and eventually discard some of the stations included in ITRF2008 before performing the combination. Therefore, at the moment, the WG concentrates on identifying the sources of disagreements between the solutions submitted to the WG and the ITRF2008 by comparing the residual position time series of all solutions. A dedicated software tools has been developed for this purpose. As soon as an agreement can be found on the discontinuities to be applied for the core solutions, and these core solutions can be successfully combined with the ITRF2008, then the WG will tackle the problem on how to integrate the third party (position and) velocity solutions.

In the upcoming year, several of the regional solutions will be reprocessed to embed the regional network in a global network and reduce the error induced by the network effect. For the regions of Asia & Pacific, Africa and North America such global solutions will become available in 2011. For South-America and Europe, however, the regional sub-commissions have no official plans to generate a global solution. Both regional groups offer as an alternative, as a first step, to combine their weekly regional solutions with the global weekly reprocessed solutions generated by the IGS or one of its Analysis Centers. In a second step, these weekly combined solutions will then be stacked and tied to the ITRF2008 taking advantage of the availability of a global set of reference stations.

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Working Group Meetings

- June 4, 2008, Miami Beach, US (IGS Analysis Centers Workshop)
- December 18, 2008, San Francisco, US (AGU 2008 Fall Meeting)
- April 20, 2009, Vienna, Austria (EGU 2009)
- September 3, 2009, Buenos Aires, Argentina (IAG 2009)
- October 5, 2010, Paris, France (REFAG 2010)

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- Bruyninx C., Z. Altamimi, M. Becker, M. Craymer, L. Combrinck, A. Combrink, R. Fernandes, R. Govind, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, J. Legrand, L. Sánchez, G. Sella, **IAG Working Group "Regional Dense Velocity Fields": Objectives and Future Plans**, IGS Analysis Centres Workshop, June 2-6, 2008, Miami, US, AFREF Workshop, June 17-18, 2008, Johannesburg, South Africa
- Bruyninx C., Z. Altamimi, M. Becker, M. Craymer, L. Combrinck, A. Combrink, R. Fernandes, R. Govind, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, J. Legrand, L. Sánchez, G. Sella, **Objectives and Challenges of the IAG Working Group "Regional Dense Velocity Fields"**, EUREF 2008 Symposium, June 18-21, 2008, Brussels, Belgium
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- Bruyninx C., Z. Altamimi, M. Becker, M. Craymer, L. Combrinck, A. Combrink, J. Dawson, R. Dietrich, R. Fernandes, R. Govind, T. Herring, A. Kenyeres, R. King, C. Kreemer, D. Lavallée, J. Legrand, L. Sánchez, G. Sella, Z. Shen, G. Wöppelmann, **Progress of the IAG SC1.3 Working Group in Providing a Dense Global Velocity Field Based on GNSS Observations**, EUREF 2009 Symposium, May 27-30, 2009, Florence, Italy
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Sub-Commission 1.4: Interaction of Celestial and Terrestrial Reference Frames

President: Harald Schuh (Austria)

Main objective of IAG Sub-Commission 1.4 is the study of the interaction of the celestial and the terrestrial reference frames. In particular, SC 1.4 is focusing on the consistency between the frames. Sub-Commission 1.4 has established three Working Groups.

WG 1.4.1 Theoretical Aspects of the Celestial Reference System and Systematic Effects in the CRF Determination (Chair: Zinovy Malkin)

WG members: Z. Malkin (Chair), N. Capitaine, A. Fey, A.-M. Gontier (deceased September 2010), S. Klioner, D. MacMillan, J. Sokolova, O. Titov, V. Zharov; ex officio: H. Schuh, President of IAG SC 1.4, C. Ma, Chair of WG 1.4.2, S. Lambert, Chair of WG 1.4.3

The main directions of the WG activity, according to its charter, are the following:

1. Analysis of ICRS definition in view of the latest development in astrometry and space geodesy.
2. Effect of 2000, 2003, 2006, and 2009 IAU resolutions related to Earth rotation on ICRS definition and realization.
3. Effect of the latest changes in the IERS Conventions on ICRS definition and realization.
4. Alignment of ICRF to ICRS.
5. Study of systematic errors in the current individual CRF and ICRF realizations.
6. Study of effects of geodetic datum definition on VLBI-determined CRF.

1. Analysis of ICRS definition in view of the latest development in astrometry and space geodesy

A detailed analysis of the ICRF definition in connection with other related issues, such as ICRF, time scales, CIO, etc., was given by the IAU Division I Working Group “Nomenclature for Fundamental Astronomy" (NFA) in its reports to the IAU 2006 and 2009 General Assemblies. No substantial progress was achieved since that report. However, the ICRF definition becomes not well understood and inconsistent when moving to the modern observations at a microarcsecond level of accuracy, e.g. VLBI2010 and GAIA. To solve arisen problems new considerations are needed. In particular, the hierarchy of relativistic reference systems should be extended beyond the galaxy to rigorously connect various kind of observations of near-Earth, galactic and extra-galactic objects at the microsecond level of accuracy.

2. Effect of 2000, 2003, 2006, and 2009 IAU resolutions related to Earth rotation on ICRS definition and realization

The IAU 2000 and 2006 resolutions on reference systems have modified the way how the Earth orientation (i.e. the transformation between the International Terrestrial Reference System (ITRS) and the Geocentric Celestial Reference System (GCRS)) is expressed. The IAU 2000, 2006, and 2009 resolutions have adopted high accuracy models for expressing the relevant quantities for the transformation from terrestrial to celestial systems. The concepts, nomenclature, models, and conventions in fundamental astronomy based on the IAU resolutions are suitable for modern and future realizations of the reference systems. This in particular allows the highest accurate realization of the celestial intermediate system linked to the CIP and the CIO that replaces the classical celestial system based on the true equator and equinox of date. The definition and the high accuracy realization of the celestial intermediate reference system based on the IAU 2000/2006 IAU Resolutions is consistent with microarcsecond accuracy of the celestial reference system and microarcsecond observational precision. The IAU 2009 resolution have significantly improved the realization of the ICRF, which allowed us the best realization of the ICRS

3. Effect of the latest changes in the IERS Conventions on ICRS definition and realization

No mentionable result is known. Improvement of the IERS Conventions is a continuous process, as well as analysis software development and collection of new observations. Thus a supplement detailed study aiming at separation of these factors is hardly feasible and difficult to be realized.

4. Alignment of ICRF to ICRS

A procedure for aligning of the ICRF2 to ICRF has been developed during preparation of the ICRF2. This procedure mainly follows the procedure used in the 1990ies for alignment of the ICRF with some updates related to the source classification, selection of the core (defining) sources, and inflation of formal errors. Special attention has been given to maintenance of stability of the ICRF2 axes, in particular through a choice of the optimal set of core sources. Development of a procedure for connection of the GAIA optical frame with radio ICRF is in progress.

5. Study of systematic errors in the current individual CRF and ICRF realizations

During the preparation and final phases of the ICRF2 construction, several IVS Analysis Centers (AUS, BKG, GSF, IAA, MAO, OPA, SHA, USN) produced a large series of the radio source position catalogs using various data sets, software and analysis options. Comparison of these catalogs allowed us to make some conclusions on a level of the CRF systematic differences depending on such factors as:

- Data set, e.g. using or omitting early observations, mobile occupations, and some other poor networks or VCS sessions (marginal effect),
- Software used (appreciable effect),
- Troposphere gradient modeling (largest effect),
- TRF vs. baseline solution (marginal/appreciable effect, needs further investigation),
- Atmosphere pressure loading (marginal effect)
- Axis offset estimation (marginal/appreciable effect, depends on software),
- NMF vs. VMF1 mapping functions (marginal effect).

In the list above, "marginal effect" means systematic differences at a level below 15-20 microarcseconds; "appreciable effect" means systematic differences at a level up to about 100 microarcseconds.

Besides, the following studies are being conducted:

- Investigation of systematic and individual (peculiar) source motion,

– Analysis of the consistency of CRF realizations at different bands,

– Methods of assessment of absolute accuracy and systematic errors of CRF catalogs.

New methods of the precision and accuracy assessment of the newest CRF realizations are under development.

6. Study of effects of geodetic datum definition on VLBI-determined CRF

A relevant study performed by the VLBI group of TU Wien has shown that the selection of celestial datum points has no significant systematic impact on source coordinates.

WG 1.4.2 Realization of Celestial Reference Frames (CRF and Transformations) (Chair: Chopo Ma)

WG members: C. Ma (Chair), O. Titov, R. Heinkelmann, G. Wang, F. Arias, P. Charlot, A.-M. Gontier (deceased September 2010), S. Lambert, J. Souchay, G. Engelhardt, A. Nothnagel, V. Tesmer, G. Bianco, S. Kurdubov, Z. Malkin, E. Skurikhina, J. Sokolova, V. Zharov, S. Bolotin, D. Boboltz, A. Fey, R. Gaume, C. Jacobs, L. Petrov, O. Sovers

1. Goal

Produce ICRF2 for IERS / IVS consideration and for submission the IAU

Charter and purpose

The purpose of Working Group 1.4.2 (which was identical with the corresponding IERS/IVS Working Groups) was to generate the second realization of the ICRF from VLBI observations of extragalactic radio sources, consistent with the current realization of the ITRF and EOP data products. The Working Group (WG) applied state-of-the-art astronomical and geophysical models in the analysis of the entire relevant S/X astrometric and geodetic VLBI data set. It carefully considered the selection of defining sources and the mitigation of source position variations to improve the stability of the ICRF. The goal was to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I WG 'On the second realization of the ICRF' for adoption at the 2009 IAU General Assembly.

2. Release and adoption of the ICRF2 in 2009

The IERS/IVS Working Group released the ICRF2 mid-2009. It was adopted at the XVII IAU General Assembly, Rio de Janeiro, as the fundamental astrometric realization of the ICRS in replacement of the first ICRF in use since 1998 (IAU Resolution B3). The catalogue is made of 3.414 sources, which is five times more than the previous ICRF. The noise floor is 40 microarcseconds, i.e., five times better than for the ICRF. The axes are defined by 295 sources, selected on the basis of their time stability, low structure index, and repartition between North and South hemispheres. The axis stability is close to 10 microarcseconds, which is better than for the 212 ICRF defining sources by a factor of two (Fey et al. 2009).

WG 1.4.3: Interaction Between Celestial and Terrestrial Reference Frames (Chair: Sébastien Lambert)

WG Members: S. Lambert (Chair), Ch. Bizouard, H. Boomkamp, R. Heinkelmann, F. Seitz, P. Steigenberger, D. Svehla; and C. Ma (Chair of WG 1.4.2), Z. Malkin (Chair of WG 1.4.1), H. Schuh (Ex officio, President of IAG SC 1.4).

1. Effects of CRF realization on EOP and TRF

1.1. ICRF2

As described above the "Second Realization of the ICRF" was released mid-2009 and adopted at the XVII IAU General Assembly as the fundamental astrometric realization of the ICRS.

1.2. On using ICRF2 in VLBI analysis

Heinkelmann (2010) and Gordon et al. (2010) summarized the effects of using ICRF2 in VLBI analysis on EOP and TRF. When the observing configuration does not allow one to estimate source coordinates, fixing the CRF to ICRF2 is significantly better than fixing it to ICRF.

2. Effects of TRF realization on EOP and CRF

2.1. ITRF2008

Mid-2010, the ITRF2008 was released by the IGN. It constitutes an improvement with respect to the previous version (ITRF2005). All IVS, ILRS, IGS, and IDS analysis centers participated in the production of the input data. As for ITRF2005, input data were time series of site positions and EOP of completely reprocessed solutions of the four space geodetic techniques. The accuracy of ITRF2008 origin and scale is 1 cm (Altamimi et al. 2011).

2.2. Effect of ITRF2008 in other geodetic products

Ma et al. (2010) compared VLBI analyses made by either fixing to ITRF2008 or estimating station coordinates and velocities. They identified a scale difference of -0.39 ppb between ITRF2008 and the VLBI TRF, and wrms differences less than 5 mm and 1 mm/yr for the 40 most participating sites. EOP obtained with both solutions agree well with the IGS solution.

3. Geophysical or technique modeling issues

3.1. Atmospheric pressure loading

Recently, new atmospheric pressure loading (APL) data were released by the Institute of Geodesy and Geophysics at TU Vienna. This new product is derived from ECMWF data and is therefore fully consistent with the VMF1 data. Differences against Petrov and Boy (2004) loading data are less than 10% of the displacement (smaller than 3 mm). See Wijaya et al. (2010). The impact of different strategies for applying atmospheric pressure loading corrections on GNSS-derived parameters was studied by Dach et al. (2010).

3.2. Modeling of celestial pole offsets and effects on VLBI data analysis

The UT1 intensive results depend on the celestial pole offset (CPO) model used during data processing. Since accurate CPO values are available with a delay of 2-4 weeks, CPO predictions are necessarily applied to the UT1 intensive data analysis, and errors in the predictions can influence the operational UT1 accuracy. Malkin (2010) showed that the impact of CPO prediction errors on UT1 is at a level of several microseconds, whereas the impact of the inaccuracy in the polar motion prediction may be about one order of magnitude larger for ultra-rapid UT1 results. He concluded that the situation could be amended if the IERS Rapid solution will be updated more frequently.

3.3. The IERS reference EOP series at the IERS EOP Center

In order to be consistent with ITRF2008, the reference EOP series IERS 05C04 is being revised. The new solution 08C04 is the reference solution starting on 1 February 2011. Relative to 05C04, changes in the EOP series consist of (i) a negligible bias in x-pole and a bias of about 50 microarcseconds in y-pole, and (ii) changes in UT1-TAI and celestial pole offsets which are at the level of the WRMS between IVS individual solutions.

3.4. Space geodetic techniques and modeling of the glacial isostatic adjustment

King et al. (2010) reviewed the ability of the four techniques to determine accurate and precise surface velocities. The study focused on the GPS network since it constitutes the corner stone for increasing the precision and accuracy to ~1mm/yr and constraining GIA models.

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Inter-Commission Project 1.2: Vertical Reference Frames

Chair: Johannes Ihde (Germany)

Introduction

At present, there are some hundred physical height systems realized worldwide. The realization of a unified global reference surface for physical height systems, the relation of individual tide gauge records with respect to this reference surface, the separation of sea level changes and vertical crustal movements at tide gauges, and the connection with the terrestrial reference system are to at large unsolved problems. To proceed towards a unified physical height system we need at the centimetre accuracy level:

– a unified global height datum,
– consistent parameters, models and processing procedures for the Terrestrial Reference Frame (TRF) and gravity field,
– a closed theory for the combination of parameters (space techniques, gravity),
– consideration of time dependency, and
– a rigorous concept for the realization.

The definition and realization of a World Height System (WHS) is a fundamental requirement of GGOS (Global Geodetic Observing System). In the same way as the ITRS/ITRF provides a high precision geometrical reference frame, the WHS shall provide the corresponding high precision physical reference frame for studying the system Earth.

ICP 1.2 is a common project of IAG Commission 1 and 2. From beginning of 2010 the activities of ICP1.2 were integrated in GGOS as Theme 1.

1. The ICP1.2 Vertical Reference Frames in the Period 2007 - 2011

The Inter-Commission Project 1.2 – World Height System-Pilot Project (ICP1.2 – WHS-PP) is an initiative of IAG ICP1.2.

The results of the work of the Inter-Commission Project 1.2 in the first term 2003 – 2007 are documented in **Conventions for the Definition and Realization of a Conventional Vertical Reference System (CVRS**), Ihde et al. 2007. In the CVRS conventions a general concept for the definition and realization of a unified, global vertical reference system is described. The CVRS conventions are aligned to the IERS 2003 Conventions. The conventions for a Global Vertical Reference System (GVRS) are a step forward to the realization of a WHS.

The main objective for the second term 2007 – 2011 is the initiation of a pilot project for a WHS realization (WHS-PP). The project continuation shall be realized in cooperation with other organizations.

This pilot project will provide an opportunity for the IAG Commission 1 (Reference Frames) and 2 (Gravity Field) to further expand and refine its existing reference frame infrastructure, to provide users with information about worldwide vertical reference frames, and to relate the regional height systems to a global datum.

The Deutsches Geodätisches Forschungsinstitut (DGFI) hosts the web site: http://whs.dgfi.badw.de. It will be used to convey further information about the project as required and as the project develops.

The main objectives in the period 2007 – 2011 are

- Considering the open topics of the period 2003 - 2007
- Further development of the CVRS conventions
- Preparation of decision about numerical standards as task in cooperation with International Astronomical Union (IAU) and international hydrological associations.
- Initiation of a pilot project for an WHS realization

2. The Realization Concept of a WHS

The realization of a WHS can be achieved mainly through the combination of different products of IAG services. The general case for realization of a WHS and unification of continental VRS is the combination of GNSS points and, if possible of GNSS/levelling points, with a global gravity model (GGM) which is named as the geodetic boundary value problem (GBVP) approach. This approach requires the following components:

– A global permanent GNSS network of stations connected with levelling networks, optionally supplemented by permanent (superconducting) and/or periodical (absolute) gravity observations at selected stations
– A global gravity model (GGM) with continental and regional densifications.

As result of this approach, we have available physical heights or geo-potential numbers related to a geoid/quasigeoid $T_{p\ RRT}$ which is related to a conventional zero level of the potential of the Earth gravity field W_0.

The WHS can be realized by two classes of points with two different procedures:

– GNSS points: $c_P = W_0 - W_P$ *and* $W_p = U_{p\ GPS} + T_{p\ RRT}$, and
– points of levelling networks k: $c_P = c_{P\ k} + W_0 - W_{0k}$. By this, $c_{P\ k}$ will be transformed from the regional level W_{0k} to the conventional global level W_0. The difference $W_0 - W_{0k}$ can be determined by GNSS/levelling in selected co-location points by
  $W_0 - T_{p\ RRT} - U_{p\ GPS} - c_{P\ k}$.

An alternative approach which can be used for the unification of vertical reference frames is based on the combination of tide gauge observations with a global sea surface topography model. It is necessary that the tide gauge stations are linked to the regional levelling network and to the geometrical reference system ITRS/ITRF. (This approach will not further be considered).

In general, the realization of a WHS and the unification of the existing height systems into the global one require a combination of different elements based on a set of consistent conventional numerical standards. The accuracy of the WHS realization depends in the first order on the resolution of the gravity field model and the appropriate regional densification with gravity data. A service providing all relevant information would be useful.

3. WHS Pilot Project

In July 2010 the description of the of WHS Pilot Project with a call for information about planned contributions was send out. The deadline for final contributions Survey of WHS-PP results is May 2011 and the final report will be given at IAG General Assembly 2011.

The four WHS-PP Work Items are:

1. *Analysis centres for determining and monitoring the relationship between a conventional W0 and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface*
2. *Regional processing centres and global combination centres for GNSS/levelling stations with coordinate time series in the current ITRF linked to TIGA stations and geo-potential numbers referred to the RHS at defined epochs*
3. *Investigations on the accuracy of computing point values Wp of the gravity potential by means of high resolution gravity field models and regional densifications of gravity data*
4. *Operative determination of physical WHS heights in regions with a weak geodetic infra-structure including and development of an information system (registry) providing relevant data*

It is assumed that the results of TIGA (i.e. land vertical velocities at tide gauges derived from GNSS positioning) are available.

Partners for the WHS-PP are inside the IAG: the IGFS (International Gravity Field Service) for GGM, absolute and super conducting gravity meter measurements, IGS (International GNSS Service) for TIGA, SC2.4 (Sub-Commission 2.4) for continental and regional densification of a GGM, PSMSL (Permanent Service for Mean Sea Level) for tide gauge measurements, and the IAS (International Altimetry Service) for a global sea surface topography model.

4. Proposed continuation

At the end of the second term of ICP1.2 and after the work of the various WIs is completed, the ICP will prepare a final report and recommendations on how to best realize the WHS (including all relevant issues such as the computation and adoption of a "best" W_0 value, an optimal global geoid surface, etc.) This report will be presented at the IAG General Assembly in Melbourne. Then the ICP will be dissolved.

In the future, the work of ICP should continue in the form of a GGOS Integrated Product (i.e., Theme 1) for the establishment and maintenance of a WHS. The International Gravity Field Service (IGFS) should take the leading role there and report directly to GGOS. GGOS has to clarify inconsistencies in the numerical parameters for integrated geodetic applications. Conventions for the definition and realization of the parameters of the MSSL have also to be agreed.

Inter-Commission Working Group 1.1: Environment Loading: Modelling for Reference Frame and Positioning Applications

Chair: Tonie van Dam (Luxembourg) , Jim Ray (USA)

Introduction

The accuracy and precision of current space geodetic techniques are such that displacements due to non-tidal surface mass loading are now measurable in many cases. Consequently, data analysts have an increasing interest in comparing geodetic and computed load displacements, or even in applying displacement corrections to geodetic results to remove the geophysical loading effects. Unfortunately, direct correction of geodetic estimates by computed load displacements can introduce undesirable errors into coordinate times series and thus into the ITRF itself if the corrections are not computed or applied with utmost care. Problems that are sometimes encountered include: a proliferation of different (and sometimes erroneous) loading models; lack of accurate load models for some effects; use of various different reference frames not always well suited to the geodetic reductions; applying corrections at the observation level versus longer-period a-posteriori average corrections; undesirable attributes of some geophysical loading models such as a lack of mass conservation or other errors. The main activity of this working group is to investigate procedures to ensure that suitable environmental corrections are available to users and that the optimal usage is made.

Objectives

The principal objective of the scientific work of Working Group 1.1 is to investigate optimal methods to mitigate loading effects in ITRF frame parameters and site coordinates. Additional goals include basic research into the determination of accurate load displacements for the various component geophysical fluids, accuracy assessment for different loading models, assessment of the propagation of errors into the site coordinates and the ITRF, and specifications of which model displacements are best applied at the geodetic observation level and which are better applied in post-processing. Results of these investigations should be integrated into the recommendations of the IERS Conventions, where appropriate.

Members

Tonie van Dam (Luxembourg, chair)
Jim Ray (USA, co-chair)
Zuheir Altamimi (France)
Xavier Collilieux (France)
Pascal Gegout (France)
David Lavallee (UK)
Ernst Schrama (Netherlands)
Xiaoping Wu (USA)

General Activities and Recommendations

The main activities of the members of this working group are represented in papers published (see reference list) or in preparation, as well as oral and poster presentations at the Fall Meetings of the American Geophysical Union (San Francisco, CA, USA), General Assemblies of the European Geosciences Union (Vienna, Austria), and occasional other special and topical meetings.

Modelling non-tidal loading a priori?

Based on our research findings, it is our specific recommendation that displacements due to non-tidal geophysical loadings not be included in the a priori modeled station positions. The most serious obstacles to including loading displacements as a priori corrections presently are:

– *reliability of the non-tidal effects in the sub-daily band* -- At best, non-tidal environmental models attempt to compensate mostly for seasonal variations, which are well outside the normal integration intervals for space geodetic data. None of the available global circulation models properly accounts for dynamic barometric pressure compensation by the oceans at periods less than about two weeks. Instead, both "inverted barometer" (IB) and non-IB implementations are produced as crude approximations of the actual Earth system behavior even though these are both recognized as unreliable in the high-frequency regime. While effective at longer periods (especially seasonal), the undesirable and unknown degradation that would affect sub-daily integrations (not only for geodetic parameters, but also for any other parameters estimated from the observations) is not an acceptable side-effect. This is particularly compelling when one considers that non-tidal loading effects can be readily considered in a posteriori studies with no loss whatsoever.

– *inaccuracies of the models* -- The basic types of studies and analyses that are normally considered a precondition to adoption of a conventional model are mostly lacking for non-tidal models. Documentation of error analyses is a basic requirement that must be fulfilled. In their statistical comparison of several publicly available atmospheric pressure loading services, van Dam and Mendes Cerveira (2007) have identified differences up to several mm (RMS) due to effects of varying model parameters and input data choices. This study does not account for possible common-mode error sources. As an illustration, van Dam et al. (2010) showed recently that high resolution topographic models were mandatory to compute atmospheric loading models. Before general users can be expected to routinely utilize non-tidal loading services sensibly, it is vital that the major sources of systematic differences identified in such studies be resolved. Studies of other loading effects (non-tidal ocean loading and continental water loading) are also mandatory. Continental water loading could also be evaluated using GRACE results (Schrama et al., 2007). Moreover, although inversion methods are sensitive to GPS systematic errors, we encourage comparison between available forward loading models and inverted loading models (Küche and Schrama, 2005; Wu et al., 2006) for evaluation purposes. However, it would be relevant to study how known GPS systematic errors (such as the harmonic of the draconitic frequency (Ray et al., 2008)) map into the inverted products. The approach considered by Koot et al. (2006) in their study of various models for atmospheric angular momentum (AAM) is a good example of how a combined series might be formed to reduce series-specific noise. This type of development should be considered in the provision of all forward non-tidal loading results, partly as a convenience to users as well as a potentially improved product.

– *must be free of tidal effects* -- Any non-tidal displacement corrections applied should be strictly free of residual tidal contaminations, otherwise the geodetic results will be adversely affected by aliasing and possible duplication of the directly modeled tidal signals. This is not always assured in operational atmospheric loading services that are currently available.– Conversely, atmospheric tides are recommended to be applied at the observation level. Indeed, applying atmospheric tide loading has been shown to reduce spurious periodic signals in the station position time series (Tregoning and Watson, 2009).

- *long-term biases in the reference frame* -- Because environmental models do not yet conserve overall mass i.e. or properly account for the exchange of fluids between states or between reservoirs e.g. atmosphere and oceans, use of non-tidal models in solutions for the terrestrial reference frame will generally suffer from long-term drifts and biases that are entirely artificial. This is a completely unacceptable circumstance.
- *new datum requirements for the reference frame* – Introducing pressure-dependent non-tidal site displacement contributions into standard geodetic solutions would necessitate the adoption of a global reference atmospheric pressure field since the load density anomaly is computed with respect to a conventional reference. The ITRF reference coordinates (mainly height) for any given site would depend directly on the associated reference pressure for that site. In order to minimize deviations from the established frame, one would probably prefer that the reference pressures closely match long-term average pressure values (10 years) at every possible geodetic site. But the lack of long-term in situ met data from many locations could make such a goal unreachable. Furthermore, many ITRF users would probably not welcome nor understand the expansion of the ITRF datum to include such non-geodetic quantities as reference pressures. In certain other non-tidal loading cases, it might also be necessary to consider additional non-geodetic quantities as reference datum contributors (such as local mean temperatures). If non-tidal displacements are not allowed, then there is no ITRF requirement to adopt a conventional reference pressure field, though this might still be considered and might be useful for other reasons. Note that it is important to continue development of improved, unbiased methods to derive local a priori pressure values globally in order to properly model tropospheric delay effects optimally, which in turn is necessary for accurate station height estimates.
- *need to easily test alternative models* -- As noted above, it is vital to be able to compare different non-tidal models easily and efficiently, something that is not facilitated by direct inclusion of the models a priori into geodetic analyses. It is far simpler to make such comparisons and studies a posteriori as has been done for many years in research into the excitation of Earth orientation variations. However, in solutions where non-tidal displacements have nonetheless been applied, it is imperative that the full time-series of corrections used must be reported in new SINEX blocks that will need to be documented. Still, the availability of such information will permit only an approximate reconstruction of the non-tidal corrections, though, if the applied sampling is finer than the geodetic integration interval. Different interpolation schemes produce slightly different results.

We recommend that models of non-tidal station displacements be made available to the user community through the IERS Global Geophysical Fluid Center and its special bureaus, together with all necessary supporting information, implementation documentation, and software. Expansion of the IERS Conventions, Chapter 7, could include some essential aspects of this material to inform users. Continued research efforts are strongly encouraged, particularly to address the outstanding issues listed above. However, in the meantime non-tidal displacements must not be included in operational data reductions that are contributed to the IERS to support its products and services. It should be recognized that nowadays the non-linear deviations of geodetic time series are themselves a crucial product for many applications seeking to better understand the geodynamics of mass load variations. They are used to compare with and interpret GRACE inversions as well as for much higher spatially resolved investigations of more localized deformations and environmental changes. Removing such signals from geodetic results, especially using diverse and possibly inconsistent load models, would block the pursuit of such important studies.

Modelling non-tidal loading a posteriori?

Notwithstanding the preceding remarks concerning a priori load displacement corrections, we believe that further research is warranted into the possible utility of including non-tidal loading displacements in the formation of ITRF, a posteriori to the reduction of the space geodetic data. Tregoning and Watson (2009) showed that applying atmospheric loading model a priori is equivalent to a posteriori correcting the estimated coordinates for daily solutions. Dach et al. (2011) found a slightly better reduction of the WRMS using weekly samples probably due to missing data during the week and also a different handling of the sub-daily variations. However, they showed that a posteriori corrections are also effective. Indeed, Collilieux et al. (2011) showed that GPS height time series correlate well with full loading models in the height although the performance for the horizontal is not so good. They indicate that systematic errors still exists in space geodesy products, especially at the annual frequency. This is confirmed by comparisons made using GRACE solutions (Tregoning et al., 2009).

It is currently assumed implicitly in the ITRF procedures that varying site deformations, such as those due to loading, average out in the long-term stacking of time series of coordinate frames from each technique. If the loading models have a SNR greater than 1, at least at seasonal periods, then the averaging should be more effective if the load corrections are applied during the stacking. Furthermore, any effects of sparse networks and non-continuous observing ("network effects") are also reduced (Collilieux et al., 2010). This is likely to be more important for the weaker SLR and VLBI networks than for GPS and DORIS.

Such an approach could be implemented in the first step of the ITRF combination process, where the individual technique coordinate frame time series are stacked. Each of the load contributions would need to be integrated over the same time intervals as the frame increments (generally daily for VLBI and weekly for other techniques). The result would be a long-term frame for each technique consisting of the usual reference positions and velocities. The estimated positions and velocities would be especially different for stations with few observations and large loading effects. Time series of station residuals could be generated in two ways, with and without the a posteriori load corrections and the characteristics of each compared and assessed. It worth mentioning that station residual position time series should be carefully constructed especially when loading corrections are not introduced (Lavallée et al., 2006; Collilieux et al. 2011) since loading effects tends to leak into the Helmert parameters, especially the scale factor.

The time series of the Helmert parameters would be nominally free of loading effects. This is likely to be most significant for those parameters dominated by the SLR or VLBI contributions, such as the overall ITRF scale variations and geocenter motions (the Helmert translations from SLR). The EOP time series would also be free of loading contaminations and less affected by network effects, but this is unlikely to be significant for those components dominated by GPS observations. This was demonstrated by Collilieux et al. (2010) who showed that 50% of the annual signal in the SLR and VLBI scale has been reduced after loading corrections.

In the second step of ITRF formation, to combine the technique long-term frames, no further loading corrections are needed. Before such a procedure as this could be considered for operational use, careful studies would be required. Among other things, the issues raised above must be carefully evaluated, particularly the possibility of long-term biases in the loading models that could adversely affect the stability of ITRF. If this is a problem, the loading fields could be detrended for secular variations before being used in the ITRF stackings, for instance. Consideration would also be needed of the consequences for user applications, particularly for the EOPs. Collilieux et al. (2010) applied this method to the combination of VLBI, SLR and GPS terrestrial frames. Although this conclusion cannot be generalized to all sites, they found an improvement in the agreement of the long-term coordinates of the different techniques for some co-location sites.

Use of non-tidal loading models in this a posteriori way would affect only globally integrated estimates (Helmert parameters, EOPs, and ITRF itself). The potentially degrading effects discussed before of applying the models a priori at the observation level would be avoided. The inter-station vectors of individual technique coordinate frames, for example, would not be affected by high-frequency noise from the load models and simultaneously estimated non-geodetic parameters would be similarly unaffected.

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Commission 2 – Gravity Field

http://www-geod.kugi.kyoto-u.ac.jp/iag-commission2/

President: Yoichi Fukuda (Japan)
Vice President: Pieter Visser (The Netherlands)

Structure

Sub-commission 2.1:	Gravimetry and Gravity Networks
Sub-commission 2.2:	Spatial and Temporal Gravity Field and Geoid Modelling
Sub-commission 2.3:	Dedicated Satellite Gravity Mapping Missions
Sub-commission 2.4:	Regional Geoid Determination
Sub-commission 2.5:	Satellite Altimetry
Comm. Project 2.1:	European Gravity and Geoid
Comm. Project 2.2:	North American Geoid
Comm. Project 2.3:	African Geoid
Comm. Project 2.4:	Antarctic Geoid
Comm. Project 2.5:	Gravity and Geoid in South America
Comm. Project 2.6:	South Asian and Australian Geoid
Study Group 2.1:	Comparisons of Absolute Gravimeters
Study Group 2.2:	High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results
IC Working Gr. 2.1:	Absolute Gravimetry
IC Working Gr. 2.2:	Evaluation of Global Earth Gravity Models

Overview

This report covers the period of activity of the entities in Commission 2 for the year 2007 to 2011. Commission 2 consists of five sub-commissions (SC), six commission projects (CP), two study group (SG) and several inter-commission projects (ICP), working groups (ICWG), study groups (ICSG). The sub-commissions cover following science themes; terrestrial, air-borne, ship borne gravimetry and relative/absolute gravity networks; spatial and temporal gravity field and geoid modelling; dedicated satellite gravity missions; regional geoid determination and satellite altimetry. Almost all entities of the Commission have been actively working for the period and made progresses in their stated objectives. Here summarized the important highlights of the Commission activities.

1. Meetings

1-1. GGEO2008

One of the most important events of Commission 2 for the period was the International Symposium on Gravity, Geoid and Earth Observation 2008 (GGEO2008), which took place in Chania, Greece, 23-27 June, 2008. It was expertly organized by the members of the Laboratory of Geodesy and Geomatics Engineering, Department of Mineral Resources Engineering, the Technical University of Crete. The title of the symposium "Gravity, Geoid and Earth Observation" is currently very pertinent and points the direction to which the commission 2 as well as the IAG are pursuing. GGEO 2008 brought together 210 scientists from 36 countries to discuss the state-of-the-art topics in 9 scientific sessions which cover the traditional research areas of Commission 2, as well as interdisciplinary topics relate to geoid, gravity modelling, geodynamics and the new challenges towards the Earth observation. All components of the Commission were well represented at the symposium not only in terms of participants but also by attracting 88 oral and more than 200 poster presentations. The Proceedings of the Symposium including 91 peer-reviewed papers has been published in the IAG Symposia series (Vol. 135, 538p, 2010) by Springer Verlag.

1-2. IAG2009 Buenos Aires

On the occasion of the IAG 2009 Scientific Assembly in Buenos Aires, Argentina, many of Commission 2 members were involved in organizing/contributing the session 2 "Gravity of the Planet Earth", which consisted of 4 sub-sessions; 2.1 Physics and Geometry of Earth; 2.2 Gravity - An Earth Probing Tool; 2.3 Modern Height Datum; 2.4. Gravity and Geoid Modelling. About 150 oral and poster papers were presented in session 2, while total number of IAG2009 papers was 424. This clearly shows the scientific activities of Commission 2. Commission 2 meeting was also held on Sep. 3, during the IAG2009 assembly.

1-3. Other Meetings

There were several Workshop/Symposium organized or sponsored by Commission 2 and/or Commission 2 entities as follows;

- Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TGSMM-2007), St. Petersburg, 20-22 August 2007,
- International Workshop on Gravity, GPS and Satellite Altimetry Observations of Tibet, Xinjiang and Siberia (TibXS 2009), held in Xinjiang, China in August 2009,
- International Workshop on Monitoring North American Geoid Change, held in Boulder, USA, Oct. 21-23, 2009,
- The 2nd IAG International Symposium on Terrestrial Gravimetry: Static and Mobile Measurements (TGSMM-2010), held in Saint Petersburg, Russia, June 22-25, 2010,
- The 2nd International Symposium of the International Gravity Field Service (IGFS), held in Alaska, Sep. 20-22, 2010,
- 2nd International Workshop on Multi-observations and Interpretations of Tibet, Xinjiang and Siberia (TibXS) to be held in Xining, China, July 22-26, 2011.

In addition, commission 2 members were involved in organizing/participating many scientific sessions in major conferences/meetings, for instance, EGU, AGU.

2. Gravimetry and Gravity Networks

There are a great number of progresses in all the fields of activities of SC 2.1, i.e., absolute gravimetry, relative gravimetry, superconducting gravimetry, airborne gravimetry, and regional gravity networks aiming at hydrological, tectonic, seismological, and other applica-tions. Among them, International Comparison of Absolute Gravimeters (ICAG) is one of the most relevant issues. It is reported that the evaluation of the results of the 7th ICAG-2005 was completed and the 8th ICAG-2009 in September-October 2009 at the Bureau International des Poids et Mesures (BIPM) in Sèvres, France was organized under umbrella of IAG and BIPM. The ICAG-2009 included a CIPM (Comité International des Poids et Mesures) -Key Comparison and a CIPM-Pilot Study. This shows that the growing demand for confident and reliable absolute gravity measurements for the Consultative Committee on Mass and Related Quantities (CCM) as well. Since the BIPM terminated the local support for organizing ICAGs after ICAG-2009 mainly due to economical aspects, SG 2.1 (Comparisons of Absolute Gravimeters), ICWG 2.1 (Absolute Gravimetry) and CCM WG on Gravimetry are jointly working to prepare the recommendations for the future ICAGs.

3. Spatial and Temporal Gravity Field and Geoid Modelling

There is no doubt that satellite gravity missions, in particular GRACE, become indispensable for gravity field modelling. SG 2.2 focuses on the application of forward gravity modelling techniques for high-resolution gravity field recovery with the specific aim to assist in processing data from current and future satellite gravity missions. To make its objective clearer, SG 2.2 has slightly modified its title from "High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results" to "High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results". The first focus of the SG is on the assessment of space-domain forward gravity modelling techniques/software with the particular view on both theory and practical determination. For this purpose, a sample topography DEM data set over parts of Australia has been prepared, and the provision of (global) forward gravity modelling results as well as meta-products for new satellite gravity mission results have been discussed.

One of the most significant improvements over the Global Earth Gravity Models was the official release of EGM2008. ICWG 2.2 has successfully coordinated the evaluation of EGM2008 and the first evaluation results were presented by the working group members at GGEO2008. These results provide a thorough external assessment of EGM2008, using a variety of geodetic data and testing methodologies. In addition, ICWG2.2 has been involving in assessing satellite-only gravity models determined by GRACE and GOCE. In particular, the evaluation of the future GOCE gravity models should be more and more important beyond 2011.

4. The gravity field satellite missions

SC 2.3 members have been involved in the derivation of new releases of global static gravity field models based on GRACE and CHAMP as well as monthly, 10-days, weekly and even daily GRACE solutions. The recent most important topics would be the new releases of GOCE gravity fields. The first gravity fields based on two months of GOCE data (Nov./Dec. 2009) were released in June 2010, and new versions of the models based on 8 months of GOCE data (Nov. 2009 – July 2010) have been released in February 2011. In addition, the first satellite-only combined global gravity model GOCO01S has been generated based on a consistent combination of GOCE and GRACE. SC 2.3 members have actively contributed to develop new methods of global and regional gravity field modelling. A key issue is the optimum combination of different ground and satellite gravity data types. For instance, a generalized remove-restore procedure in the frame of the least squares collocation concept has been investigated.

Studies on the future satellite missions, in particular, GRACE follow-on missions are an other important topics. Several workshops have been organized mainly by SC2.3 members. One of the outputs of these activities was the proposal entitled "e.motion" (Earth System Mass Transport Mission), although it was not selected. The e.motion team will continue to work together with the goal to define a next generation gravity field mission.

5. Regional Geoid Determination and Commission Projects

Under the coordination of SC 2.4, the regional geoid and gravity projects on the continental scale are advancing well, especially in Europe (CP2.1), North-America (CP2.2), South-America (CP2.5) and Antarctica (CP2.4). In these regions, the collaboration of National authorities works rather good.

In the other projects the collaboration is sometimes difficult and the lack of data is an important problem. Nevertheless, the progress in some of these regions (especially CP2.3: African Geoid) is clearly visible. An important step of the CP2.3 was the airborne gravity mission over Ethiopia. Some countries (Algeria, Egypt, South Africa) advance well on the national level.

CP2.6 (South Asia/Australia) has big problems mainly due to the missing collaboration of the countries and the problems in data exchange. Nevertheless good results have been achieved in Australia, New Zealand and Indonesia. The principal actions in the near future should focus on improving the collaboration between the countries.

6. Satellite Altimetry

SC 2.5, "Satellite Altimetry" has been newly established as a sub-commission of Commission 2 with a like to Commission 1, following the discussion made in the IAG Executive Committee meeting held in San Francisco, Dec. 2007. It is certainly reasonable to have a sub-commission on satellite altimetry within the IAG organization, because this technique contributes to all the three pillars of geodesy; the gravity field, the geometry and the rotation of the Earth. SC 2.5 has organized the scientific sessions on satellite altimetry in GGEO 2008 and IAG 2009 in Buenos Aires as well. In addition SC 2.5 has organized two international workshops; TibXS 2009 and TibXS 2011. All these proved the successful launch of the new Sub-commission.

7. Summary

In summary, the Commission 2 has achieved significant progress in their stated objectives in almost all entities; a few unfortunately have not reported significant activity not due to apathy but rather a lack of time and other reasons. In particular, as already described and reported in their own entities below, SGs 2.1, 2.2, ICWGs 2.1 and 2.2 have shown notable progresses in their activities. Therefore the continuation of these entities, with some modifications if necessary, should be confirmed.

Followings are the reports of the sub-commission presidents and chairs of individual entities. They provide the details of the activities within the substructure of the Commission.

Sub-Commission 2.1: Gravimetry and Gravity Networks

President: Leonid F. Vitushkin (All-Russian D.I. Mendeleev Research Institute for Metrology-VNIIM)

1. International Comparisons of Absolute Gravimeters ICAG-2005 and ICAG-2009

The increasing number of absolute gravimeters (today it is about 60) and absolute gravity measurements worldwide, including repeated gravity observations for the monitoring of temporal gravity variations associated, for example, with tectonic activities, requires the elaboration of the international data base for absolute gravity observations, the establishment of the development of agreed common standards for absolute gravity observations and data processing and presentation. This is the field of activity of inter SC2.1 and IGFS Working Group on Absolute Gravimetry which collaborates with SG2.1 and CCM WGG.

The IAG SG2.1 which works in collaboration with CCM WGG report that the evaluation of the results of the 7th International Comparison of Absolute Gravimeters ICAG-2005 was completed by Pilot Laboratory International Bureau of Weights and Measures (Bureau International des Poids et Mesures – BIPM) [1]. The 8th ICAG-2009 in September-October 2009 at the BIPM in Sèvres, France was organized under umbrella of IAG and BIPM.

The ICAG-2009 was organized in accordance with the proposal of the 3rd Joint Meeting of the CCM WGG and SG 2.1 of the IAG on 24 August 2007.

ICAG-2009 included a CIPM (Comité International des Poids et Mesures) -Key Comparison and a CIPM-Pilot Study.

The status of Key Comparison (KC) for ICAG-2009 was approved by the Consultative Committee on Mass and Related Quantities (CCM). Only National Metrology Institutes that are signatories of the CIPM Mutual Recognition Arrangement (CIPM MRA) and laboratories officially designated by those institutes can participate in a Key Comparison, their measurements can contribute to the evaluation of the KCRVs (Key Comparison Reference Value) and their degrees of equivalence can be published in the Key Comparison Data Base (KCDB). Only results of absolute measurements will be used in the KC part of ICAG-2009 to evaluate the KCRVs. This Key Comparison is designated CCM.G-K1.

The BIPM was a pilot laboratory in ICAG-2009. The members of the steering committee of the ICAG-2009 were: L. Vitushkin (BIPM, currently with VNIIM, Russia), H. Baumann (METAS), M. Becker (IPG DTU), O. Francis (LU, ECGS), A. Germak (INRiM), Z. Jiang (BIPM), V. Palinkas (VUGTK/RIGTC), L. Robertsson (BIPM), H. Wilmes (BKG).

One of the important reasons to support the key comparison status for the comparison of absolute gravimeters at the BIPM was that the absolute gravity measurements with relative uncertainty of less than 1 part in 10^8 are necessary in the watt-balance experiments currently being carried out at several metrology institutes. Such systems are the potential means for the realization of a proposed re-definition of the mass unit (kilogram) currently under intense discussion. Another reason was to establish and maintain a precise and consistent gravity reference system in SI units which can act as the global basis for geodetic and geophysical observations.

The ICAG-2009 was also open to those participants who would be excluded from participation in a CCM.G-K1, or who did not wish to participate in it. The steering committee proposed therefore to accept in ICAG-2009 also other absolute gravimeters for participation in the Pilot Study only. The Pilot Study of ICAG-2009 followed as closely as possible the rules of KCs (see website of the BIPM www.bipm.org/en/convention/mra) but certain procedural rules will be relaxed to allow a wider participation.

Relative measurements needed to support comparisons among absolute gravimeters during the ICAG-2009 were organized by Z.Jiang and M. Becker. Relative measurements were used to determine the gravity field distribution with a height above the benchmark at the gravity stations of the BIPM.

11 absolute gravimeters took part in Key Comparison and 10 absolute gravimeters took part in Pilot Study. For the first time the cold atom absolute gravimeter (LNE-SYRTE, France) took part in KC part of ICAG-2009.

The reports on the results of ICAG-2009 are under the preparation at BIPM.

References

1. L.Vitushkin, Z.Jiang et al, "Results of the Seventh International Comparison of Absolute Gravimeters ICAG-2005 at the Bureau International des Poids et Mesures, Sevres", Gravity, Geoid and Earth Observation, IAG Symposia, vol. 135, Springer, 2010, pp 47-53.

2. The 4th Joint Meeting of the CCM Working Group on Gravimetry and IAG Study Group on Comparisons of Absolute Gravimeters.

The 4th Joint Meeting was organized in St Petersburg at All-Russian D.I. Mendeleev Research Institute for Metrology (VNIIM) on 21 June 2010.

The president of the Consultative Committee on Mass and Related Quantities Prof. Mitsuru Tanaka took part in the meeting with the presentation on the current situation in the organization of International Comparisons of Absolute Gravimeters which includes from 2009 the CCM Key Comparisons of Absolute Gravimeters and the Pilot Study Comparisons.

The Key Comparisons (KC) are that organized only for National Metrology Institutes and designated laboratories. The KCs are organized according to the well defined rules developed by metrology community and with well developed Technical Protocol.

The Pilot Studies (PS) are open for all the owners of the absolute gravimeters and at the BIPM the PS were also organized according to the Technical Protocol of KCs.

Prof. Tanaka has informed the meeting on the closure of the work in gravimetry and the ICAGs at BIPM and about the suggestions to organize the next ICAG-2013 in Walferdange (Luxembourg) and the ICAG-2017 in St Petersburg. The meeting has supported the organization of the ICAG-2013 in St Petersburg.

On 22 June 2010 Prof. Tanaka has visited the Lomonosov site of VNIIM where the gravimetric site for the ICAGs will be prepared to 2017.

Leonid Vitushkin was re-elected as the chairman of CCM WGG.

Also at the meeting and by e-mail correspondence Vojtech Palinkas was elected as a new chairman of IAG SGCAG.

3. Joint work of SG 2.1 on Comparisons of Absolute Gravimeters, WG on Absolute Gravimetry and CCM WG on Gravimetry on organization of future comparisons of absolute gravimeters.

After the 4th Joint Meeting of the CCM WGG and IAG SGCAG in St Petersburg the IAG President Michael Sideris initiated a joint work of CCM WGG, IAG WGAG, IAG SGACG and the president of IAG SC2.1 aiming the goal to prepare the decision on future organization of international comparisons of absolute gravimeters after the closure such comparisons at BIPM.

The chairs of working group have sent on 17 January 2011 the letter to all the members of working groups (Annex 1). In this letter the absolute gravimetry community was informed on the closure of ICAGs at BIPM and some basic ideas on the organization of future comparisons have been proposed. Two important goals were declared. The first one was that the future system of organization of comparisons should be accepted by both metrology and geodetic-geophysical communities. The second one was that system of absolute gravimetry sites on continental scale should be established for the CCM Key Comparisons and Regional comparisons of absolute gravimeters. The mentioned system of gravimetry sites will be used as the base for establishment of the International Gravity Reference System.

After the analysis of the responses to the letter a small meeting of the chairs of working groups and some members of working groups was organized on 28 February – 1 March 2011 at BKG (Germany).

The meeting proposed (Annex 2 and SG 2.1 report) that

- Participants in CIPM Key Comparisons of absolute gravimeters will be the NMIs (National Metrological Institutions), DIs (Designated Institutes) and all other laboratories having the highest technical competence and experience, ensuring that all the principal and new techniques in the field are represented,
- Only the results from one gravimeter per country will contribute to the key comparison reference value (KCRV) evaluation. The selection of this representing gravimeter will be made prior to the comparison,
- The KCRV will be evaluated using the results issued by NMIs, DIs or by other laboratories in countries that do not have NMI or DI in the field of absolute gravimetry. In these cases the laboratories have to fully comply with the Technical Protocol Requirements,
- The results of the gravimeters used for the evaluation of the KCRV will be placed on the key comparison database (KCDB) of BIPM,
- The BKG (Bundesamt für Kartographie und Geodäsie) and BGI (Bureau Gravimetrique International) will place all the results (including the results of other laboratories) on the website of AGrav.

It was decided that the draft of the Recommendations for geodetic-geophysical community on the organization of future comparisons of absolute gravimeters will be prepared for the discussion at the CCM WGG meeting on 10 May 2011 at BIPM. The Recommendations should be agreed with metrology community.

Currently there is a very alive discussion between the members of working groups concerning the content of future Recommendations.

There are three official proposals to CCM and IAG from Geophysical Laboratory in Walferdange (Luxembourg), National Institute of Metrology of China (Changping Campus of NIM) in the Nature Reserve for Ming Tombs) and from All-Russian D.I. Mendeleev Research Institute for Metrology - VNIIM (the branch of VNIIM in a little town Lomonosov near from St Petersburg) to host the CCM Key Comparisons of Absolute Gravimeters in 2013, 2017 and 2021.

4. The 2nd IAG International Symposium "TGSMM-2010" and the X-th International Geoid School

The Sub-Commission 2.1 was especially active in the organization of the IAG Symposium TGSMM-2010 and the Xth International Geoid School in St Petersburg.

4-1. The 2nd IAG International Symposium "Terrestrial Gravimetry. Static and Mobile Measurements. TGSMM-2010", 22-25 June 2010, St Petersburg, Russia

The TGSMM-2010 was organized by IAG, Russian Foundation for Basic Research, St Petersburg Scientific Center of Russian Academy of Sciences, Committee for Sciences and Higher Education of St Petersburg Government and State Research Center of the Russian Federation Concern "Elektropribor".

- The slogan of the symposium was "Measuring gravity, measuring the Earth".
- 44 oral and 36 plenary presentations were made within four sessions:
- Terrestrial, shipboard and airborne gravimetry.
- Absolute gravimetry.
- Relative gravimetry, gravity networks and applications of gravimetry.
- Atom interferometric gravimetry and gravitational experiments.

About 200 participants from 18 countries took part in TGSMM-2010.

- The participants strongly recommended that the next TGSMM will be organized in St Petersburg in 2013 or 2014.

The proceedings of the TGSMM-2007 will be published not later than in April 2010.

4-2. The X-th International Geoid School 'The Determination and Use of Geoid', 28 June-2 July 2010, St Petersburg

The X-th International Geoid School 'The Determination and Use of Geoid' has been organized by IGeS, the State Research Center of Russian Federation "Concern CSRI ELEKTROPRIBOR, JSC" and IAG with the support of Russian Foundation for Basic Research and Committee for Science and Higher Education of St Petersburg Government in the period from 28 June to 2 July 2010 at the CSRI ELEKTROPRIBOR in St Petersburg, Russian Federation.

The school included both theoretical lectures and numerical exercises on local geoid computation. The lectures and exercises were given on the following matters:

1st day: Monday 28 June

09:00 – 13:00: Lecture 1: Introduction to Physical Geodesy - Prof. R. Barzaghi

14:30 – 17:00: Absolute gravity measurements, Dr. L.Vitushkin

2nd day: Tuesday 29 June

09:00 – 13:00: Lecture 1: The Global Geopotential Models - Prof. N. Pavlis

14:30 – 18:00: Exercises on Global Models - Prof. N. Pavlis

Marine gravity - Prof. O. Andersen

3rd day : Wednesday 30 June

09:00 – 13:00: Lecture 1: The Terrain Effect in Geoid Estimation - Prof. R. Forsberg

14:30 – 18:00: Exercises on Terrain Effect - Prof. R. Forsberg

4th day : Thursday 1 July

09:00 – 13:00: Lecture 1: The Collocation Method in Geodesy - Prof. I. Tziavos

14:30 – 18:00: Exercises on Collocation - Prof. I. Tziavos

5th day: Friday 2 July

09:00 – 13:00: Lecture 1: The FFT Methods to Geodesy - Prof. M. Sideris

14:30 – 18:00: Exercises on FFT - Prof. M. Sideris

The school was attended by 15 participants coming from 5 countries. All the students received the certificates of successful graduation.

5. Gravity Networks in South America, East Asia and Western Pacific.

The chairs of the CP 2.5 Maria Cristina Pacino and Denizar Blitzkow reported on the efforts undertaken by the different organizations in South America in the last few years to improve the gravity data coverage all over the countries there are available at the moment approximately 925,878 gravity data points in the continent, including Central America (CP 2.5 report).

The activity of the Gravity Networks in East Asia and Western Pacific was reported by S. Okamura, Y. Tanaka and Y. Fukuda (Annex 3). In particular, it was reported on completion by Geospatial Information Authority of Japan (GSI) of the third round of national gravity connection survey using FG5 absolute gravimeters and relative gravimeters.

Annex 1

17.01.11

To the members of the IAG Working Group on Absolute Gravimetry (WGAG), IAG Study Group on Comparisons of Absolute Gravimeters (SGCAG) and Working Group on Gravimetry of CIPM Consultative Committee on Mass and Related Quantities (CCM WGG)

Dear colleagues,

You will probably have been informed that BIPM decided to close the International Comparisons of Absolute Gravimeters (ICAGs) at BIPM. As this is of high importance for almost all Absolute Ballistic Gravimeter (ABG) users the chairmen of IAG WGAG, CCM-WGG and SGCAG propose to discuss in the working groups the organization of future ICAGs and Regional Comparisons of Absolute Gravimeters.

Until now four-yearly comparison campaigns have been carried out at BIPM to relate the instruments to SI standards and to determine the offset of each individual instrument with respect to the comparison reference values. The last ICAG in 2009 was subdivided into a CCM "Key Comparison" (KC) where the National Metrology Institutes (NMI) and designated national laboratories took part and a "Pilot Study" (PS) for all other institutions. Both parts of ICAG-2009 were organized following the Technical Protocol according to the rules of international comparisons specified in the documents of CIPM Mutual Recognition Arrangement (http://www.bipm.org/en/cipm-mra/) which now has been signed by the representatives of 79 NMI – from 48 Member States, 28 Associates of Metre Convention and 3 international organizations – and covers a further 134 institutes designated by the signatory bodies.

The results of CCM KC part of ICAG-2009 will be placed on the Key Comparison Data Base of BIPM and the results of both KC and PS will be published then in the magazines and reported at the symposiums and conferences.

Additional intermediate comparisons were organized by the community of ABG users as so-called Regional International Comparisons of Absolute Gravimeters (RICAGs). The connection between RICAG and ICAG was realized, in principle, by the participation of some instruments which took part in both comparisons.

Key comparisons reflect the importance for the National Metrology Institutes to maintain the national gravity measurement standards. For the geodetic and geophysical applications the emphasis is placed on establishing the worldwide System of Absolute Gravity Stations, consistent gravity networks and determining small gravity temporal variations with metrologically assured instruments.

Prof. Tanaka, President of the Consultative Committee on Mass and Related Quantities announced the termination of BIPM's support but also proposed to continue future ICAGs with the support of both CCM and International Association of Geodesy (IAG), Commission 2.1 "Gravity field". This could be realized in continued cooperation of the CCM Working Group on Gravimetry (WGG) with IAG. As the community of AG users we should ensure the close link to international SI units, and we should also prevent that the community of AG users splits up into groups with purely metrological, with geodetic/geophysical interest or with merely regional applications which following different rules of metrological ensuring in gravity measurements.

A major element of the aspired solution would be to create and maintain a set of global consistent Absolute Gravity reference and comparison sites. After the closure of ICAGs at BIPM the future ICAGs as well as Regional Comparisons can be organized at different sites which can be positioned at different continents. Such sites should, of course, fulfil the developed by the CCM WGG and IAG SGCAG requirements to the sites for the comparisons of absolute gravimeters.

Already during the time of the four-yearly BIPM comparisons the necessity of regional comparisons sites was expressed, and we worked out criteria and recommendations for these locations. Several institutions have already realized stations with carefully monitored gravity component and which provide facilities where two or more ABG instruments can be compared.

Examples of the sites for the international comparisons are Walferdange (Luxembourg) where comparisons took place already in 2003 and 2007 and a new proposal is made for 2011, and Table Mountain Observatory (Boulder, USA) where the North American ABG Comparison took place in October 2010. The next comparison in Walferdange will have the support by the colleagues of METAS (Federal Office of Metrology, Switzerland)

and steering committee formed by CCM WGG, IAG WGAG and IAG SGCAG. Further sites with excellent conditions for ABG comparisons exist (Russia and China already officially proposed their sites for the comparisons) and should be included in the future planning.

To cover the realization of a permanent gravity reference we need to specify how to maintain the gravity signal at the sites and how to connect the sites and the results of the future comparisons.

We should use the opportunity to maintain the gravity standard by monitoring the gravity variations at the comparison sites and by connecting the sites with the help of instruments which take part in ICAGs and Regional Comparisons.

As an example: In December 2010 a regional comparison of five FG5-ABGs was carried out at the Geodetic Observatory Wettzell in Germany. With the support of our American colleagues one of the ABGs could take part in the recent comparison in Boulder (October 2010) and connected in this way two regional comparisons on different continents. Of course, the methods of linking the results of ICAGs and Regional Comparisons should be officially established.

Another aspect will be to use a parallel running SG to support the ABG comparison and evaluation of instrumental offsets. This support is in principle required in the above-mentioned recommendations for the sites for the comparisons. This continuous gravity record makes less dependent of un-modelled gravity variations during the comparison and it enables to include other ABG which observed in the time before or after the specific comparison campaign. This requires cooperation and coordination with the Global Geodynamics Project (GGP) and takes into account that (seasonal) gravity variations can reach several tens of microgal at specific sites.

An important benefit of such a distributed network of Regional Comparison Stations would be that it makes an invaluable contribution to establishing a Global Absolute Gravity Reference System. The repeated AG measurements and - where available - Superconducting Gravimeters document the time dependent gravity variations. The comparisons of AG instruments can be used to inter-connect the different comparison sites.

The conclusion is that the community of ABG users needs to develop and agree in collaboration with metrology community the procedures to ensure the accurate and confident gravity measurements over the world, and integrate also the observations of certified metrological instruments and data taken with equally well-maintained gravity measuring instruments which have correctly determined uncertainty budgets.

Quality criteria and standards need to be worked out and should be documented as a basis for the comparisons in a unified procedure. The chairpersons of CCM WGG (L.Vitushkin), IAG SGCAG (V. Palinkas) and IAG Working Group on Absolute Gravimetry (H. Wilmes) together with interested members of the AG community should prepare the first draft of such recommendations and discuss it, first of all, within the working groups. It would be important to prepare the Recommendations to the IUGG General Assembly.

Please tell us if you support this idea. Would you propose one of your reference sites to be used as RICAG comparison site? Would you contribute to the realization of a Global Absolute Gravity Reference Network? Would you contribute to the evaluations of proposals for the execution of ABG comparisons?

Please send your reply by January 28, 2011 to <herbert.wimes@bkg.bund.de>, <vojtech.palinkas@pecny.cz>, <vlf@vniim.ru>.

Best regards and all good wishes for a successful and happy New Year 2011,

Herbert Wilmes, IAG WGAG chairman
Vojtech Palinkas, IAG SC2.1 SGCAG chairman
Leonid Vitushkin, IAG SC2.1 President / CCM WGG chairman

Annex 2

Document CCM WGG/11-22

To:

CCM WGG (Working Group on Gravimetry of Consultative Committee on Mass and Related Quantities) members:

- IAG SGCAG (IAG Study Group on Comparison of Absolute Gravimeters) members
- IAG SGCAG observers
- IAG WGAG (IAG Working Group on Absolute Gravimetry) members and observers
- Mitsuru Tanaka, President of Consultative Committee on Mass and Related Quantities
- Alain Picard, executive secretary of President of Consultative Committee on Mass and Related Quantities,
- Felicitas Arias, director of department of time, frequency and gravimetry, BIPM,
- Yoichi Fukuda, President of IAG Commission 2 "Gravity field"
- Michael Sideris, President of IAG,
- Rene Forsberg, President of International Gravity Field Service,
- David Crossley, IAG SC2.1 Steering Committee,
- Uwe Meyer IAG SC2.1 Steering Committee,
- Maria Christina Pacino, AG SC2.1 Steering Committee
- Gerd Boedecker, Vice-President of IAG SC 2.1,
- Oelof Kruger, <oakruger@nmisa.org>
- Richard Davis, <rdavis@bipm.org>

10.03.11

Dear colleagues,

Please find below the report on the meeting at BKG on the organization of future comparisons of absolute gravimeters.

Please send your comments and proposals on the matter to Herbert Wilmes, Vojtech Palinkas and Leonid Vitushkin not later than 25 March 2011.

In March we plan to prepare the first version of the recommendations on the organization of future comparisons of absolute gravimeters based on the proposals presented in Report.

In April we plan to distribute this draft for the discussion. The modified document will be discussed then at the CCM WGG meeting on 10 May 2011 at BIPM.

Best regards,

Leonid Vitushkin, chairman CCM WGG, president IAG SC 2.1
Herbert Wilmes, chairman IAG WGAG
Vojtech Palinkas, chairman IAG SGCAG

Report on the Meeting on Organization of Future Comparisons of Absolute Gravimeters

28 February – 1 March 2011
BKG, Germany

Preamble:

Absolute gravimeters have been compared in international campaigns (ICAG) since more than 30 years at the BIPM in a cooperation of metrological and geosciences institutions. After BIPM's decision to terminate the local support for the International Comparisons of Absolute Gravimeters, working groups of CCM and IAG came together to discuss the possibilities of continuing the comparisons. The plans of the metrology community in the future to use alternating comparison sites and to integrate the results of the Key Comparisons in the CIPM key comparison database correspond to the aim of the geodesy community to realize a new International Gravity Reference System. Worldwide institutions have been asked if they are able to support the establishment of the decentralized system of the sites for the comparisons of absolute gravimeters and repeated absolute measurements which then could be used as the basis for the real reference system and about 20 positive answers have been received to date. Based upon these proposals the members of the three working groups came to the following suggestions.

The meeting supported

- the continuation of CIPM[1] Key Comparisons (CIPM KC) of Absolute Gravimeters and the official proposal from METAS (Switzerland) to be a pilot of CIPM KC in 2013 hosted by the laboratory in Walferdange, as well as the proposals from the All-Russian D. I. Mendeleyev Research Institute for Metrology (Russian Federation) and from the National Institute of Metrology (China) to host and pilot the CIPM KC on absolute gravimetry in 2017 and 2021 respectively,
- the continuation of regional comparisons of absolute gravimeters on a two-year time scale and extending them to include all Regional Metrology Organizations (RMO).

The meeting emphasized the importance of including the gravity sites for CCM KC and Regional KC of absolute gravimeters in the Global Absolute Gravity Reference Network. By doing so it was proposed to establish an International Gravity Reference System (IGRS) which can replace the outdated IGSN71.

The meeting recommended that CCM WGG[2], IAG WGAG[3] and IAG SGCAG[4] renew the Requirements of the sites for regional comparisons of absolute gravimeters (document CCM-WGG-06-24) and, in particular, that they change the priority to equip those sites which will be used for CIPM KC with superconducting gravimeters from "desirable" (priority 2) to "mandatory" (priority 1).

The meeting welcomed the proposals from the 18 institutions (list appended to this document, status 02/2011) to use their gravimetric sites for the regional comparisons and inclusion in the materialization of the IGRS. All the proposals will be studied by CCM WGG, IAG WGAG and IAG SGCAG and classified for the optimal applications.

The meeting proposed that the future CIPM KC and RMO KC be organized in compliance with the MRA[5] rules.

Taking into account the specific nature of these comparisons and the traditional International Comparisons of Absolute Gravimeters (ICAG) organized by the BIPM and IAG with the participation of metrologists and geoscientists, the meeting also proposed the following:

- Participants in CIPM KC will be the NMIs (National Metrological Institutions), DIs (Designated Institutes) and all other laboratories having the highest technical competence and experience, ensuring that all the principal and new techniques in the field are represented,

[1] International Committee for Weights and Measures
[2] Consultative Committee on Mass and Related Quantities, Working Group on Absolute Gravimetry
[3] IAG Working Group on Absolute Gravimetry
[4] IAG Study Group on the Comparison of Absolute Gravimeters
[5] CIPM Mutual Recognition Arrangement

- Only the results from one gravimeter per country will contribute to the key comparison reference value (KCRV) evaluation. The selection of this representing gravimeter will be made prior to the comparison,
- The KCRV will be evaluated using the results issued by NMIs, DIs or by other laboratories in countries that do not have NMI or DI in the field of absolute gravimetry. In these cases the laboratories have to fully comply with the Technical Protocol Requirements,
- The results of the gravimeters used for the evaluation of the KCRV will be placed on the key comparison database (KCDB) of BIPM,
- The BKG (Bundesamt für Kartographie und Geodäsie) and BGI (Bureau Gravimetrique International) will place all the results (including the results of other laboratories) on the website of AGrav[1].

The meeting suggested that the next comparison of absolute gravimeters in Walferdange in 2011 be organized as RMO KC according to the above proposals.

The meeting proposed that the first draft of the recommendations for the organization of future CIPM KCs and RMO KCs be prepared and distributed by CCM WGG, IAG WGAG and IAG SGCAG by the end of March 2011.

The proposals was prepared by

- Leonid. F. Vitushkin (VNIIM), Chairman of Working Group on Gravimetry of Consultative Committee on Mass and Related Quantities, President of IAG Sub-Commission 2.1 "Gravimetry and gravity networks"
- Herbert Wilmes (BKG), Chairman of IAG Working Group on Absolute Gravimetry
- Vojtech Palinkas (VUGTK), Chairman of IAG Study Group on Comparison of Absolute Gravimeters
- Lennart Robertsson (BIPM), Member of CCM WGG
- Alessandro Germak (INRiM), Member of CCM WGG
- Mirjam Bilker (FGI), Member of CCM WGG
- Sergiy Svitlov (MPI), Member of IAG SGCAG
- Reinhard Falk (BKG), Member of IAG WGAG
- Hartmut Wziontek (BKG), Member of IAG WGAG
- Jan Mueller (BKG), Member of IAG WGAG

Annex 3

East Asia and Western Pacific Gravity Networks

(reported by S. Okamura, Y. Tanaka and Y. Fukuda)

Geospatial Information Authority of Japan (GSI) has completed the third round of national gravity connection survey using FG5 absolute gravimeters and relative gravimeters. The network of gravity survey consists of 30 fundamental gravity stations (FGSs) including 4 newly established ones (Wakkanai in 2007, Ashizuri and Kushi-moto in 2009, Hachinohe in 2010) and 144 first-order gravity stations (GSs). In addition, GPS and leveling surveys have also been carrying out at those gravity stations to precisely determine their geodetic coordinates; to date the survey has been completed at 18 percent of the network stations for GPS and 44 percent for leveling.

GSI conducted absolute gravity measurements at Nagaoka FGS in 1997, 2004, 2005 and 2008. Nagaoka FGS is located within 50km from the epicenters of the 2004 Niigata-ken Chuetsu Earthquake (Mw6.6) and the 2007 Niigata-Ken Chuetsu-oki Earthquake (Mw6.6). GSI reported that the gravity decrease of 7.3 micro-gals has been detected during May 2005 and December 2008.

[1] http://agrav.bkg.bund.de/, http://bgi.dtp.obs-mip.fr/agrav/

Since 1996, the GSI and Earthquake Research Institute of the University of Tokyo have cooperatively conducted repetitive absolute gravity measurements at Omaezaki FGS. The station is located in the area of the anticipated great Tokai earthquake epicenter and the measurements are expected to monitor the absolute gravity changes of geophysical origin. They made measurements 11 times during 2007 to 2010. Using these data, Tanaka et al. (2010) discussed the capability for detecting the future fluid flow at the Tokai slow-slip area.

GSI started intensive gravity survey in the areas of tectonically active regions by combination of absolute and relative measurement (hybrid gravity measurement) in 2010, which is to be repeated in every five years. In 2010 first-round measurements were conducted in five areas, namely, Shionomisaki, Ashizuri, Hakodate, Hachinohe, and Sendai.

In order to detect the gravity changes associated with the land movements in West Java, Indonesia, gravity measurements with a field type absolute gravimeter, Micro-G LaCoste Inc. (MGL) A10-#017 have been conducted every year (three times) since 2008. The gravity points in Jakarta and Bandung have been selected mainly from the GPS points with large subsidence. The results of the GPS measurements in Jakarta show more than 10cm/yr subsidence along the northern coastal area and the gravity measurements show the same tendency. The comparison between the height changes and the gravity changes shows more like the gradient of water density. However the uncertainty is still large and further data accumulation should be necessary for more precise conclusions. The gravity changes in Bandung show the similar spatial pattern with the GPS data. However the quantitative comparison is still difficult.

Reference

Tanaka, Y., A. Kato, T. Sugano, G. Fu, X. Zhang, M. Furuya, W. Sun, S., Okubo, S. Matsumoto, M. Honda, Y. Sugawara, I. Ueda, M. Kusaka, M. Ishihara, Gravity changes observed between 2004 and 2009 near the Tokai slow-slip area and prospects for detecting fluid flow during future slow-slip events, Earth Planets Space, 62, 905-913, doi:10.5047/eps.2010.11.00, 2010.

Sub-Commission 2.2: Spatial and Temporal Gravity Field and Geoid Modeling

President: Martin Vermeer (Finland)

Terms of Reference

The subjects of study that the Sub-commission supports and promotes can be summarized, without claim to completeness, as follows. Research work in the spatial domain concentrates on:

- Global and regional gravity modelling
- Topographic/isostatic modelling
- Downward and upward continuation problems
- Boundary value problem approaches
- Spectral techniques like (but not limited to) spherical harmonics
- Height theory and height systems
- Geodetic aspects of satellite radar altimetry

Studies in the temporal domain of the gravity field include, among others, the following:

- Tides
- The effect of postglacial land uplift
- Time derivatives of the Jn
- Short/medium term gravity change due to movements of air and water
- Anthropogenic gravity changes.

Activities

To meet these goals, the Sub-commission sets up the Study Group 2.2 on High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results (Chaired by Michael Kuhn) and Commission 2 and IGFS Inter Commission Working Group 2.2 on Evaluation of Global Earth Gravity Models (Chaired by Jianliang Huang).

The SG 2.2 focuses on the application of forward gravity modelling techniques for high-resolution gravity field recovery with the specific aim to assist in processing data from current and future satellite gravity missions. To make its objective clearer, the SG 2.2 has slightly modified its title from "High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results" to "High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results". The first focus of the SG is on the assessment of space-domain forward gravity modelling techniques/software with the particular view on both theory and practical determination. For this purpose the chair prepared a sample topography DEM data set over parts of Australia. Furthermore, the provision of (global) forward gravity modelling results as well as meta-products for new satellite gravity mission results (e.g. spherical harmonic representation of gravitational effects) have been discussed. In addition, individual SG members have obtained several important results.

The ICWG 2.2 has successfully coordinated the evaluation of both PGM2007 and EGM2008. This evaluation project was carried out through three phases: the implementation and testing of the NGA software for spherical harmonic synthesis using ultra-high degree geopotential models (2006-2007), the evaluation of the PGM2007 model (2007-2008), and finally the evaluation of the official EGM2008 model (2008-2009). Phase 3 started right after the official release of EGM2008 at the EGU General Assembly in April 2008. The first results of the EGM2008 evaluation tests were presented by the working group members in a dedicated session during the GGEO 2008 symposium. In addition, a dedicated special issue of Newton's Bulletin was published in 2009. It consists of 25 peer-reviewed evaluation papers of EGM2008. The ICWG2.2 has been also involving in assessing satellite-only gravity models determined by GRACE and GOCE. In particular, evaluation of the future GOCE gravity models should be an important task. Therefore this working group should be continued beyond 2011.

Sub-Commission 2.3: Dedicated Satellite Gravity Mapping Missions

President: Roland Pail (Germany)

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

1. 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, altimetry, etc.), both on a global and a regional/local scale;
2. investigation of alternative methods and new approaches for gravity field modelling, with special emphasis on functional and stochastic models and optimum data combination;
3. identification, investigation and definition of enabling technologies for future gravity field missions: observation types, technology, formation flights, etc.;
4. communication/interfacing with gravity field model user communities (climatology, oceanography/altimetry, glaciology, solid Earth physics, geodesy, ...).

In the following, a brief report on the activities, main results, and a selection of key references related to these subjects is given for the reporting period 2007 to 2011.

1. Static and temporal global gravity field models

Activities and results

Sub-commission members are involved in the derivation of new releases of global gravity field models based on GRACE and CHAMP mission data, applying updated background models, processing standards and improved processing strategies (e.g.: EIGEN-6S, GGM03S, ITG-Grace2010S, AIUB-GRACE02S). 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., [7], [9], [13]). In addition to improved static gravity field models, also monthly, 10-days, weekly and even daily GRACE solutions (CNES-GRGS, GFZ, Univ. Bonn) have been derived (e.g., [3], [5], [6], [15], [16], [17]). The GRACE Science Data System has started to reprocess the complete GRACE mission data with improved instrument data, background models and processing standards. The release 05 static and monthly models (e.g. GFZ's EIGEN-GRACE06S; [5]) shall be provided to the user community in summer 2011. A combination with complementary gravity field information derived from terrestrial and air-borne data, satellite altimetry, and satellite laser ranging led to the generation of high-resolution combined gravity field models, such as EGM2008 (degree 2190), EIGEN-5C (degree 360), GGM03C (degree 360). These models have been thoroughly validated and inter-compared (e.g., [8], [28]), and are now extensively used by a wide geo-scientific community.

The GOCE High-Level Processing Facility (HPF) is responsible for the generation of GOCE final orbit and gravity field products ([14]). 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, gradio-meter, and star-tracker observations have been investigated (e.g., [1], [2], [10], [20], [21], [30], [31]). An alternative algorithm for the angular rate reconstruction in the frame of the gravity gradient processing has been developed ([29]), which is currently being implemented in the official ESA Level 1b processor and will further improve GOCE Level 1b products. Additionally, extensive validation activities of GOCE observations have been performed, e.g., [12], [23].

The first gravity fields in the framework of HPF, which are based on two months of GOCE data (Nov./Dec. 2009), were delivered to ESA in June 2010 and presented at the GOCE workshop during ESA's Living Planet symposium in Bergen, Norway ([24]). In the processing of these three solutions, which are based on different processing rationales, members of the subcommission have been deeply involved. The model obtained by mean of the direct approach (GO_CONS_GCF_2_DIR_R1; [4]), complete to degree/order 240, was constrained with the spherical cap regularization method by [18] using a combined model as prior information. In contrast, the time-wise gravity field model (GO_CONS_GCF_2_TIM_R1; [25]) is a GOCE-only model in a rigorous sense, because no external gravity field information was included, neither as a-priori model, nor for constraining the solution. The philosophy of the space-wise model (GO_CONS_GCF_2_SPW_R1; [19], [22]) is similar, but still a-priori knowledge (EGM2008) was included in the low degrees. In February 2011, new versions of the direct and the time-wise models (GO_CONS_GCF_2_DIR_R2, GO_CONS_GCF_2_TIM_R2), based on 8 months of GOCE data (Nov. 2009 – July 2010), have been delivered. A global gravity field model derived only from GOCE GPS-SST data has been developed by [11]. These activities have been followed by the generation of the global gravity field model GOCO01S ([26]), which represents the first satellite-only combined global gravity model based on a consistent combination of GOCE and GRACE.

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2. Alternative methods for gravity field modelling

Activities and results

Sub-commission members have actively contributed to the development and investigation of alternative methods of global and regional gravity field modelling, e.g. using space localized base functions ([36], [40]). New strategies such as the use of tensor invariants are investigated to exploit GOCE gradiometry ([33]).

Another key issue is the optimum combination of different ground and satellite gravity data types. As an example, this problem has been investigated by setting up a generalized remove-restore procedure in the frame of the least squares collocation concept, which also takes into account the global model error covariance ([38]). Additionally, the possible combination of a space-wise GOCE-only model with an ultra high resolution model such as EGM08 has been studied ([41]).

Several Sub-commission members execute projects dealing with the optimum inclusion of global gravity field information for the improvement of regional gravity field (geoid) solutions, as an example [32], [37]. The most recent high resolution European quasigeoid model EGG2008 was computed within the framework of the European Gravity and Geoid Project (EGGP; [34]). Another key application is the validation of global models with ground data, e.g., [35], [42].

In the framework of the collaborative research project RESEL-GRACE (Refined European sea level estimations by combining altimetry, tide gauges, hydrographic and other data sets with improved regional GIA modeling and tailored regional GRACE gravity field models) within the EUROCORES Program TOPO-EUROPE founded by the European Science Foundation (ESF), Sub-commission members have worked on alternative processing procedures such as the energy conservation law for a more suitable focusing on regional geophysical processes in the Mediterranean Sea or Fennoscandia ([39]).

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3. Future gravity field missions

Activities and results

The science community as well as representatives from space agencies and industry were brought together at two workshops on future gravity field missions in order to point out the urgent need for a next generation gravity field mission. A first workshop named "The Future of Satellite Gravimetry" was conducted in April 2007 at ESTEC/Noordwijk. The resulting report [48] identifies the future needs of gravity field observations from space. As a follow-on a joint GGOS/IGCP565 – IAG – GEO Workshop "Towards a Roadmap for Future Satellite Gravity Missions" was held in September/October 2009 at Graz University of Technology. The workshop aimed at bringing together stakeholders in satellite gravity missions in order to establish a roadmap for future satellite gravity missions that outlines the sensor developments, mission concept developments, and mission implementation, and that is consistent with anticipations of the major space agencies, CEOS, and GEO, and with the needs of key user groups (such as IGWCO, the GEO Water Tasks, GOOS and GCOS, Earth scientists, and GGOS itself).The outcome of this workshop is summarized in [54]. It identifies the need for a continuous observation of the time variable gravity field in order to implement an operational observing system for mass redistribution, global change, and natural hazards.

In parallel to the international programmatic meetings mentioned above and based on the success of the gravity mission CHAMP, GRACE and GOCE, which brought an enormous improvement in the knowledge of the Earth's gravity field and particularly in its temporal evolution, a number of studies and proposals for future gravity field mission concepts have been performed. All these studies and proposals address science requirements to be met by such a mission, observations and orbit concepts needed in order to improve spatial and temporal resolution and in order to reduce temporal aliasing, and candidate satellite and instrument technology needed for the identified mission concepts.

On ESA level during the reporting period three studies on future gravity field missions were conducted. The first study was about "Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the Earth system by Means of Satellites" and run in the period from 2007 to 2008. Goals of this study were the development of a complete multi-year forward simulation of mass variations in the Earth system and the identification of potential mission scenarios and their performance. Results of this study are reported in [53]. In the period from 2009 to 2010 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. 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. Both studies recently were finalized and final reports are under preparation ([43] and [51]).

Further studies and mission proposals on national and international level have been worked out during the reporting period. In Germany a series of studies was conducted by GFZ Potsdam. These are GRAF in 2008/2009 (GRACE Follow-on), 3M4C in 2009 (Mass Motion Monitoring for Climate) and 3M4C-FPS in 2010 (Mass Motion Monitoring for Climate Fine Pointing Study) [46]. Within the framework of the German Geotechnologien Programme further studies on future gravity field missions with a medium to long perspective are carried out (e.g., [52]), and additionally the OPTIMA study was performed ([44]). In France the "Micromega" project which was selected by the CNES science committee to enter phase 0 was conducted with similar goals. As a result of these activities a full proposal for a future gravity field mission was prepared for ESA's Earth Explorer 8 call. The proposal, entitled "e.motion" (Earth System Mass Transport Mission) was submitted in May 2010 [47]. Unfortunately the proposal was not selected to proceed into the next phase. The e.motion team composed by a multi-disciplinary science team and an industrial team working in the area of satellite gravimetry will continue to work together with the goal to define a next generation gravity field mission. In Italy studies on future gravity field missions based on satellite-to-satellite tracking and laser interferometry have been performed ([45]), and applications of this concept to geophysical data interpretation have been studied together with geophysics experts ([50]).

In response to the U.S. Administrations's climate initiative, NASA has decided to initiate and implement a GRACE Follow-on mission for launch no later than 2016. Due to the productive and successful partnership with DLR and GFZ, NASA seeks a continuation for GRACE-FO with parties assuming similar roles and responsibilities as for GRACE. Therefore, GFZ has submitted mid of 2010 a proposal to the research program for sustainable development (FONA) of the German ministry of education and research (BMBF) to receive funding for a GRACE-FO Launcher, the development of a Laser Ranging Instrument (add-on to the prime MW K-band instrument) and Science which is currently still under evaluation by the ministry.

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[54] http://www.igcp565.org/workshops/Graz/roadmap.php

4. Interfacing with user communities

Activities and results

The workshops discussed above ([48], [54]) 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.

Several national platforms have been set-up or are maintained by Sub-commission members to interface with user communities, exemplarily, the German GOCE Project Office (which was finalized in May 2010) and GOCE-ITALY (funded by the Italian Space Agency), aiming at the interpretation of GOCE data for geological, geophysical and oceanographic applications in the Italian area.

Sub-commission members are also involved in joint projects with representatives of various user communities in many fields of applications, such as mantle dynamics (e.g., [56]), or glacioisostatic adjustment (e.g., [60]). First results of GOCE gravity fields for oceanographic applications are evaluated in [55]. First experiments on geophysical analysis have been carried on based on GOCE space-wise internal products such as grids of potential and second derivatives at satellite altitude with their error covariance matrix. Moreover, using gridded data the Politecnico di Milano group has performed studies on the Moho estimation, producing first preliminary results ([57], [58]).

Online service access points for geoscientific data products, such as the Information System and Data Center (ISDC) portal maintained by the GFZ ([59], [62]) show a steadily growing number of users (status March 2, 2011: 2678) from various user communities (climatology, oceanography, glaciology, geodesy, solid Earth physics, etc.).

The International Center for Global Earth Models (ICGEM; [61]) 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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Sub-Commission 2.4: Regional Geoid Determination

President: Urs Marti (Switzerland)

Terms of Reference

Sub-Commission 2.4 is concerned with the following areas of investigation:

Regional geoid projects: data sets, involved institutions, comparison of methods and results, data exchange, comparison with global models, connection of regional models

Gravimetric geoid modeling techniques and methods, available software

GPS/leveling geoid determination: methods, comparisons, treating and interpretation of residuals common treatment of gravity and GPS/leveling for geoid determination

Geoid applications: GPS heights, sea surface topography, integration of geoid models in GPS receivers, vertical datums.

Other topics: topographic effects, downward and upward continuation of terrestrial, airborne, satellite data specifically as applied to geoid modeling.

Objectives

Sub-Commission 2.4 initiates and coordinates continental and regional geoid and gravity projects. It encourages and supports the data exchange between agencies and assists local, regional and national authorities in their projects of gravity field determination. It helps in the organization of courses and symposia for gravity field determination

The Continental Gravity and Geoid Projects

One main part of Sub-Commission 2.4 is the initialization and coordination of the commission 2 geoid projects on the continental scale. These usually long-term projects are the following:

Project 2.1: European Gravity and Geoid Project (EGGP), chaired by Heiner Denker (Germany)
Project 2.2: North American Geoid, chaired by Daniel R. Roman (USA)
Project 2.3: African Geoid, chaired by Hussein Abd-Elmotaal (Egypt)
Project 2.4: Antarctic Geoid (AntGP), chaired by Mirko Scheinert (Germany)
Project 2.5: Gravity and Geoid in South America (GGSA), chaired by Maria Cristina Pacino (Argentina)
Project 2.6: South Asian and Australian Geoid, chaired by William Kearsley (Australia)

All these projects already existed in the period 2003-2007 and could be continued with slight modifications.

2 projects are chaired now by new persons: 2.2 (formerly Marc Véronneau, Canada) and 2.3 (formerly Charles Merry, South Africa).

The 2 former projects "South American Geoid" and "South American Gravity" have been combined into one single project, which is now chaired by MC Pacino.

The area of investigation of the North-American geoid projects could be extended to Mexico, which is now a participating member of the project. A further extension towards Central America and the Caribbean would be of great interest.

The former project 2.6 "Geoid in South-East Asia" was renamed and extended to "South Asian and Australian Geoid".

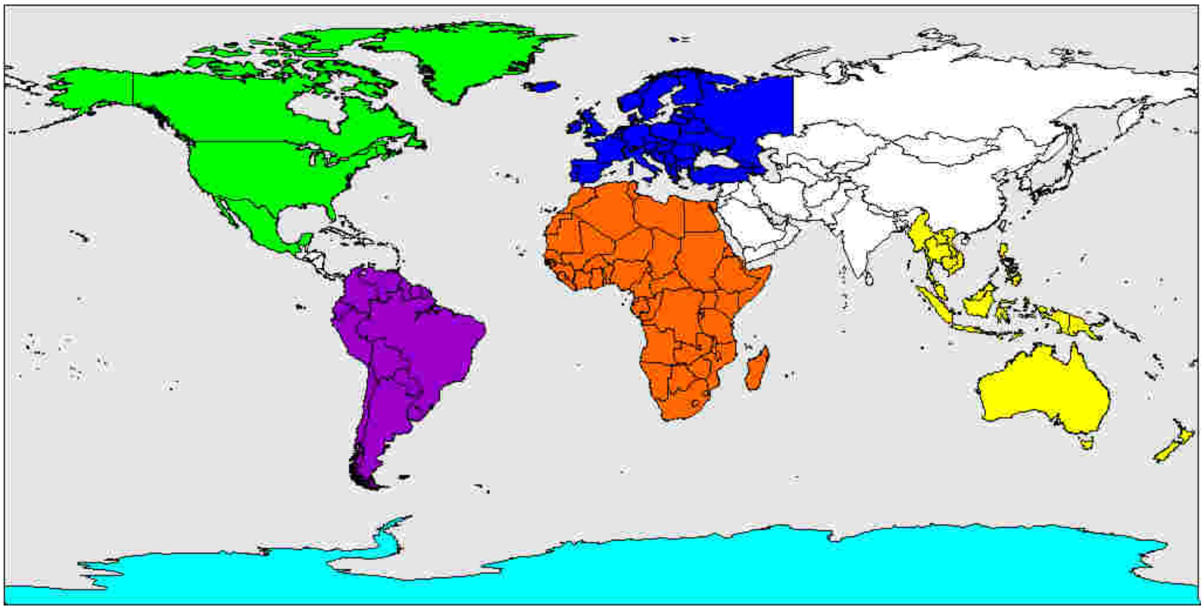

Figure 1: Overview of the coverage of the Commission 2 geoid projects

Activities of the Continental Gravity and Geoid Projects

Each of these projects published a report of their own (see further down). So, here, only a very rough overview is given.

The projects in Europe, North-America, South-America and Antarctica are advancing well and some results are available. The collaboration of National authorities works rather well there. In the other projects the collaboration is sometimes difficult and the lack of data is an important problem. Nevertheless, the progress in some of these regions (especially Africa) is clearly visible.

The EGGP advanced well and a solution EGG2008 was presented. It was compared and evaluated with GPS/leveling in the EUREF project EUVN-DA. If the availability of GOCE data makes it necessary to release a new version of the European geoid is still under investigation. A further great success was the release of the Auvergne dataset to compare various methods of geoid computations.

The North-American Geoid project is on a good way and several meetings took place mainly between American and Canadian authorities. Mexico as well is now an active member of the project and offered to take the lead in an extension towards Central America. The USA mainly focuses on the harmonization of their gravity data set by means of airborne gravity missions (GRAV-D project) as the basis for a national to continental height system. There are interests in extending these activities towards the Caribbean and even some northern parts of South America. Funding for such activities seems to be granted. The IAG project should continue beyond 2011.

For the African geoid project, a result was presented in 2007 by Charles Merry but a further improvement is difficult due to poor collaboration of countries, missing data and funding. An important step was the airborne gravity mission over Ethiopia. Some countries (Algeria, Egypt, South Africa) advance well on the national level. Tanzania calculated a national geoid model as well. Big improvements were reached by the new GRACE and GOCE models which were verified in some of the countries. An extended collection of available gravity data over Africa is foreseen. The project should be continued beyond 2011.

The Antarctic Geoid Project profited from the activities for the International Polar Year 2007/2008. Several important projects could be realized and the interdisciplinary collaboration between the involved groups is good. The gravity coverage could be significantly improved mainly through airborne campaigns but as well by terrestrial relative and absolute observations. But there are still important data gaps that have to be covered in the future. The goal should be a complete data coverage that can be used for the geoid determination and other application. Of most importance is to cover the polar gap where no GOCE data is available. This long term project should be continued beyond 2011.

For South America a new geoid solution (Geoid2010) was released. Further works included the densification of gravity networks and the evaluation of geopotential models. The gravity database was extended towards Central America and the Caribbean.

Project 2.6 (South Asia / Australia) has big problems mainly due to the missing collaboration of the countries and the problems in data exchange. Therefore, activities in gravity field modeling are mainly limited to national projects. Good results have been achieved in Australia, New Zealand and Indonesia. An Indonesian Geoid workshop was held in 2009. The principal actions in the near future should focus on improving the collaboration between the countries.

Other regional geoid projects

Besides of the commission 2 projects, there are many activities in national to local geoid determination. Many of them were presented at the main symposium of commission 2 in Chania, Greece in 2008 (GGEO2008) or at other meetings of organizations such as AGU or EGS.

Important national activities in countries that are not covered by a commission 2 project include Russia, Japan, China, Korea, Mongolia, Iran, Saudi Arabia and others.

The main goal of these activities is usually to present a national geoid model which can be used in practice for height determination with GPS. Many activities include as well the introduction of GPS/leveling in geoid determination and the comparison of local models with global models.

Other activities

Sub-commission 2.4 is active in the assistance of the organization of symposia such as the GGEO2008 in Chania (2008) or the IAG scientific Assembly in Buenos Aires (2009).

The sub-commission supports education and assists local authorities in their geoid and gravity projects. In the last years there have been activities in Azerbaijan, Kosovo, Sri Lanka, Jordan and Guatemala.

Sub-Commission 2.5: Satellite Altimetry

President: Cheinway Hwang (Taiwan)

1. Introduction

IAG sub-commission 2.5 (SC2.5) serves as an interface between altimeter data and their users to promote the visibility of IAG in altimetric science. Selected research highlights/objectives are:

- Establish a close link between this sub-commission and International Altimeter Service (IAS) to facilitate data distribution, problem solving and application.
- Promote new applications of satellite altimetry in solid earth science and environmental geodesy, e.g., studies of postglacial rebound, vertical displacements at major tectonic-active zone, melting of permafrost zones.
- Promote applications and evaluations of interferometric altimetry
- Promote interdisciplinary applications of altimetry in geodesy, geophysics and oceanography.
- Develop techniques to improve altimeter data quality in coastal zones and land

A web page of altimetry service of SC2.5 is being established (http://space.cv.nctu.edu.tw/altimetryworkshop/ALT.html). Tools for satellite altimetry data processing and applications are freely available at this webpage.

2. Workshops

To achieve the objectives of this sub-commission, two workshop have been organized. The first workshop is the "International Workshop on Gravity, GPS and Satellite Altimetry Observations of Tibet, Xinjiang and Siberia (TibXS 2009)" , held from August 20 to 22, 2009, Urumqi, Xinjiang, China. (see http://space.cv.nctu.edu.tw/altimetryworkshop/TibXS2009/ TibXS2009.htm). This workshop brought together scientists to present their research results and thoughts in the fields of geodynamics, climate change, hydrology, over Tibet, Xinjiang and Siberia using the tools of satellite altimetry, plus gravimetry and GPS. Evidences from satellite gravimetry and altimetry show the hydrological evolutions over these regions are sensitive to global climate change. Inter-annual lake level changes over Tibet and Xinjiang from satellite altimetry are found to be connected to El Nino Southern Oscillation (ENSO). Lakes in central Asia originating from Xinjiang and lakes in eastern Siberia show sharp changes in lake levels that can be explained by climate change. Satellite altimetry is a potential tool to study vertical displacement and permafrost thawing and changes in the active layers in Siberia and Tibet.

Fourteen papers from the TibXS 2009 workshop were selected, peer-reviewed and compiled into a special issue of the SCI-indexed journal "Terrestrial, Atmospheric and Oceanic Sciences (TAO)"; see http://tao.cgu.org.tw/. The guest editors are BF Chao, Jeff Freymueller, WB Shen, CK Shum and Cheinway Hwang. This special issue is published in April 2011 and the electronic files of the papers will be freely available on the SC2.5 web page. A special of TAO, published in April 2008, also covers papers of an IAG altimetry workshop held in 2006, Beijing, China. This special issue (Vol. 19, No. 19, 2008, TAO) deals with similar issues as SC2.5, and particularly emphasize satellite altimetry applications over land and coastal zones.

Readers will find interesting altimetry techniques in waveform retracking, gravity derivation, land surface deformation monitoring and other applications in this special issue.

The second workshop, to be held July 22-26, 2011, will be organized by IAG SC2.5, Wuhan University, Qinghai Seismology Bureau, China. The topics to be included in this workshop are:

– Results of satellite and terrestrial-based gravimetric observations.
– Results of GPS observations, GPS meteorology and ionosphere
– Satellite altimetry observations on regional hydrology and vertical displacements; improvement in data processing techniques
– Geophysical interpretations and consequences of gravity, GPS, satellite altimetry and seismic observations
– Detections and interpretations of anomalous signals prior to large earthquakes

Again, a special issue in a SCI-indexed journal will be launched to publish outstanding papers from this workshop. Comparison of GRACE and altimetry results will be highlighted.

3. Summary

Over the past four years (2007-2011), SC2.5 has been trying to achieve some of the proposed objectives. A summary of the achievements and status of SC2.5 is:

– All activities and publications of SC2.5 can be found on the web page http://space.cv.nctu.edu.tw/altimetryworkshop/ALT.html
– Two workshops have been organized in 2009 and 2011 to promote altimetric applications in geodesy, geophysics and oceanography
– Two special issues of the journal "TAO" have been published to address the problems and applications of satellite altimetry
– Computer programs and papers for altimetric applications are freely available on the SC2.5 web page

Commission Project 2.1: European Gravity and Geoid Project (EGGP)

Chair: Heiner Denker (Germany)

The EGGP was established after the IUGG General Assembly in Sapporo, 2003, and then extended at the IUGG General Assembly in Perugia, 2007. The structure consists of a steering committee (SC, 8 persons: H. Denker (Chair), R. Barzaghi, R. Forsberg, J. Ihde, A. Kenyeres, U. Marti, M. Sarrailh, I.N. Tziavos) and about 50 project members from nearly all European countries.

The EGGP status in 2007, the beginning of the present IAG 4-year term, is summarized in Denker et al. (2008a). In 2007, the geoid and quasigeoid model EGG2007 was computed; this model is a complete update as compared to the previous computation from 1997 (EGG1997). All high resolution gravity and terrain data available for Europe in mid-2007 as well as a GRACE based global geopotential model (EIGEN-GL04C) were employed, utilizing the remove-restore technique, residual terrain model reductions and the spectral combination approach.

The evaluation of the EGG2007 gravity data, especially the comparisons with the ultra-high-degree geopotential models PGM2007A and EGM2008 from NGA, indicated that some of the EGGP gravity sources had biases due to incorrect gravity reference system information (e.g., Denker et al., 2007; Denker, 2008). After a re-evaluation of the suspicious sources, some land data sets were updated, and, in addition, several marine gravity data sets were improved, up-to-date altimetric gravity anomalies were employed, and the terrain reduction procedure was revised. Then a new model EGG2008 was developed (based on the global model EGM2008) and evaluated by national and European GPS and levelling data sets (Denker et al., 2008b and 2009). The new model showed improvements over the 2007 model in selected regions where data updates were realized. The results indicate an accuracy potential of 0.03 – 0.05 m at continental scales and 0.01 – 0.02 m over shorter distances up to a few 100 km, provided that high quality and resolution input data are available. The EGG2008 model was made available to selected people and agencies for evaluation (e.g., Tziavos et al., 2010).

Regarding the evaluation of the gravimetric geoid and quasigeoid models, the EUVN_DA project lead by A. Kenyeres contributed an important set of GPS/levelling control points (Kenyeres et al., 2008, 2009a, 2009b, 2010). In total, about 1500 European high precision GPS/levelling stations were collected within the framework of the EUVN_DA initiative. These control points agree with the gravimetric quasigeoid EGG2008 at the level of about 0.08 m, just considering a constant bias parameter to account for different zero level definitions. Only two areas show larger discrepancies. The first area is Great Britain, where the levelling heights are suspected to contain significant systematic errors; in this case, the removal of a north-south and east-west trend in the comparisons reduces the RMS difference from about 0.15 m (bias case) to 0.05 m (bias and tilt case). The second area with larger discrepancies is Italy, where some improvements were made recently (Kenyeres et al., 2009b). In addition, an attempt was made to combine the EUVN_DA GPS/levelling data with the gravimetric quasigeoid (Kenyeres et al., 2009b).

With the availability of the first results from the GOCE gravity field mission, the available data sets for Europe and especially Germany were used for evaluation purposes (Ihde et al., 2010, Voigt et al., 2009). After a consistent filtering of the terrestrial gravity data sets and the GOCE models, using a Gauss filter with 100 km radius, the RMS gravity differences were about 2.5 … 4.0 mgal for the GOCE models (first generation models) as compared to about

5.0 mgal for a current GRACE solution. For a filter radius of 200 km, the RMS differences were about 1.1 mgal for all models (GRACE and GOCE). Meanwhile, a second generation of GOCE models was released, and corresponding investigations are underway. The combination of the first generation of GOCE models with the terrestrial gravity and terrain data has not yet lead to significant improvements as compared to the EGM2008 based solution (i.e., EGG2008). Further tests are currently made with the second generation of GOCE models. In the mid of 2011, a final decision is made whether the EGG2008 model is retained or a new solution is adopted on the basis of a global geopotential model from the GOCE mission; the final EGG20yy model will then be distributed to all persons and agencies that contributed to the EGGP.

Furthermore, a valuable test data set was created by Henri Duquenne, consisting of high resolution gravity and terrain data as well as GPS/levelling control points, covering large parts of France with a focus on the Massif Central region (for details cf. Duquenne, 2007). The data set was made available to interested people and agencies for testing different geoid and quasi-geoid computation methods, softwares, reduction procedures, etc. The collection and evaluation of the test results is done as a joint effort of the EGGP and the International Geoid Service (IGeS) in Milan (Agren et al., 2009); this effort is still ongoing.

A project meeting was held on June 26, 2008, at the IAG International Symposium "Gravity, Geoid and Earth Observation 2008", GGEO2008, in Chania, Crete, Greece, and about 15 people participated. The main discussion items were the project status, further plans, the creation of a 5' × 5' gravity data set, and the exploitation of the French test data set, made available by H. Duquenne.

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Commission Project 2.2: North American Geoid

Chair: Dan Roman (USA)

Bottom Line Up Front

A series of splinter meetings at various international and national meetings has served as the primary mechanism for members to meet. Collaboration continues to develop as the national geodetic agencies for Canada, the U.S.A., and Mexico leverage each others' results and successes to expand their own respective national programs. The U.S.A. has initiated the Gravity for the Redefinition for the American Vertical Datum (GRAV-D) primarily to develop a gravimetric geoid model as a replacement for the existing outdated model (NAVD 88). Data are primarily collected using airborne platforms with flights extending over adjacent regions in the oceans and over Canada and Mexico. The data are being shared and a consistent, accurate gravity field is sought. Discussions continue on the best means for reducing the gravity data into a geoid height model that is desired to be accurate to the cm-level at least in uncomplicated geophysical regions (i.e., low lying regions near passive boundaries). Canada is proceeding with a planned 2013 release of such a model, while the U.S.A. will likely release in 2022 about the time the Canadian model is updated (semi-dynamic datum). Mexico hasn't firmly committed but is keeping all options open and is taking on a leadership role in Central America by coordinating training and overall research for that region. Collaboration continues and networks are expanding to include other nations in the region.

Meeting Activities

Meetings have been held concurrent with major meeting held by IAG including the last IUGG meeting in Perugia, Italy (2007), GGEO in Chania, Greece (2008), IAG meeting in Buenos Aires, Argentina (2009), and the IGFS meeting in Fairbanks, Alaska, U.S.A. (2010). Additional meetings and workshops have been held during the Canadian Geophysical Union Annual Meetings and Canadian Geoid Workshops held in Calgary (2008), Ottawa (2010) and Banff (2011). Discussions at these meetings focused more on the practical implementation of geodetic theory but also covered the time varying geoid/gravity signal and its impact on a regional geoid height model and derived vertical datums. Splinter group meetings were also held during the Fall AGU meetings in San Francisco (2008, 2009, 2010) as well as during the AGU Joint Assembly in Ottawa in 2009 (held jointly with CGU) and the Meeting of the Americas in Igassu Falls, Brazil in 2010. This last meeting served as a focal point for discussions with South American investigators (Denizar Blitzkow and several others) pursuing a unified South American geoid/geopotential datum and the means to compare any North and South American models in the overlap area in Central America. The National Geodetic Survey hosted a meeting under the auspices of the IAG in Boulder, Colorado, U.S.A. specifically to get together all parties in North America with an interest in the time varying geoid, monitoring it, and developing models to account for it. This meeting helped to bridge several disparate communities and helped to focus on the third element in the GRAV-D project that involves collaborating with researchers who are responsible for development of various geophysical models that have primary or secondary impacts on the accuracy of geoid height models. Several exchanges have been made between the NGS and the National Geospatial--Intelligence Agency (NGA) and the U.S. Geologic Survey (USGS) to facilitate data exchanges and increase collaboration in collecting other geophysical information during the GRAV-D flights. During 2010, meetings were held at the F.I.G General Meeting in Sydney, Australia where the overall plan for developing a gravimetric geoid in the U.S.A. was presented and close discussions were held with New Zealand representatives, where this has already occurred. Refinements of the techniques employed in the development of the recent gravimetric geoid model were presented at the EGU 2011 meeting and further presentations were made during the F.I.G. 2011 meeting in Marrakech, Morocco to reinforce the reliability of using GNSS technology with a geoid height model to promulgate vertical heights consistent with a global vertical datum but meeting local needs.

Data Improvement

NGS invited Lars Solberg for a one month visit to help improve the theoretical basis for modeling (2008) and Heiner Denker to aid in refinement of modeling techniques (2009, 2010). Adjustment of the techniques and data handling resulted in significant improvements over current U.S. Gravimetric Geoid model developed in 2009 (USGG2009). The reductions were quite significant in the more mountainous western regions (Washington, Oregon, Idaho, Montana) and will result in 30% improvement for that region. These results are expected to be less in other regions but represent a step forward in the overall improvement in the treatment of the underlying terrestrial data. The most significant data improvements result from the work by Jarir Saleh, under contract to the NGS. He will soon publish a technical paper that lays out the extent to which the two million terrestrial gravity data points in the NGS archives have systematic effects buried in them. Significant (3-5 mgal) biases exist in entire surveys. These surveys span various scales from regional to local. While GRACE and GOCE will be useful in detecting and mitigating those biased surveys that span regional scales, many of the surveys are below the resolution of even GOCE (150 km and smaller). Even those these surveys span a smaller region, the impact of the errors is such that errors propagate into the geoid at 10-20 cm or more. The aerogravity collected under GRAV-D will serve to bridge the gap between the terrestrial data and the satellite mission data that will serve as the backbone. Given that a bulk of these data have been incorporated into many combined earth gravity model solutions, resolving the magnitude and mitigating these systematic errors is paramount in determining a cm-level accurate geoid model.

Discussions with Canada establish a higher degree of confidence in data there. Data collected in the U.S.A. come from many sources with uncertain metadata. This is less of a problem for Canada where the data collection has been under the direct purview of the geodetic agency. Any problems that might arise should be addressed by the combined GRACE and GOCE model. Overflights by the U.S.A. for the GRAV-D project are planned deeply into Canada over the Great Lakes region and to a lesser extent over other border regions. None the less, this overlap will help to establish continuity of the gravity field over the border and a more consistent and accurate gravimetric geoid model. The problem is more protracted over Mexico where significant biases are known to exist between base stations. There is some effort underway in Mexico to standardize this network and determine more consistent and accurate gravity as a part of extending the NAVD 88 network further into Mexico.

However, the primary mechanism for improvement of data in the region will be by implementation of the GRAV-D project. This project has potential funding starting in October 2009. Airborne data will be collected and integrated with GRACE/GOCE models to ensure a consistent gravity field through 20 km resolution. In turn, these combined data will be used to detect and hopefully fix surface gravity data to ensure a seamless gravity field to the shortest wavelengths. Additionally, terrain and density data are being explored as a mechanism for refining the shortest wavelengths of the gravity field. This aspect of the program is geared towards improvements in the USA specifically.

Talks with NGA explored alternative funding and potential interest by NGA in collections over Canada, Mexico, the Caribbean, and northern portions of South America that represent the other regions that are a part of the North American Geoid project. Additional funding opportunities are being sought through USAID and World Bank. The aim is to locate funding, personnel, and equipment opportunities to expand upon the project centered on the USA. The meetings mentioned above are designed to ensure that appropriate agencies from the involved countries have an opportunity to participate should funding develop. The expectation is that future meetings will be used as opportunities to expand basic project membership to more involved levels.

Planned Implementation

Canada remains in the lead with implementation planned in 2013 for use of a gravimetric geoid height model in conjunction with GNSS to provide a vertical reference system. The USA remains committed to a goal of 2022. Canada looks towards a semi-dynamic datum that will likely be updated at the time of the implementation of a common geoid height model for the USA. At the 2011 CGU/Geoid Workshop Meeting, representatives from Canadian and USA agencies as well as Canadian Academia discussed topics related to this implementation. For consistency with IAG rules, a Tide-Free system will be adopted. Additionally, a W0 value will likely be adopted that is consistent with that selected by the IAU and endorsed by the IAG. Determination of this value must confirmed by November 2012 to ensure that the Canadian implementation (which occurs first) will be consistent with the later USA implementation. The determination of the working group was that the "true" value would continue to be refined over time and that customers (surveyors, GPS users, mapping agencies, etc.) would better be served by adopting a value that is nearly correct but doesn't change often. As long as the offset to the currently adopted best value is known, this can be applied as need to get to the selected value.

Mexico is planning to implement an adjustment of its gravity network considering time variations. An updated geoid model shall follow in order to integrate with the North American Geoid project. The completion dates for these have not yet been established.

International Great Lakes Datum of 2015 (IGLD15)

A unique aspect of cooperation between Canada and the USA will be the development of a replacement for the existing dynamic height datum employed on the common shared Great Lakes. IGLD85 is scheduled for replacement in 2015. The existing model was developed from geopotential numbers developed as a part of the North American vertical Datum of 1988 (NAVD 88). While Canada did not adopt NAVD 88 as a vertical reference system they did allow for its use in development of dynamic heights across the Great Lakes. As both Canada and the USA move towards a common gravimetric geoid height model as the basis for a vertical reference system, it is imperative that this effort be synchronized. Separate meetings of the International Great Lakes Commission involve many of the same people involved with this project. The intention of members of this project is to ensure that IGLD15 is based on geopotential values determined from the common geoid height model. As a part of GRAV-D, airborne collection and data cleaning will occur early on (2011) to permit analysis and model development by both national agencies as well as academic groups interested in evaluating modeling theory and techniques. The goal is to develop separate approaches and evaluate them together. Ideally, several different approaches should result in similar models with error allowances. The likely implementation date for IGLD15 will be around the time of the release of the gravimetric geoid height model for a new vertical reference system in 2018 (IGLD85 actually was released in 1988).

Collaboration with Other Groups/Projects/Commissions

As stated above, cooperation already exists between Natural Resources Canada and NGS. Additionally, NGA has expressed a greater interest in collaborating. Since NGA's mandate is for outside the conterminous USA, they will be closely involved with other nations in the region interested in participating in the GRAV-D project. Previous contact has been made with a number of people representing different groups. A list of members (mainly passive to this point due to lack of funding) is given below:

- Daniel R. Roman (chairman), NGS (U.S.A.) Marc Veronneau, GSD (Canada)
- David Avalos, INEGI (Mexico) Rene Forsberg, DNSC (Denmark)
- Laramie Potts, NJIT (U.S.A.) Anthony Watts, L&SD (Cayman Islands)
- Karim V. D. Hodge, L&SD (Anguilla)

The aim will be to expand this membership and have them take on a more active role as this project develops. Initial participation will likely be through analysis of collected data and modeling techniques. As coverage of the project expands, more active participation in the data collection efforts will be necessitated.

Additionally, this will likely represent the first effort at matching a global standard for a vertical reference system in support of Johannes Idhe's efforts. It will also require some coordination through the IGFS to develop analysis centres located around the world – presumably in sites developing other regional geoids. These centres would analyze our data as we would, in turn, analyze theirs. The intent of this is to provide separate analysis centres much like those employed by IGS to analyze GNSS data.

Outlook

Funding for GRAV-D has begun in FY 10 (October 2010) and data has been collected over 11% of the country. Processing software is now in place to refine this data and start developing gravimetric geoid height models and analyzing the terrestrial gravity data sets. Presentations at the IUGG 2011 meeting will focus on comparing the aerogravity from GRAV-D with the combined GRACE/GOCE gravity model. The intent is to verify the quality of the spectral overlap. Theoretical improvements continue that will serve as the basis for future USA models. Canadian and other researchers will have access to this data to test their own theoretical approaches. NGA, USAID, and the World Bank are being sought as partners in this effort to help expand this project into a truly regional effort for a common North American Geoid to serve as a uniform vertical reference system for scientific and coastal/emergency management applications.
Future meetings are scheduled to discuss these results. The likely timeline for the activities will be beyond the end of the current four-year cycle and will necessitate a continuation of efforts in the future.

Website: http://www.ngs.noaa.gov/GEOID/NAG/NAG.html

Commission Project 2.3: African Geoid

Chair: Hussein Abd-Elmotaal (Egypt)

Primary Objectives

The African Geoid Project (AGP) is a project of Commission 2 of the International Association of Geodesy (IAG). The main goal of the African Geoid Project is to determine the most complete and precise geoid model for Africa that can be obtained from the available data sets. Secondary goals are to foster cooperation between African geodesists and to provide high-level training in geoid computation to African geodesists.

The objectives of the project are summarized as follows:

– Identifying and acquiring data sets - gravity anomalies, DTM's, GPS/levelling.

– Training of African geodesists in geoid computation.

– Merging and validating gravity data sets, producing homogenous gravity anomalies data set ready for geoid computation.

– Computing African geoid**.**

– Evaluating the computed geoid using GPS/levelling data.

Main activities (2007–2011)

This document presents the status report of IAG African Geoid Project (Commission Project 2.3) since 2007. During the period 2007–2011 the AGP established its terms of references, organized its membership structure and is currently working on the main objectives of the project. It is acknowledged that this report can only cover the main activities of the AGP as per information provided by its members and that there are likely more activities within as well as outside the AGP.

Merry (2007) has computed a new version of the African geoid. This version is seen as an update of the preliminary geoid model for African published in 2003 by Merry and members of the African Geoid Project.

Merry (2009a) has evaluated the recently published EGM08 geopotential model for Africa. Merry (2009b) has focussed on evaluating the EGM08 model with particular reference to Africa and Southern Africa. Evaluation of the EGM08 for Algeria has been investigated by Benahmed Daho (2009a, 2009b, 2010a). Abd-Elmotaal (2008b, 2009a) has evaluated the EGM08 model for Egypt.

Benahmed Daho et. al (2009) has focussed on study of the impact of the new GRACE derived Geopotential Model and SRTM data on the Geoid modelling in Algeria. A revised geoid model, incorporating the SRTM and GRACE data, for Algeria was computed. A new investigation on the choice of the tailored geopotential model in Algeria has been carried out by Benahmed Daho et. al (2008). Benahmed Daho (2010b) has made a precision assessment of the orthometric heights determination in Algeria by combining GPS and local geoid model.

Different models for corrector surfaces between the gravimetric and GPS/levelling geoids were evaluated and the best geopotential models were investigated for Algeria by Zeggai et. al (2008). Chandler and Merry (2010) have generated a geoid model for South Africa.

Abd-Elmotaal (2007a, 2007b, 2007c) has computed a set of reference geopotential models tailored to Egypt for better modelling of the Egyptian gravity field. These tailored geopotential models have been used for a recent geoid modelling in Egypt by Abd-Elmotaal (2008a). Kühtreiber and Abd-Elmotaal (2007) as well as Abd-Elmotaal and Kühtreiber (2007, 2008a) have carried out attempts towards the optimum combination of gravity field wavelengths in geoid computation using several approaches and modern techniques. Abd-Elmotaal and Kühtreiber (2008b) have implemented gravity interpolation in mountainous areas with high accuracy. Ulotu (2009) has computed a geoid model for Tanzania from sparse and varying gravity data density.

Abd-Elmotaal (2009b, 2010a) has created new DHM for Egypt having a finest resolution of 3"×3". Abd-Elmotaal (2009c, 2010b) has studied the effect of DHM resolution on geoid computation. Kühtreiber and Abd-Elmotaal (2009) have introduced the geoid as a transformation surface. Abd-Elmotaal and Kühtreiber (2010) have studied the effect of DHM resolution in computing the topographic-isostatic harmonic coefficients within window technique. Abd-Elmotaal (2011a) has compared a geoid for Egypt using FFT versus least-squares collocation. Abd-Elmotaal (2011b) studied the interpolation of gravity data in Egypt.

Future Activities

Abd-Elmotaal is going to make an official visit during summer of 2011 to the BGI in order to incorporate a better near-to-complete gravity data set for the African continent, aiming to better regional solution for the geoid of Africa.

Problems and Request

The African Geoid Project suffers from the lack of data (gravity, GPS/levelling and height). The great support of IAG is needed in collecting the required data sets. It can hardly be all done on a private basis. Physical meetings of the members of the project would help in solving the project problems and would definitely contribute to the quality of its outputs. IAG is thus kindly invited to support that action.

Membership Structure

The AGP's membership structure as of June 2009 is given below. No distinction between full and corresponding members has been made.

- Hussein Abd-Elmotaal (Egypt) – Chairman (abdelmotaal@lycos.com)
- Charles Merry (South Africa) – Past chairman (cmerry1@gmail.com)
- Addisu Hunegnaw (Ethiopia) (Addisu.Hunegnaw@ed.ac.uk)
- Adekugbe Joseph (Nigeria) (nigeria.ipost@skannet.com)
- Albert Mhlanga (Swaziland) (sgd@realnet.co.sz)
- Benahmed Daho (Algeria) (d_benahmed@hotmail.com)
- Chuku Dozie (Ethiopia)
- Francis Aduol (Kenya) (fwoaduol@uonbi.ac.ke)
- Francis Podmore (Zimbabwe) (podmore@science.uz.ac.zw)
- Godfrey Habana (Botswana) (ghabana@gov.bw)

- Hassan Fashir (Sudan) (fashir@lycos.com)
- Jose Almeirim (Mozambique) (jose.carvalho@tvcabo.co.mz)
- Joseph Awange (Kenya) (J.awange@curtin.edu.au, joseph.awange@gmail.com)
- Karim Owolabi (Namibia) (kowolabi@namibia.com.na)
- Ludwig Combrinck (South Africa) (ludwig@hartrao.ac.za)
- Peter Nsombo (Zambia) (pnsombo@eng.unza.zm)
- Prosper Ulotu (Tanzania) (pepulotu@gmail.com)
- Saburi John (Tanzania) (saburi@uclas.ac.tz)
- Solofo Rakotondraompiana (Madagascar) (sorako@syfed.refer.mg)
- Tsegaye Denboba (Ethiopia) (ema@telecom.net.et)

Publications

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Abd-Elmotaal, H. (2011b) On the Interpolation of Gravity Data in Egypt. 26th Annual meeting of the Egyptian Geophysical Society, Cairo, Egypt, March 15, 2011.

Abd-Elmotaal, H. and Kühtreiber, N. (2007) Modified Stokes' Kernel versus Window Technique: Comparison of Optimum Combination of Gravity Field Wavelengths in Geoid Computation. Proceedings of the 1st International Symposium of the International Gravity Field Service, Istanbul, Turkey, August 28 – September 1, 2006, Harita Dergisi, Özel Sayı, Vol. 18, 102–107.

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Commission Project 2.4: Antarctic Geoid

Chair: Mirko Scheinert (Germany)

Short Review

Adopted in 2003, it is the first time that within IAG a special group is dedicated to the determination of the gravity field in Antarctica. This should be done utilizing terrestrial and airborne methods to complement and to densify satellite data. Because of the region and its special conditions the collaboration extends beyond the field of geodesy – an interdisciplinary cooperation has been established, especially incorporating geophysics and glaciology. This is also reflected in the group membership (cf. below).

During the two four-year periods of AntGP being a Commission Project of IAG (2003-2011), a great step forward has been made concerning the establishment of cooperation and close linkages between the different scientific disciplines working in Antarctica. It is one of the main tasks of AntGP to improve the availability of gravity data in Antarctica. It is anticipated to finally deliver a suitable grid of terrestrial gravity data and of the regional geoid.

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. Within a number of IPY projects gravity observations have been carried out, mainly aerogravimetric surveys, but also terrestrial relative gravimetry or tidal gravimetry. Especially the following IPY projects should be mentioned: #67 "Origin, evolution and setting of the Gamburtsev subglacial highlands (AGAP)" – where a number of new results have been reported (e.g. Bell et al., 2011) –, #97 "Investigating the Cryospheric Evolution of the Central Antarctic Plate (ICECAP), and #185 "Polar Earth Observing Network (POLENET)".

A close linkage to the Scientific Committee on Antarctic Research (SCAR) was realized by M. Scheinert, who also chairs the project 3 "Physical Geodesy" of the SCAR Standing Scientific Group on Geosciences (SSG-GS), Expert Group on Geospatial Information and Geodesy (GIANT Geodetic Infrastructure in Antarctica).

With high relevance to AntGP the workshop "Aerogravimetry: Techology and Applications", was held in Dresden, June 4 and 5, 2009. A number of AntGP members actively took part in this workshop, which provided an excellent opportunity to exchange information and also to discuss the progress of AntGP.

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 survey campaigns, coordination is organized well in advance and on a broad international basis. Within AntGP, 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 gravimetry at coastal stations). The main goal is to finally deliver a suitable grid of terrestrial gravity data and of the regional geoid. A presentation dedicated to this topic will be given at the IUGG General Assembly 2011 in Melbourne.

With regard to new gravity surveys in Antarctica, aerogravimetry provides the most powerful tool to survey larger areas. In this context, airborne gravimetry forms a core observation technique within an ensemble of aerogeophysical instrumentation. In continuation of the IPY several projects are in progress which include aerogravimetry 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 (e.g. utilizing the German research aircraft HALO, cf. Scheinert et al., 2010).

Conferences and workshops play an important role to coordinate work between AntGP members and the diverse communities. In this respect, the following conferences shall be mentioned:

- 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 .

Selected conferences and workshops with participation of AntGP members

- IUGG General Assembly, Perugia, July 2 – 13, 2007.
- X International Symposium on Antarctic Earth Sciences, Santa Barbara, August 26 – 31, 2007.
- XXX SCAR Meeting and Open Science Conference (jointly with IASC), St. Petersburg, July 4 – 11, 2008.
- IAG Scientific Assembly, Buenos Aires, August 31 – September 04, 2009.
- International Workshop "Aerogravimetry: Technology and Applications", Dresden, June 4-5, 2009.
- XXXI SCAR Meeting and Open Science Conference, Buenos Aires, July 30 – August 08, 2010.
- 2nd International Symposium of the International Gravity Field Service (IGFS), Fairbanks, September 20 – 22, 2010.

Membership

(active members)

Mirko Scheinert (chair)	TU Dresden, Germany
Martine Amalvict	Université Strasbourg, France
Alessandro Capra	Universita di Modena a Reggio Emilia, Italy
Detlef Damaske	BGR Hannover, Germany
Reinhard Dietrich	TU Dresden, Germany
Fausto Ferraccioli	British Antarctic Survey
René Forsberg	Danish National Space Center
Larry Hothem	USGS, USA
Cheinway Hwang	National Chiao Tung University, Taiwan
Wilfried Jokat	AWI Bremerhaven, Germany
Gary Johnston	Geoscience Australia
A.H. William Kearsley	University of New South Wales, Australia
Steve Kenyon	National Geospatial-Intelligence Agency, USA
German L. Leitchenkov	VNIIOkeangeologia, Russia
Jaakko Mäkinen	Finnish Geodetic Institute, Finland
Kazuo Shibuya	NIPR, Japan
C.K. Shum	OSU Columbus, USA
Dag Solheim	Statens Kartverk, Norway
Michael Studinger	Lamont-Doherty Earth Observatory, USA

(corresponding members)

Graeme Blick	LINZ, New Zealand
Dave McAdoo	National Oceanic and Atmospheric Administration, USA

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Bell RE, Ferraccioli F, Creyts TT, Braaten D, Corr H, Das I, Damaske D, Frearson N, Jordan T, Rose K, Studinger M, Wolovick M (2011): Widespread Persistent Thickening of the East Antarctic Ice Sheet by Freezing from the Base, *Science Express*, published online 3 March 2011, doi: 10.1126/science.1200109

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Commission Project 2.5: Gravity and Geoid in South America (GGSA)

Chair: Maria Cristina Pacino (Argentina)
Co-Chair: Denizar Blitzkow (Brazil)

Primary Objectives

The project entitled Gravity and Geoid in South America, as part of the Commission II of IAG, was established as an attempt to coordinate efforts to establish a new Absolute Gravity Network in South America, to carry out gravity densification surveys, to derive a geoid model for the continent as part of the height reference and to support local organizations in the computation of detailed geoid models in different countries.
Besides, a strong effort is being carried out in several countries in order to improve the distribution of gravity information, to organize the gravity measurements in the continent and to validate the available gravity measurements.

Activities

Introduction

This report shows the many activities going on by different organizations like universities and research institutes. Due to the big efforts undertaken by the different organizations in the last few years to improve the gravity data coverage all over the countries there are available at the moment approximately 925,878 gravity data points in the continent, including Central America. Figure 1 shows gravity data distribution.

Geoid Model

A new version of the geoid model for South America (Geoid2010) was computed, limited by 15º N and 57º S in latitude and 30º W and 95º W in longitude. EGM2008 (Pavlis et al., 2008) up to degree and order 150 as the reference field was used. The reduced Helmert mean gravity anomalies were estimated in blocks of 5' for continental area. DNSC08 satellite altimetry model (Andersen *et al.*, 2008) was used for the Ocean. The digital terrain model SAM3s_v2 (Blitzkow *et al.*, 2008), with a grid size of 3" x 3" (~90m x 90m), was selected for computing the related quantities. The processing of the modified Stokes integral was carried out using FFT, as mentioned.

Evaluation of Geopotential Models

A total of 1,304 GPS points available on Bench Marks (GPS/BM) in South America and 85,018 mean free air gravity anomalies in a grid of 5' are used to evaluate the gravity field model EGM2008.

The global gravity models GO_CONS_GCF_2_DIR_R2 (degree and order 240; Bruinsma et al, 2010), GOCO01S (degree and order 224; Pail et al, 2010) and EIGEN 51C (degree and order 359; Bruinsma et al, 2010) are also evaluated.

The statistics of the differences between the tested geopotential models and GPS/BM show that the best agreement is obtained with EGM2008 (degree 2190 and order 2159) in South America.

The gravity disturbances derived from EGM2008 show the best agreement when compared with terrestrial gravity anomalies. Most of the still existing inconsistencies of this GGM are in mountainous regions, mainly in the Andes.

The general conclusion is that the recent geopotential models represent an important improvement on the knowledge of the gravitational potential in South America.

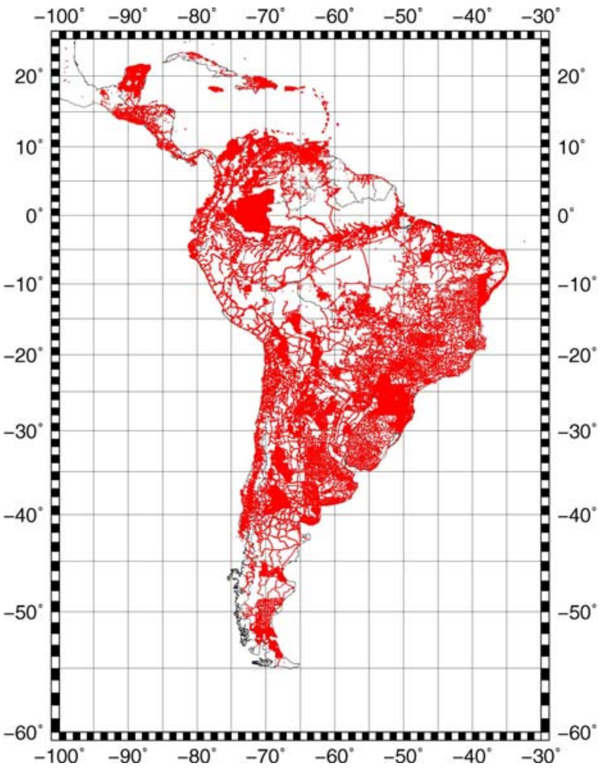

Figure l: South America gravity data

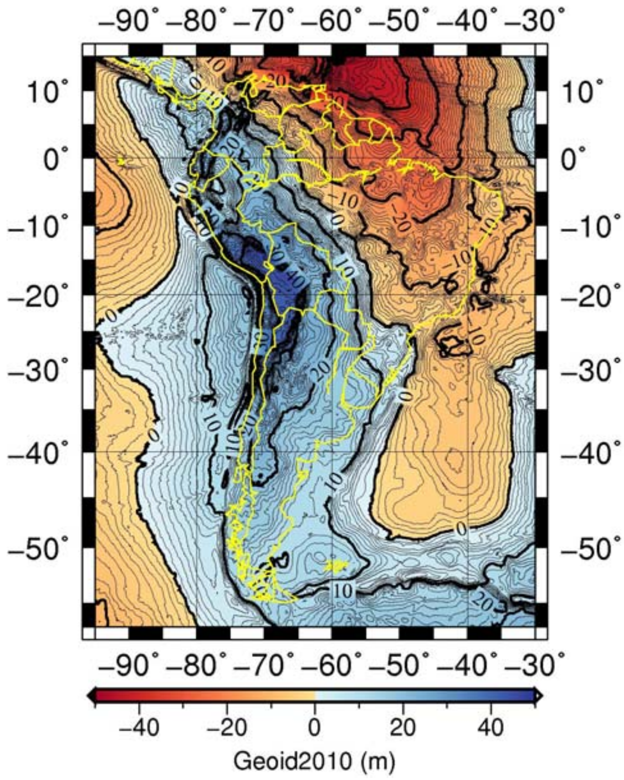

Figure 2: South America geoid model

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Commission Project 2.6: South Asian and Australian Geoid

Chair: A. H. W. Kearsley (Australia)

1. Primary Objectives

To promote cooperation in and knowledge of geoid and related studies in the region of South East Asia (including Australasia). This includes countries in or associated with ASEAN and other countries in the region including The Philippines, Papua New Guinea, Indonesia, Malaysia, Singapore, Brunei, Thailand, Vietnam, Cambodia, Laos and Myanmar, as well as Australia and New Zealand. Because of the synergy which exists between the objectives of this Committee and those of the Geodesy Working Group of the UN Permanent Committee for GIS Infrastructure for Asia and the Pacific (PCGIAP), it would appear logical to extend the borders of the subject region to those covered by this UN Committee which have geographical connections with the above countries.

Ideally, we should explore ways in which we may

(a) share available gravity data

(b) share available DEM's along common borders (e.g. between National Geodetic Authorities)

(c) combine resources for terrestrial gravity surveys along common borders

(d) combine resources for airborne gravity surveys in the region.

Clearly an important phase of this study is to identify and catalog the gravity that exists – including the recently observed airborne campaigns. It is also important to establish a protocol for sharing the data. However, national authorities are reluctant to give ***all*** the data available and at the precision available. It should be possible for geoid evaluation purposes, however, to decrease the resolution and accuracy of data shared along common borders without either comprising the precision of the geoid significantly, or the security of the national data shared.

We should also explore ways in which countries of the region may co-operate by

(a) sharing geometric (GPS/levelling) geoid control data

(b) combining efforts in regional GPS campaigns

(c) undertaking joint campaign for the inter-connection of National Height Datums (in such campaigns as these the activities of the PCGIAP group would be most relevant),

*and e*ncourage and sponsor, for the region,

(a) meetings and workshops, in co-operation with the International Geoid Service, (such as the IAG Workshop on Height Systems, Geoid & Gravity of the Asia Pacific held in Ulan Bataar, Mongolia in June, 2006) to foster understanding in the evaluation and use of gravimetric geoids, and in their application to heighting with GPS.

(b) technical sessions in scientific and professional conferences

(c) research into matters of common concern/interest.

Sadly, the above objectives have not been realised in any significant manner, due in part to the difficulty which exists between countries in the sharing of data of common interest. Indeed, any such outcome comes possibly indirectly through the GGM's, the most recent of which is EGM08. Obviously, even there the quality of data derived from this model depends largely upon the quality of the data supplied to the computing authority. As a result, the work done over the last few years has mainly been based upon individual national geoid studies, and a brief summary of these now follows.

2. Main activities (2007–2011)

No specific meetings have been held at the recent IAG events (e.g. IUGG 2007 at Perugia, Italy (2007), GGEO 2008 in Chania, Crete ot IAG Buenos Aires (August, 2009). However a number of papers and presentations were given which reflect the geoid-related research in this region over this period. These include investigations into the *Australian and New Zealand* Geoid and Height datums (Amos, 2007, Claessens et al, (2007), Featherstone (2007), Filmer (2007, 2011) , Kearsley et a l(2007)***;*** and *Indonesia* (Kasenda, 2009; Kasenda and Kearsley (2007).

The Indonesian Geoid workshop was held at Gadjah Mada University, Yogyakarta from 26 to 29 October, 2009. It was convened by Rene Forsberg, organised by Adolfientje Kasenda and Aris Sunantyo, and included the following. Jacob Rais: Geodesy in Indonesia, a historical overview[1] Bill Kearsley: An introduction to physical geodesy; Rene Forsberg: Geoid computations (FFT, GRAVSOFT package); A. Kasenda, R. Forsberg: GRAVSOFT computer exercises; Steve Kenyon: EGM08 development; Cecep Subarya: the Indonesian CORS network; and Arne Olesen: Airborne Gravimetry. It was well attended, with over forty from various parts of the industry attending.

3. Future Activities

As before, the SE Asian Geoid Commission needs to establish stronger links with both the Geodesy Sub-Committee of PCGIAP, now chaired by John Dawson, Geoscience Australia. [This group (PCGIAP) is made up of the main authorities which deal with national geoids and height datums in the region and beyond], and with the FIG Commission 5 (who also have a strong interest in these matters from the stand-point of operational geodesy). The on-going economic uncertainty is of course affecting much progress in research areas of science, in many of the subject countries, but the emerging issues of climate change and Sea Level Rise are giving some urgency to these studies.

4. Problems and Request

As has been stated above, the South East Asian Sub-Commission 2.6 suffers from the natural caution which exists between nation states in the region to share their data and resources. The support from IAG, as well as the abovementioned bodies, may help to overcome some of these

5. Membership Structure

The membership includes the chief Geodesists of all the National Geodetic and Mapping Agencies, as well as individual researchers.

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[1] On 29 March, 2011 we learnt the sad news that Jacub had passed away on the 28/3/2011. We have thus lost a very dear friend and colleague - a giant in the discipline of Geodesy in this region. Through his work and activities in research and collaboration, his legacy will remain with us for many generations.

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Study Group 2.1: Comparisons of Absolute Gravimeters

Chair: Leonid F. Vitushkin (BIPM, VNIIMsince 2010), Vojtech Pálinkáš (VUGTK) chair since 2011

The 4th Joint Meeting of the CCM Working Group on Gravimetry (CCM WGG) and Study Group on Comparisons of Absolute Gravimeters (SGCAG) was organized in St Petersburg at All-Russian D. I. Mendeleev Research Institute for Metrology (VNIIM) on 21 June 2010. The main topics of discussion were related to the current situation of International Comparisons of Absolute Gravimeters (ICAGs), where two important facts has to be taken into consideration: 1) the ICAG-2009 was at first time organized as CIPM (Comité International des Poids et Mesures) key comparison, 2) the BIPM decided to don't host the ICAGs in the future. At first glance, both actualities seem to be opposing, but generally it cannot be explained by such a way. The BIPM terminated just they local support for organizing ICAGs mainly due to economical aspects related with the ICAGs. The most important fact is the incessant support of the CCM and CIPM to continue ICAGs as key comparisons. Regarding to the organization of ICAGs in the future, there are already suggestions to host next ICAGs, namely the ICAG-2013 in Walferdange (Luxembourg), the ICAG-2017 in St Petersburg and the ICAG-2021 in China.

The current situation and the future of ICAGs and relevant Regional ICAGs (RICAGs) have been discussed within the IC-WG2.1 Working Group on Absolute Gravimetry (WGAG), SGCAG and CCM WGG. Chairmen of these groups prepared a letter, addressed to the member of groups and broad community dealing with absolute gravimetry. Among others an interesting idea were presented in the letter. Namely, the idea of worldwide distributed Regional Comparison Stations as important contribution to establishing an International Gravity Reference System. The parallel running superconducting gravimeters at such stations should play an important role for supporting of comparisons. The absolute gravity community was asked to propose their reference sites for RICAG comparison sites. About 20 positive answers have been received.

Actually, the new situation in ICAGs make possible to move ICAGs in step towards: 1) the activity regarding to the future organisation of ICAG showed a possibility to host an high-quality comparisons at many sites and also the huge interest of the metrology and geoscience community about ICAGs, 2) the ICAGs and mainly the RICAGs should help with distribution of comparison sites over the world, 3) the decentralized system of the sites for the comparisons of absolute gravimeters can be used as the basis for the real International Gravity Reference System, 4) the inclusion of superconducting gravimeters into the comparison allow to improve ICAGs and RICAGs due to the possibility to correct precisely the gravity variations (mainly due to hydrological and atmospherical effects) during comparison.

All these actual issues were discussed on the Meeting on Organization of Future Comparisons of Absolute Gravimeters held in Frankfurt in 28 February - 1 March 2011 with chairmen and few members of the three working groups CCM WGG, WGAG and SGCAG. The report of the meeting was distributed among the members of groups. The main results can be summarised to these points:

- The meeting proposed that the future CIPM KC and RMO KC be organized in compliance with the Mutual Recognition Arrangement rules,
- Participants in CIPM KC will be the NMIs (National Metrological Institutions), DIs (Designated Institutes) and all other laboratories having the highest technical competence

and experience, ensuring that all the principal and new techniques in the field are represented,

- Only the results from one gravimeter per country will contribute to the key comparison reference value (KCRV) evaluation. The selection of this representing gravimeter will be made prior to the comparison,
- The KCRV will be evaluated using the results issued by NMIs, DIs or by other laboratories in countries that do not have NMI or DI in the field of absolute gravimetry. In these cases the laboratories have to fully comply with the Technical Protocol Requirements,
- The meeting emphasized the importance of including the gravity sites for CCM KC and Regional KC of absolute gravimeters in the Global Absolute Gravity Reference Network. By doing so it was proposed to establish an International Gravity Reference System (IGRS) which can replace the outdated IGSN71.
- The meeting recommended that CCM WGG[1], IAG WGAG[2] and IAG SGCAG[3] renew the Requirements of the sites for regional comparisons of absolute gravimeters (document CCM-WGG-06-24) and, in particular, that they change the priority to equip those sites which will be used for CIPM KC with superconducting gravimeters from "desirable" (priority 2) to "mandatory" (priority 1).

[1] Consultative Committee on Mass and Related Quantities, Working Group on Absolute Gravimetry
[2] IAG Working Group on Absolute Gravimetry
[3] IAG Study Group on the Comparison of Absolute Gravimeters

Study Group 2.2: High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results

Chair: Michael Kuhn (Australia)

1. Primary Objectives

The IAG Study Group 2.2 (SG) focuses on the application of forward gravity modelling techniques for high-resolution gravity field recovery with the specific aim to assist in processing data from current and future satellite gravity missions. The SG focused mostly on the following topics:

- Derivation and analysis of the Earth's gravity field's high-resolution content on a local, regional and global scale.
- Provision of high-resolution gravity field corrections/reductions and anomalies to the geodetic and wider research community.
- Review of forward gravity modelling techniques in the space domain with particular view on fast algorithms not requiring considerable approximations.
- As an application the SG will also focus on the construction of high-resolution synthetic Earth gravity models (SEGMs) partly or completely based on forward gravity modelling.

2. Main activities (2007-11)

This document presents the status report of IAG Study Group 2.2 (SG) since its creation in 2007. During the 4-year period 2007-11 the SG established its terms of references, organized its membership structure, created an internet site, held three meetings and established a special focus topic on the assessment of space domain forward gravity modelling techniques (see primary objectives above). It is acknowledged that this report can only cover the main activities of the SG as per information provided by its members and that there are likely more related activities within as well as outside the SG.

2.1 Meetings

During the period covered the SG had three meetings during the following conferences:

1. IAG International Symposium Gravity, Geoid and Earth Observation 2008 (GGEO2008), Chania, Crete, Greece, June 23-27, 2008.
2. IAG Scientific Assembly, Geodesy for Planet Earth, Buenos Aires, August 31 - September 4, 2009.
3. Second International Symposium of the IGFS, Fairbanks, Alaska, September 20-22, 2010.

2.2 Study Group Webpage

A webpage of the SG has been created, which summarizes the group's activities and publications. The SG's webpage is available under: http://www.cage.curtin.edu.au/~218180B/IAG_SG22/2007-11/index.html.

2.3 Study Group's special focus:

The SG agreed during its meeting at the GGEO2008 conference to focus on the assessment of space-domain forward gravity modelling techniques/software with the particular view on both theory and practical determination (e.g. required computation time and accuracy). For this purpose the chair prepared a sample topography DEM data set (9-arc-sec by 9-arc-sec) over parts of Australia. The sample data as well as a description of the special focus can be downloaded from the SG's webpage (see link above). Furthermore, the provision of (global) forward gravity modelling results as well as meta-products for new satellite gravity mission results (e.g. spherical harmonic representation of gravitational effects) have been discussed. See also individual activities below.

2.4 Individual Activities

The material presented here has been compiled from information and feedback obtained from individual SG members.

Papp et al. (2009) tested an alternative technique for the precise determination of potential differences through the joint application of measured and synthetic gravity data. Results for a test bed with a very dense point density (~ 1 point/30 m corresponding to change points along a 4.3 km long levelling line) suggest modelling errors in the potential difference over a distance of 4 km are in the order of 10^{-3} mm expressed in terms of length unit.

Benedek (2009) studied the synthetic modelling of the gravitational field using analytical formulae of the gravitational potential of the polyhedron volume element and its first and second order derivatives. The analytical formulae were studied in terms of their numerical stability and computation time required for their evaluation. Subsequently, the polyhedron formulae were applied to synthetic modelling of the gravitational potential. This included the gravitational modelling of the crustal structure of the Carpathian – Pannonian region and the analysis of second order vertical derivatives at near-surface points as well as at the altitude of 250 km for the GOCE satellite (Benedek 2004 and Benedek and Papp 2009).

Kuhn et al. (2009) have computed complete (or refined) spherical Bouguer gravity anomalies for over 1 million land gravity observations of the Australian national gravity database. This involved the determination of spherical terrain corrections over the whole of Australia on a 9 arc-second grid (~250 m by ~250 m spatial resolution) from a global Newtonian integration using heights from version 2.1 of the GEODATA digital elevation model (DEM) over Australia and the GLOBE and JGP95E global DEMs outside Australia. Apart from a comparison of the spherical Bouguer gravity anomalies with the complete planar counterpart the study has shown that precise and high-resolution terrain effects can be evaluated via space-domain techniques over continental scales. A comprehensive study on the evaluation of precise terrain effects using high-resolution digital elevation models has been done by Tsoulis et al. (2009a). In this study the terrain effects are obtained by using prismatic and tesseroidal descriptions of the topographic masses. While, offering exact analytical formulations the prismatic method is usually applied in planar and spherical approximation the tesseroidal method can be used in spherical or ellipsoidal approximation. The study revealed that both methods provide results at the same level of accuracy with the tesseroidal method requiring significantly less computational effort.

Tsoulis et al (2009b) and Jamet et al. (2010) implemented and tested a numerically stable recursive algorithm which evaluates the potential harmonic coefficients of a constant density polyhedron. By improving previous methods the present contribution demonstrates an efficient numerical computation of these coefficients up to degree 60 when applied from simple tetrahedral simplices to more complicated triangulated shape models. The presented linear algorithm opens possibilities to practical applications especially in the frame of gravity field modelling and interpretation, e.g. in satellite gradiometry or terrestrial gravimetry.

Novák (2010a) studied the high resolution constituents of the Earth gravitational field as implied by DTM06, the digital terrain model (DTM) used for the construction of EGM08. The spherical harmonic coefficients of the global height functions have been evaluated numerically through high-degree spherical harmonic expansion in terms of the gravitational potentials of the Earth's atmosphere, ocean water (fluid masses below the geoid) and topographical masses (solid masses above the geoid). Analyzing the respective power spectra it has been shown that substantial parts of the topographical and sea water potentials are compensated by global isostasy.

Various studies on gravity field modelling have been conducted with particular aims on precise geoid modelling including forward gravity modelling results (Kühtreiber and Abd-Elmotaal 2007, Abd-Elmotaal 2008, Abd-Elmotaal and Kühtreiber 2007a, 2007b), the determination and use of gravity reductions, gravity anomalies and gravity disturbances (Novák 2007, Tenzer and Novák 2010a, Tenzer et al. 2008, 2011, Vajda et al. 2008a, 2008b, 2010) and the evaluation of newly released global geopotential models (Abd-Elmotaal 2007a, 2007b, 2009) and the direct modelling of the gravitational field using harmonic series (Novák 2010b). Flury and Rummel (2009) used forward modelling based on high-resolution (50m) DTM models to determine the difference between quasigeoid and geoid height reference surfaces. The study includes efficient methods for the computation of the gravitational potential of topographic masses from DTM grids. Results show that such high resolution is required to achieve mm to cm height accuracy. Various aspects including the use of forward gravity modelling results have been studies by Vajda et al. (2007) and Tenzer et al. (2009) in relation to gravity inversion.

Tsoulis and Kuhn (2007) provide an overview on the developments in synthetic Earth gravity models in view of the availability of high-resolution digital terrain and crustal databases of global coverage. The inclusion of topographic/isostatic compensation models in gravity recovery is discussed as well. Furthermore, the overview article provides information on global and regional synthetic Earth gravity models. Fellner et al. (2010) present a 3D mass optimisation algorithm suitable to create synthetic mass distributions that fit a given gravity field functional (e.g. geoid height or gravity). The procedure has been successfully applied to geoid modelling over Austria demonstrating its potential use in the construction of synthetic Earth Gravity Models solely based on forward gravity modelling of existing and synthetic mass distributions.

The European Space Agency (ESA) has developed a realistic mass transport model of the system Earth (http://esamultimedia.esa.int/docs/gsp/completed/C20403ExS.Pdf). Based on dynamic (mass) models for the atmosphere, oceans, cryosphere, continental water and the solid Earth synthetic gravity values have been derived through forward gravity modelling using spherical harmonic developments of the corresponding mass density functions.

3. Membership Structure

The SG's membership structure as of March 2011 is given below.

Michael Kuhn (Australia) (Chair)
Hussein Abd-Elmotaal (Egypt)
Ira Anjasmara (Australia)
Judit Benedek (Hungary)
Heiner Denker (Germany)
Will Featherstone (Australia)
Johannes Fellner (Australia)
Luciana Fenoglio-Marc (Germany)
Jakob Flury (Germany)
Thomas Gruber (Germany)
Michael Kern (The Netherlands)
Atef Makhaloof (Germany)
Pavel Novak (Czech Republic)
Spiros Pagiatakis (Canada)
Roland Pail (Germany)
Nikolaos Pavlis (USA)
Gabor Papp (Hungary)
Dan Roman (USA)
Gabriel Strykowski (Denmark)
Gyula Toth (Hungary)
Dimitris Tsoulis (Greece)
Yan Wang (USA)

Publications

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Inter-Commission Working Group 2.1: Absolute Gravimetry

Chair: Herbert Wilmes (Germany)

Overview

The Working Group on Absolute Gravimetry "WGAG" has been set up under the umbrella of the International Gravity Field Service[1] and the IAG Sub-Commission 2.1 Gravimetry and Gravity Networks. This working group cooperates with the "CIPM Consultative Committee on Mass and Related Quantities[2], Working Group on Gravimetry (CCM WGG)" and the "IAG Study Group 2.1 Comparisons of Absolute Gravimeters". CCM WGG is responsible for the organization of the four-yearly International Comparisons of Absolute Gravimeters.

Motivation

Absolute gravity measurements have increased in significance because new questions and application have arisen about the time-varying geophysical processes. This is underlined by a continuously growing number of absolute gravimeters and observations. Applications are to monitor, for example, mass transports in the system Earth or regional gravity changes and the comparison of these variations with time-dependent gravity field models derived with present-day satellite gravity field missions. IAG's Global Geodetic Observing System GGOS[3] encourages combining the observed absolute gravity values with geometric geodetic data like VLBI[4], SLR[5] and GNSS[6]. A combination of the different observation techniques requires agreed standards for observation and data processing.

Following three topics should be addressed in the description of the working group activities in the reporting period:

- The database for absolute gravity measurements,
- The continuation of the International Comparison of Absolute Gravimeters,
- The realisation of a new International Gravity Reference System.

The absolute gravity database AGrav

The growing number of AG instruments and absolute gravity measurements encouraged to build up a web-based database for absolute gravity data. This database developed at the Bundesamt für Kartographie und Geodäsie (BKG) is operated now together with the Bureau Gravimétrique International (BGI) and can be reached on two mirrored servers with addresses http://bgi.dtp.obs-mip.fr/ and http://agrav.bkg.bund.de/ respectively. This database improves the visibility and use of the AG observations. It supports cooperation in regional and global gravity projects, allows for synergy effects and improves the value of the existing networks and observations. Fig. 1 shows the appearance of the AGrav database with a graphical web interface.

[1] cf. IGFS – http://www.igfs.net/
[2] cf. CCM – http://www.bipm.org/en/committees/cc/ccm/
[3] cf. GGOS – http://www.ggos.org/
[4] cf. IVS – International VLBI Service for Geodesy and Astronomy http://ivscc.gsfc.nasa.gov/
[5] cf. ILRS – International Laser Ranging Service http://ilrs.gsfc.nasa.gov/
[6] cf. IGS – International GNSS Service http://igscb.jpl.nasa.gov/

Figure 1: Layout of the AGrav database web interface (status 2011)

The AGrav database informs about station location, observation epoch, instrument type and serial number, instrument owner and measurement results. Accordingly, the basic structure of the relational database is composed by four tables to store information about the stations, instruments, measurement epochs, and involved institutions, which are linked to each other. Other details like station descriptions can be stored in supplemental tables. In this way, storage of redundant information is avoided and a flexible adaption to future needs is possible.

A database query distinguishes between two basic features:

– The database can inform with meta-data about measurements and, where the details are available, about results, but with limited accuracy. This service is freely available without any access restrictions.

– The database can provide measurement results including all corrections and processing details. Here, restrictions are applied, access is granted only to those users, who have contributed own data.

In such a way it is possible to inform interested groups about the existence of the station and observations. On the other hand the database can support the data exchange and enable the projects with international contributions. In this way the database is not only very helpful for the cooperation between different groups, but would also serve as a safe permanent data repository. In any case, the user retains control over the own data, which means, later editing of the own submitted data is still possible at any time (Wilmes et al. 2009).

The international community of absolute gravimeter users in geodesy, geophysics and metrology has been asked to contribute to this database. The status of March 2011 is that data from 26 AG instruments, 419 AG stations and in total 1352 AG observations have been uploaded to the database. The database works as the official database of the International Association of Geodesy.

Continuation of the International Comparison of Absolute Gravimeters

In 2010 BIPM decided to close the support of future International Comparisons of Absolute Gravimeters (ICAG) in Sevres (Paris). And as these comparisons are seen as vital for the realization of a common metrological and geodetic standard for absolute gravimetry, the three involved working groups CCM WGG[1], WGAG[2] and SGCAG[3] started an initiative to continue the international comparisons in a new form of organization. A working meeting was held at the BKG in Frankfurt a.M. (Germany), 28 February to 1 March, 2011 on the continuation of the International Comparisons. The meeting participants agreed that the ICAGs should be continued on varying comparison sites. The plans are to hold comparisons 2013 in Walferdange (Luxembourg), 2017 at St. Petersburg, All-Russian D.I.Mendeleyev Research Institute for Metrology (Russian Federation) and in 2021at the National Institute of Metrology (China). To achieve consistency for worldwide applications it was agreed that except National Metrological Institutes (NMI) and Designated Institutions (DI) all other laboratories institutions from Geodesy and Geophysics having the highest technical competence and experience should be admitted to contribute to the ICAG Key Comparisons. Results shall be stored in the CIPM Key Comparison Database (KCDB). An important new feature is that the three working groups propose to include superconducting gravimeters at the comparison sites into the future AG comparisons.

Realisation of a new International Gravity Reference System

The calibration and standardization of AG measurements and evaluation are important conditions to build up a precise and consistent gravity reference system. It is proposed that a new International Gravity Reference System be built up which can replace the International Standardization Net 1971 (Morelli 1974). IGSN71 is still the valid gravity reference system of the IAG. Its accuracy is estimated with ±1 $\mu m/s^2$ (±100 µGal!) and therefore cannot cover the needs of observations with modern absolute gravimeters. This value shows the strong discrepancy between the realization of the gravity reference system and the much improved absolute gravimeters. The gap between gravity reference system and present-day instrument reaches almost two orders of magnitude.

The proposed new International Gravity Reference System (ITRS) should be based upon the future sites of the International and Regional Comparisons (ICAGs and RICAGs) together with all other stations where repeated AG measurements and continuous superconducting gravity observations are carried out. Such a reference network should be proposed to the IAG as the realisation of a precise reference system

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[1] CIPM Consultative Committee on Mass and Related Quantities, Working Group on Gravimetry
[2] IAG Working Group on Absolute Gravimetry
[3] IAG Study Group on Comparisons of Absolute Gravimeters

Inter-Commission Working Group 2.2: Evaluation of Global Earth Gravity Models

Chair: Jianliang Huang (Canada)
Vice-Chair: Christopher Kotsakis (Greece)

1. Terms of Reference

The CHAMP and GRACE satellite gravity missions, along with the upcoming GOCE mission, are and will be mapping the Earth's gravity field with significantly increasing accuracy and spatial resolution. The data obtained from these missions are being and will be used to develop a series of new static satellite-only gravity models down to 150 – 200 km wavelength, as well as combined Earth Gravity Models (EGMs) down to about 20 km wavelength. The evaluation of such global EGMs is commonly based on comparisons with other "external" data sets that depend on the same gravity field. The various centers responsible for the development of these models routinely perform such comparisons using a variety of validation data sets such as geoid heights from GPS and leveling heights, airborne and surface gravity measurements, marine geoid heights from mean oceanographic sea surface topography models and altimetry observations, orbits from other geodetic and altimetry satellites etc.

In response to the call of having an independent and coordinated initiative for the evaluation of the new EGMs, a new Joint Working Group (JWG) has been established between IGFS and the IAG Commission 2. The main objective of the JWG is to develop standard validation/calibration procedures, and to perform the quality assessment of GRACE-, CHAMP- and GOCE-based satellite-only and combined solutions for the static Earth's gravity field. The external data sets that will be used for such purposes include mainly GPS-leveling data, airborne and surface gravity data, mean oceanographic sea surface topography models and altimetry data, orbit data from other geodetic and altimetry satellites and astro-geodetic deflection data etc.

2. Evaluation of EGM08 model

The IGFS/IAG IC-WG 2.2 has successfully coordinated the evaluation of both PGM2007 and EGM2008, in close collaboration with the EGM development team from the U.S. National Geospatial-Intelligence Agency (NGA). This joint evaluation project was carried out through three phases: the implementation and testing of the NGA software for spherical harmonic synthesis using ultra-high degree geopotential models (2006-2007), the evaluation of the PGM2007 model (2007-2008), and finally the evaluation of the official EGM2008 model (2008-2009). Most of the results of the above tasks are publicly available at the official webpage of the working group: http://users.auth.gr/~kotsaki/IAG_JWG/IAG_JWG.html.

The first splinter meeting of the JWG was held on July 31, 2006 in Istanbul during the first IGFS international symposium, and it marked the end of Phase 1. The PGM2007A model was released to the members of the JWG in July 2007, initiating the beginning of Phase 2. A total of thirty evaluation reports for PGM2007A were completed and published at the JWG's website by December 2007. Phase 3 started right after the official release of EGM2008 at the EGU General Assembly in April 2008. The first results of the EGM2008 evaluation tests were presented by the working group members in a dedicated session during the IAG international symposium 'Geoid, Gravity and Earth Observation' that was held in Chania, Greece, June 23-27, 2008.

A dedicated special issue of Newton's Bulletin was published in 2009. It consists of 25 peer-reviewed evaluation papers of EGM2008 (and partially of PGM2007A), which are grouped into four different sections according to the geographical region of the evaluation tests: Global, the Americas, Europe and Africa, and Asia, Australia and Antarctica. Their results provide a thorough external assessment of EGM2008, using a variety of geodetic data and testing methodologies (see **Appendix A**). In addition, members of this working group have also published their evaluation results in other journals and conferences (see **Appendix B and C**). Some of these results are not included in Newton's Bulletin N. 4.

3. Evaluation of GRACE and GOCE models

The IGFS/IAG IC-WG 2.2 has been also involving in assessing satellite-only gravity models determined by GRACE and GOCE (see **Appendix B and C**). In the IGFS Advisory Committee meeting in Fairbanks, Alaska USA in September 2010, it was recommended that this working group should continue to evaluate the future GOCE gravity models after the IUGG Assembly in Melbourne in June/July 2011.

Appendix A

Contents of Newton's Bulletin N. 4

Foreword (J. Huang, C. Kotsakis)

Global

- Evaluation of the EGM08 gravity field by means of GPS-levelling and sea surface topography solutions (T. Gruber)
- Evaluation of the EGM2008 gravity model (M. K. Cheng, J. C. Ries, D. P. Chambers)
- Evaluation of EGM2008 by comparison with other recent global gravity field models (C. Förste, R. Stubenvoll, R. König, J-C Raimondo, F. Flechtner, F. Barthelmes, J. Kusche, C. Dahle, H. Neumayer, R. Biancale, J-M Lemoine, S. Bruinsma)
- Evaluation of EGM08 - globally, and locally in South Korea (C. Jekeli, H. J. Yang, J. H. Kwon)
- Results of EGM08 geopotential model testing and its comparison with EGM96 (M. Burša, S. Kenyon, J. Kouba, Z. Šíma, V. Vatrt, M. Vojtíšková)
- Evaluation of PGM2007A by comparison with globally and locally estimated gravity solutions from CHAMP(M. Weigelt, N. Sneeuw, W. Keller)

The Americas

- Evaluation of the GRACE-based global gravity models in Canada (J. Huang, M. Véronneau)
- EGM08 comparisons with GPS/leveling and limited aerogravity over the United States of America and its Territories (D. R. Roman, J. Saleh, Y. M. Wang, V. A. Childers, X. Li, and D. A. Smith)
- EGM2008 and PGM2007A evaluation for South America (D. Blitzkow, A. C. O. C. de Matos)
- Validation of the EGM08 over Argentina (M. C. Pacino, C. Tocho)

Europe and Africa

- Evaluation of EGM2008 and PGM2007A over Sweden (J. Ågren)
- Evaluation results of the Earth Gravitational Model EGM08 over the Baltic Countries (A. Ellmann, J. Kaminskis, E. Parseliunas, H. Jürgenson, T. Oja)

- Testing EGM2008 on leveling data from Scandinavia, adjacent Baltic areas, and Greenland (G. Strykowski, R. Forsberg)
- Testing EGM08 using Czech GPS/leveling data (P. Novák, J. Klokočník, J. Kostelecký, A. Zeman)
- Testing EGM2008 in the central Mediterranean area (R. Barzaghi, D. Carrion)
- Evaluation of EGM08 based on GPS and orthometric heights over the Hellenic mainland (C. Kotsakis, K. Katsambalos, M. Gianniou)
- Evaluation of the Earth Gravitational Model 2008 in Turkey (A. Kiliçoğlu, A. Direnç, M. Simav, O. Lenk, B. Aktuğ, H. Yildiz)
- Evaluation of the Earth gravity model EGM2008 in Algeria (S. A. Benahmed Daho)
- Evaluation of the EGM2008 geopotential model for Egypt (Hussein A. Abd-Elmotaal)
- EGM2008 evaluation for Africa (C. L. Merry)

Asia, Australia and Antarctica

- Is Australian data really validating EGM2008, or is EGM2008 just in/validating Australian data? (S. J. Claessens, W. E. Featherstone, I. M. Anjasmara, M. S. Filmer)
- Evaluation of the Earth Gravitational Model 2008 using GPS-leveling and gravity data in China (J. C. Li, J. S. Ning, D. B. Chao, W. P. Jiang)
- Gravity and geoid estimate in South India and their comparison with EGM08 (D. Carrion, N. Kumar, R. Barzaghi, A. P. Singh, B. Singh)
- Assessment of EGM2008 over Sri Lanka, an area where 'fill-in' data were used in EGM2008 (P. G. V Abeyratne, W. E. Featherstone, D. A. Tantrigoda)
- Evaluating EGM2008 over East Antarctica (P.J. Morgan and W. E. Featherstone)

Appendix B

Selected publication in other scientific journals and proceedings

Benahmed Daho S. A., Fairhead J.D., Zeggai A., Ghezali B., Derkaoui A., Gourine B., Khelifa S. (2008). A new investigation on the choice of the tailored geopotential model In Algeria. Journal of Geodynamics. doi:10.1016/j.jog.2007.10.002. Volume 45, Issues 2-3, pages 154-162

Blitzkow, Denizar, Matos, Ana Cristina Oliveira Cancoro De, Fairhead, J. D., Pacino, M. C., Lobianco, Maria Cristina Barbosa, Campos, Ilce de Oliveira (2010) The progress of the geoid model computation for South America under GRACE and EGM2008 models. INTERNATIONAL ASSOCIATION OF GEODESY SYMPOSIA

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Gruber, T.; The HPF Team; GOCE Gravity Field and Orbit Results - The HPF Experience; 4th GOCE User Workshop, Munich, Germany, 31.3.2011

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Commission 3 – Geodynamics and Earth Rotation

http://www.earthsciences.osu.edu/IAG-C3

President: Michael Bevis (USA)
Vice President: Richard Gross (USA)

Structure

Sub-commission 3.1:	Earth Rotation and Earth Tides
Sub-commission 3.2:	Tectonic Deformation
Sub-commission 3.3:	Geophysical Fluids
Sub-commission 3.4:	Cryospheric Change and Earth Deformation
IC Project 3.1:	Global Geodynamics Project (GGP)
IC Project 3.2:	Working Group of European Geoscientists for the Establishment of Networks for Earth Science Research (WEGENER)

Overview

The main innovations in the structure of Commission 3 were the generalization of terms of reference of Sub-commission 3.1, so that it now addresses Earth rotation as well as Earth tides, and initiation of an entirely new Sub-commission, 3.4, which focuses on Earth deformation associated with the changing loads imposed upon our planet by changes in the cryosphere. This latter topic might seem to be a subset of the subject area addressed by Sub-commission 3.3, which focuses on 'geofluids' and Earth's various responses to the mass fluxes associated with these fluids. However, in practice the geodesists studying glacial isostatic adjustment and also elastic adjustments near present-day ice sheets tend to have a rather different set of shared interests. Sub-commission 3.2 now focuses mainly on *tectonic* deformation, which nevertheless constitutes a very broad subject area.

Terms of Reference

Geodynamics in the broader and most traditional sense addresses the forces that act on the earth, whether they derive from outside or inside of our planet, and the way in which the earth moves and deforms in response to these forces. This includes the entire range of phenomena associated with Earth rotation and Earth orientation such as polar motion, length of day variation, precession and nutation, the observation and understanding of which are critical to the transformation between terrestrial and celestial reference frames. It also includes tidal processes such as solid Earth tides and ocean loading tides.

During the last few decades many geophysicists have come to use geodynamics in a more restricted sense to address processes such as plate tectonics and postglacial rebound that are dominantly endogenic processes. Because the Earth as a mechanical system responds to both endogenic and exogenic forces, and these responses are sometimes coupled, Commission 3 studies the entire range of physical processes associated with the motion and the deformation of the solid Earth. 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 Rotation and Earth Tides) addresses the entire range of Earth rotation phenomena including tidal deformation. Sub-commission 3.2 (Tectonic Deformation) addresses the entire range of tectonic phenomena including plate tectonics, intraplate deformation, the earthquake deformation cycle, a-seismic phenomena such as episodic tremor and slip, and volcanic deformation. Sub-commission 3.3 (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 Change and Earth 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 will study postglacial rebound at all spatial scales, and also the elastic deformation taking place in the near-field of existing ice sheets and glaciers.

The areas addressed by the various Sub-commissions sometimes overlap. Commission 3 also has overlapping interests with other entities within the IAG, and with Commissions in other Associations such as the International Astronomical Union (IAU). The recent space mission GRACE has expanded our common interests with IAG Commission 2 (Gravity) since temporal changes in gravity are associated with both the drivers of Earth deformation (e.g. changing ice and loads) and with Earth's response to these and other forcing.

Objectives

The objectives of Commission 3 are to develop cooperation and collaboration in computation, in theory, and in observation of geodynamics and Earth rotation, and to ensure development of research in these areas by organizing meetings, symposia, and general assemblies, by creating working groups on specific topics, and by encouraging exchange of ideas and data, comparisons of methods and results improving the accuracies, content, methods, theories, and understanding of geodynamics and Earth rotation. The Commission also serves the geophysical community by helping the IAG to link scientists to the official organization providing the International Reference Systems/Frames and Earth orientation parameters (IERS and related bodies), and organizations providing all the other data on which geodynamics and Earth rotation studies can be performed.

Activities

The activities of Commission 3 during the last quadrennial are given in detail in the Sub-commission reports given below. Other major activities of Commission 3 during 2007–2011 include:

– Participation in IAG's Global Geodetic Observing System (GGOS). Many of the members of Commission 3 are members of the GGOS Steering Committee and the GGOS Executive Committee.

– Participation in special workshops and conference sessions related to geodynamics and Earth rotation such as the Journées Systèmes de Références Spatio-temporels that were held in greater Paris (2007, 2010) and in Dresden (2008). Of special interest to Commission 3 during the past 4 years are the many great earthquakes and associated tsunamis that have occurred recently and their impact on geodynamics and Earth rotation. Sessions at major conferences have been dedicated to these topics.

– Strengthening the link between the Sub-commissions and Inter-commission Projects. A Symposium on "New Challenges in Earth Dynamics" was held in Jena, Germany in September 2008 that included broad participation by all components of Commission 3. Another symposium planned to be held in Egypt in 2012 is also expected to involve all of the Commission 3 components.

- Strengthening the link between Commission 3 and the IAG Services. The IAG Services provide the data and products needed to study geodynamics and Earth rotation and it is important that Commission 3 and the Services be closely linked to each other. This is being accomplished by Commission 3 members participating in GGOS and in the IERS Global Geophysical Fluids Center.
- Strengthening the tie between IAG Commission 3 and IAU Commission 19 (Rotation of the Earth). Discussions have been held with the President of IAU Commission 19 about the possibility of holding a joint workshop on Earth rotation like the joint GGOS/IAU workshop on "Observing and Understanding Earth Rotation" that was held in Shanghai, China during October 25–28, 2010.

Sub-Commission 3.1: Earth Rotation and Earth Tides

President: Gerhard Jentzsch (Germany)
Vice-President: Spiros Pagiatakis (Toronto)

During the IUGG General Assembly in Perugia, 2007, Gerhard Jentzsch was asked to continue his presidency. And again, Gerhard Jentzsch asked Spiros Patiatakis to act as Vice-President of this Sub-Commission. Since Olivier Francis did not want to continue as Secretary we decided that we would pass on without nominating a secretary.

1. Symposium on New Challenges in Earth Dynamics, including the 16th International Symposium on Earth Tides, together with the other two sub commissions

Because of the re-organisation the old 'Earth Tide Commission' was renamed and the scope was extended to 'Earth Rotation and Earth Tides'. The new definition and the development of the terms of reference covered the first months after the IUGG 2007.

A main task was the preparation of the 16th International Symposium on Earth Tides to be held in Jena in September 2008 together with the other Sub-Commissions of Commission 3 and including inter-commission projects and study groups. The symposium was a successful event: 116 colleagues from 24 countries took part. The motto of the symposium was "New Challenges in Earth Dynamics".

During the symposium, the Earth Tide Commission Medal was awarded to two well known colleagues:

Bernard Ducarme and Tadahiro Sato

The documents as well as the nominating essays written by Walter Zürn for Tadahiro Sato and David Crossley for Bernard Ducarme are published in volume 144 of the Bulletin d'Information Marées Terrestres. This was the third and last time this medal was awarded: The name of the commission has changed, and, thus, the name of the medal has to be changed as well (see below).

The proceedings were split up in two parts: The *first part* contains speeches, reports and organizational details as well as the resolutions and the more technical papers collected for the Bulletin d'Information Marées Terrestres (BIM); the first volume no. 144 was already published in December 2008, no. 145 followed in Dec. 2009, and no. 146 was available in Dec. 2010. The *second part* of the proceedings contains papers published by the Journal of Geodynamics: a special issue containing 40 papers was prepared by guest editors Jentzsch, Jahr, and Kroner. The special issue, Vol. 45, Nos. 3-5, appeared in Dec. 2009.

The resolutions approved at the end of the symposium touch different topics:

1. The Earth Tide Commission Medal should be renamed as *Paul Melchior Medal* to acknowledge first the fact that the Earth Tide Commission does not exist any more under this name. More important are the tremendous activities Paul Melchior put into the development of tidal research, especially his activities world-wide, to name this medal after him.
2. The next symposium to be held in Egypt in 2012 (invited by the National Research Institute for Astronomy and Geophysics) should also combine all sub-commissions and inter-commission committees.

3. One scientific point concerns the estimation of ocean tide models which often give the tide height only. Since also the angular momentum of tidal currents is needed to model tidal effects, in future beside tide heights also barotropic tidal currents should be taken into account.
4. Organisational points concern the Global Geodynamics Project (GGP): Its transition from an Inter-Commission project to an IAG Service should be discussed to prepare a proposal to be decided during the next IUGG (2011). Second, the running of the GGP data base should cover several tasks for the benefit of the community of users, like standardisation to 1-minute data, calibration history of the SGs, and providing corrected 1-minute data as well as the results of the tidal analyses to all users.

Following these resolutions, the family of Paul Melchior was asked to agree to name the medal after Paul Melchior – the answer was positive. Concerning the next symposium to be held in Egypt, invited by the National Research Institute for Astronomy and Geophysics (NRIAG), the negotiations were carried on. Prof. Dr. Khaled Zahran is the responsible scientist. The intention is to hold the meeting in Cairo, outside the period of high temperatures.

2. ICET and next meeting

Another task was the move of the International Center for Earth Tides to another place, because the Royal Observatory of Belgium did not agree to continue to host ICET after Bernard Ducarme's retirement at the end of 2007. After discussions with several potentially interested institutions, during the last meeting of Sub-Commission 3.1 in Perugia, 2007, it was decided to accept the offer of the University of French Polynesia, Tahiti, to host ICET; Jean-Pierre Barriot is the responsible scientist.

From Oct. 03 to 11, 2010, Jentzsch visited the new ICET in Tahiti to see the progress and to talk to the local staff. In all, the impression is promising, but there is still a lot to do until the previous standard is reached again. The problems concern the work with the data as well as the Bulletin (BIM), which appears now electronically with only a few printed copies.

In connection with ICET we also had to discuss the future of the GGP data base as an integral component of the IAG GGOS program: There exists a cooperation agreement between ICET and GFZ – Potsdam to host and maintain this data base within the GFZ/ISDC. But after some changes involved colleagues have some concerns about the future support. Therefore, during the last symposium Gerhard Jentzsch was asked to discuss the matter with the president of GFZ or the management board. Up to now several letters were written, but without any answer. Also before the IAG in Buenos Aires in 2009 there was no official answer to be reported during the splinter meeting of Sub-Commission 3.1.

On 30th of June, 2011, the Sub-Commission 3.1 will have a splinter meeting during the IUGG General Assembly in Melbourne. During this meeting a new president has to be elected; Jentzsch will not more be available due to retirement.

3. Working groups of SC3.1

The SC3.1 has three working groups which continued during the period 2005-2011:

- Earth Tides in Geodetic Space Techniques, co-chaired by H. Schuh and Wu Bin,
- Analysis of Environmental Data for the Interpretation of Gravity Measurements, chaired by C. Kroner,
- Precise Tidal Prediction, chaired by Y. Tamura.

4. Future work

The future work will have two main tasks:

1. First, we will have to support the new International Center to help to develop its new feature following modern needs and using the available digital and internet facilities. Here, we have to consider that Tahiti is quite far away and not so easy to reach like Brussels was. Further, new ICET has to develop research goals and, thus, gain experiences and to make them available to the community.
2. The second task is the next symposium: It will be the first symposium in Africa, and a small but quite active group in Cairo will be responsible (supported by the National Research Institute for Astronomy and Geophysics). With this symposium in Egypt we hope to advertise for research in geodynamics and long-period crustal dynamics, also in countries not so much involved up to now.

Further, we need a new president to be elected during the meeting in Melbourne, 2011.

Sub-Commission 3.2: Tectonic Deformation

President: Markku Poutanen (Finland)

Members of the board:

Markku Poutanen (Finland), President
Jeffrey Freymueller (USA), vice president
James Davis (USA), Cryospheric Change and Earth Deformation
Kosuke Heki (Japan), Asia-Pacific area coordinator
Janusz Sledzinski (Poland), Geodynamics of the Central Europe
Susanna Zerbini (Italy), WEGENER and GEO

Overview

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. This 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 spaceborn, 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.

One of the key issues nowadays is the definition and stability of global and regional reference frames. Tectonic deformations in all time and spatial scales as well as mass transfer will affect reference frames. The work done in SC3.2 will deal in information essential to the reference frames.

Events 2008-2011

Earth Tides Symposium

The Commission 3 of the IAG together with sub-commissions on Earth Tides (3.1), Crustal Deformation (3.2), Geophysical Fluids (3.3) and the Global Geodynamics Project (GGP) organized for the first time a joint meeting in Jena, Germany, September 1-5, 2008. It included the 16th International Symposium on Earth Tides. The assembly provided a unique opportunity to exchange new results and strategies to meet the current challenges of Earth's dynamics from different viewpoints. Subcommission 3.2 was responsible of plans and arrangements of one session, as well as arranging the review of papers in session submitted for the proceedings.

A special issue containing 40 papers was published in Journal of Geodynamics special issue, Vol. 45, Nos. 3-5, 2009. A non-reviewed publication containing speeches, reports and the technical papers appeared in the series of Bulletin d'Information Marées Terrestres 144, 145 and 146 in 2008-2010.

DynaQlim - GGOS workshop

The Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) and the International Lithosphere Program (ILP) Regional Co-ordination Committee DynaQlim organized a joint workshop "Understanding Glacial Isostatic Adjustment" in Espoo, Finland June 23-26, 2009. Local Organisers were the ILP National Committee, and DynaQlim, IAG Subcommission 3.2. Tectonic deformations, Finnish Geodetic Institute, Geological Survey of Finland, and University of Helsinki. The objective of the workshop was to review the current state of the science in modeling glacial isostatic adjustment, to review the use of geodetic measurements to both constrain and to test GIA models, to identify obstacles to improving GIA models, and to identify the improvements to the global geodetic observing system that are required to advance our understanding of glacial isostatic adjustment.

The major outcome of the workshop was a report summarizing the current state of the science, a description of future research directions, and a description of the future observations that are needed to improve our understanding of glacial isostatic adjustment. This summary was published in Gross, R., M. Poutanen (2009): Geodetic Observations of Glacial Isostatic Adjustment. EOS, Vol. 90, No. 41, p. 365. The proceedings will be published in the Physics and Chemistry of the Earth, in 2011.

Steering Committee meeting 2009

A meeting of the steering committee was arranged during the IAG Assembly in Buenos Aires, Sept. 2, 2009. Present: Markku Poutanen, Jeff Freymueller, Kosuke Heki and Janusz Sledzinski. Susanna Zerbini consulted.

1. Short report by MP about last year activities.
2. Janusz Sledzinski gave a report on Central European Initiative activity.
3. Discussion on ways to activate the work of the SC.

Based on the discussion in the SC meeting two tasks were initiated:

a) Attempt to co-organize a session in the IUGG General Assembly in Melbourne 2011 and arranging a special issue in a peer reviewed journal. There are now two SC3.2 related sessions in the Melbourne GA where SC3.2 members are as co-organizers:

   J-G04: Structure and Deformation of Plate Interiors.

   – Organiser: IAG
   – Co-sponsor: IASPEI, IAVCEI
   – Lead Convenor: John Dawson
   – Co-convenors: Sierd Cloetingh, Kevin Furlong, Markku Poutanen

J-G06: Tectonic Geodesy and Earthquakes

- Organiser: IAG
- Co-Sponsors: IASPEI
- Lead Convenors: David D. Jackson, Jeff Freymueller
- Co-Convenors: Valentin Mihkailov

b) Co-operation with IAG Working Group "Regional Dense Velocity Fields", chaired by Carine Bruyninx. There has been some preliminary discussion with MP and Carine Bruyninx about the idea, and it was agreed to continue discussion.

Permanent working group Geodynamics of the Central Europe

Permanent Working Group on '*Geodynamics of the Central Europe*', (reported by Janusz Sledzinski, Poland) has continued studies on geotectonic regions of Central Europe. Till 2008 the programme of activities was coincided and overlapped with actions performed by the Section C, Geodesy, of the WG Science and Technology of the Central European Initiative (CEI). In 2008 CEI has abolished. The formal membership list of the IAG WG includes 27 scientists from 12 European countries. The activities of the WG concentrated on the following subjects:

- European geodetic and geodynamic programmes:
  - CERGOP = Central Europe Regional Geodynamics Project;
  - CEGRN = (Central European GPS Reference Network) Consortium,
- Local geodynamic projects
  - subgroups of the CERGOP Study Group CSG.5 Geotectonic Analysis of the Region of Central Europe in the following regions:
    - Eastern Alps and the North and Eastern Adriatic Sea; Romania Plate; Pannonian Basin; Plitvice Lakes, Croatia; Tatra Mountains; Northern Carpathians; Balkan Peninsula.
- Cooperation of CEI Section C Geodesy and European Geosciences Union (EGU)

Future plans

A new president for SC3.2 will be elected during the GA in Melbourne.

One should seek ways to activate the work of subcommission in the framework defined by the Commission 3. Establishing regional working groups similar to WG in Central Europe may help in this. Close contacts with related groups outside IAG, like WEGENER (Working group of European Geoscientists for the Establishment of Networks for Earth science Research) and DynaQlim (Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas) will be continued.

Sub-Commission 3.3: Geophysical Fluids

President: *Aleksander Brzezinski (Poland)*
Vice-President: *Mike Thomas (Germany)*
Members: *David Salstein (USA) - Atmosphere*
Rui Ponte (USA) - Oceans
Richard D. Ray (USA) - Tides
Benjamin F. Chao (Taiwan) - Hydrology
Richard Peltier (Canada) - Mantle
Tim van Hoolst (Belgium) - Core
Erricos Pavlis (USA) - Gravity/Geocenter
Tonie van Dam (Luxembourg) - Loading

Terms of Reference

Charter

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

Objectives

The objective of the Sub-Commission is to serve the scientific community by supporting research and data analysis in areas related to variations in Earth rotation, gravitational field and geocenter caused by mass transport in the geophysical fluids, which include the atmosphere, ocean, continental water, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle.

– The Sub-Commission is aware that its objectives overlap with the objectives of the IAG Global Geodetic Observing System (GGOS) with its central theme "Global deformation and mass exchange processes in the Earth system" and the following areas of activities
– deformation due to the mass transfer between solid Earth, atmosphere, and hydrosphere including ice;
– quantification of angular momentum exchange and mass transfer.

Program of Activities

Sub-Commission 3.3 follows the program defined by Commission 3. In addition, SC 3.3 interacts with the sister organizations and services, particularly with the Global Geophysical Fluids Center (GGFC) of the International Earth Rotation and Reference Frames Service (IERS) and its components: three operational Special Bureaus - for the Atmosphere SBA, Oceans SBO, and Hydrology SBH, Special Bureau for combination products and the non-operational components. Due to the overlapping of the tasks, SC 3.3 should also have close contacts to the GGOS activities.

Report on Activities 2007-2011

The Sub-Commission 3.3 participated, together with the Sub-Commissions 3.1 "Earth Rotation and Earth Tides", 3.2 "Crustal Deformation", and the Inter-Commission Global Geodynamics Project (GGP), in organization of the Earth Tide Symposium 2008 "New Challenges in Earth's Dynamics" in Jena, Germany, 1-5 September 2008. This joint symposium was an important event strengthening interactions between these 3 Sub-Commissions and the GGP. The Organizing Committee of ETS2008 decided to continue the idea of joint symposium with the next ETS, to be held in Egypt.

Important exchanges of information at meetings during the period occurred at the IERS Workshops, 2007 in Sevres, France, and 2009 in Warsaw, Poland, at the conferences of the series Journées Systèmes de Référence Spatio-Temporels, 2007 in Meudon, France, 2008 in Dresden, Germany, and 2010 in Paris, France, at the American Geophysical Union meetings, and the European Geosciences Meeting, Vienna, where special sessions were held on "Observing and understanding Earth rotation variability and its geophysical excitation" (2008, 2009, 2010, 2011), "Geophysical models for the analysis of space-geodetic techniques" (2008) and "Geodetic observations: model advances and time series effects" (2009). We should also mention a Joint GGOS/IAU Science Workshop 2010 "Observing and understanding Earth rotation" in Shanghai, P.R. China.

There has been considerable development of the global circulation models of geophysical fluids in recent years. Progress has been attained in modelling the atmospheric circulation, examples being new reanalysis model ERA40 and an experimental model with hourly resolution (Salstein et al., 2008a). The IERS GGFC Special Bureau for the Atmosphere www.aer.com/scienceResearch/diag/sb.html continues its effort to provide atmospheric data relevant to the study of the Earth's variable rotation. The time series are updated on regular basis and are available in near-real time. The IERS GGFC Special Bureau for the Oceans http://euler.jpl.nasa.gov/sbo/ provide data relating to non-tidal changes in oceanic processes such as the global Ocean Angular Momentum (OAM) mass and motion terms. The OAM series based on the ECCO ocean global circulation model are updated up to the recent months and are available for users in two versions, derived by analysis with and without data assimilation. The user should be aware of the fact that the OAM series based on the model with data assimilation, which should be better than the standard series, in general, appear to be corrupted by the tidal effects which have not been removed perfectly form the satellite altimetry observations; see (Gross, 2009) for details. The IERS GGFC Special Bureau for the Hydrology www.csr.utexas.edu/research/ggfc/ provides data sets and numerical model results related to the changing distribution of water over the planet, especially over land. Other important data sets concerning the influence of geophysical fluids on the Earth's dynamics are provided by the GGFC http://geophy.uni.lu/ and its remaining components, Special Bureau for combination products and the non-operational components.

One important problem in estimation of the influence of external fluids, the atmosphere, the oceans and the land hydrology, on Earth rotation and other geodynamical phenomena is associated with the inconsistencies in the treatment of mass conservation problem in models of those components; see the report of Maik Thomas below for further details. The results obtained from the satellite Gravity Recovery and Climate Experiment (GRACE) are of crucial importance for solving this problem. This experiment measures changes of the Earth's gravity field with monthly time resolution. From the GRACE observations one can estimate the mass redistribution on the planet surface including contribution from the three components mentioned above. Some recent results comparing results using GRACE data and those based on outputs of the available models of geophysical fluids (e.g., Nastula et al., 2007; Brzezinski et al., 2009) are quite promising.

Below we present brief reports provided by the members of the Sub-Commission 3.3: by Maik Thomas – on the related research projects in Germany, concerning the modelling of the atmosphere (David Salstein), the oceans (Rui Ponte), and the gravity and geocenter (Erricos Pavlis).

Report on research concerning geophysical fluids (Maik Thomas, Germany)

In order to consistently represent mass transports in the global hydrological cycle and to estimate variations in global geodetic parameters due to water mass redistributions a model combination for the atmosphere-hydrosphere system has been established at the German Centre for Geosciences (GFZ). The model combination consists of the hydrological land surface discharge model (LSDM; Dill, 2008) and the ocean model for circulation and tides (OMCT). Both models are consistently forced with operational data from the European Center for Medium Weather Forecasts (ECMWF). The ECMWF-LSDM-OMCT model combination is running on a daily operational basis producing global mass variations and Earth rotation parameters in near real time (Dobslaw et al., 2010). These operational time series as well as short-term predictions for Earth rotation parameters based on ECMWF's forecasts are available via the corresponding sub-bureaus of the GGFC (Dill and Dobslaw, 2010).

In close cooperation with the German research unit "Earth rotation and global dynamic processes" an Earth system model for physically consistent simulations of atmospheric, oceanic and hydrological induced variations of Earth rotation, deformation and gravity field has been developed in a research project supported by DFG with participating German scientists from geodesy, meteorology and oceanography (Hense et al., 2009). The dynamical system model couples numerical models of the atmosphere, of ocean tides and circulation as well as of continental discharge considering consistent mass, energy and momentum fluxes between these near-surface subsystems of the Earth in order to allow for explanations and interpretations of geodetically observed variations of global parameters of the Earth.

Report on research concerning the atmosphere (David Salstein, USA)

During this period we continued the archives of the atmospheric angular momentum series at the IERS Special Bureau for the Atmosphere. We used GRACE and other gravity and hydrological data as information for excitations of polar motion by hydrology, supplementing the other geophysical fluids (Nastula et al., 2007). We examined the high frequency series from hourly fields using an experimental series from U.S. NASA (Salstein et al., 2007). We assessed the quality of data sets including the surface pressure for various geodetic applications, including surface pressure fields needed for the GRACE mission (Salstein et al., 2008). We analyzed the partition between the tropospheric and stratospheric angular momentum series, and found a negative correlation between the angular momentum in these two regions (Zhou et al., 2008). Lastly, we partitioned the regional excitations of polar motion, due to equatorial atmospheric angular momentum into their temporal bands, and discovered where the atmospheric impact has the greatest variability on polar motion. (Nastula et al., 2009).

Report on research concerning the ocean (Rui Ponte, USA)

Among the activities pursued in the period 2007-2011, we have continued to produce global estimates of the ocean circulation and mass fields need for calculation of ocean angular momentum (OAM) and related quantities, in collaboration with our ECCO partners (Wunsch et al., 2009). Other efforts were focused on evaluating the quality of available atmospheric pressure fields (Salstein et al., 2008) and including their effect on ocean circulation estimates (Ponte and Vinogradov, 2007), and on using GRACE data for assessing and improving the quality of OAM variables (Nastula et al., 2007; Ponte et al., 2007; Quinn and Ponte, 2008). A detailed discussion of the uncertainties associated with GRACE-derived ocean mass trends was provided by Quinn and Ponte (2010). Observations from GRACE also permitted a new study of how wind stress torques are balanced quickly by bottom pressure torques acting on bottom topography (Ponte and Quinn, 2009). Vinogradova et al. (2010) call attention to the importance of accounting for self-attraction and loading effects when determining the annual cycle in ocean bottom pressure. The potential for extracting information about the oceanic mass fields from observations of sea level was addressed in Vinogradova et al. (2007).

Report on research concerning the gravity/geocenter (Erricos Pavlis, USA)

My main contribution to SC 3.3 is in the development and maintenance of time series of "geocenter" variations with respect to each ITRF. A series is updated weekly with a new vector estimate referenced to the middle of the week, based on the analysis of LAGEOS 1 & 2 and ETALON 1 & 2 satellite laser ranging (SLR) data. We simultaneously solve for the second-degree terms of the gravitational field, so series of those harmonics are also available for the same time period. Up until a year ago the series were still with respect to ITRF2000. However, with the reanalysis of all SLR data since 1983 in view of the ITRF2008 project, a new series was obtained which is referenced to ITRF2005S (i.e. the version of ITRF2005 that has the correct scale).

Another area of contribution is the improved modeling of geodetic data used to monitor geophysical fluids and their motions. An area that required improved models for increased accuracy SLR analyses was that of the atmospheric delay modeling. The 1973 model used up until recently has now been replaced by a model that was derived in part to support the above activities and it has been adopted by the ILRS and IERS as the standard for optical wavelengths (Pavlis et al., 2008). Going further, we have now established an approach (Hulley and Pavlis, 2007) that utilizes meteorological fields to more accurately approximate the atmospheric delay with data beyond the observing SLR station and to account for horizontal atmospheric gradients.

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Sub-Commission 3.4: Cryospheric Change and Earth Deformation

President: James L. Davis
Vice-President: Detlef Wolf

Introduction

Subcommission 3.4 (Cryospheric Change and Earth Deformation) was started in 2007, and is intended to focus on those methods and techniques in Geodesy that focus on the deformational response of the Earth to changes in glacier mass balance. This area is thus an important component of the geodesy of the Earth system. Although, for consistency's sake, there is some minor overlap with other subcommissions, the focus on Earth deformation brings in a variety of geodetic observations and techniques, including ground- and space-based observations of global and regional deformation, gravity, sea level, and ice thickness.

The members' activities are a mixture of observational and theoretical, covering short-term (i.e., ongoing melting) and longer-term (i.e., glacial isostatic adjustment) solid-Earth response to cryospheric changes. (See also the Terms of Reference, below.) Members of the sub-commission include: J. Davis, R. Dietrich, P. Elósegui, H. Geirsson, E. Ivins, S. A. Khan, M. King, O. Kristiansen, G. A. Milne, I. Sasgen, D. Wolf, and X. Wu.

Terms of Reference

Past and present changes in the mass balance of the earth's glaciers and ice complexes induce present-day deformation of the solid earth on a range of spatial scales, from the very local to global. The earth's deformational response to cryospheric change is complex due to a number of factors, including: complexities in the viscoelastic structure of the earth; the spatial and temporal variability of the mass changes; and the interaction between the cryosphere and the ocean, which lead to a redistribution of cryospheric mass in a highly dynamic system. These complexities pose both observational and modeling challenges. The purpose of Sub-commission 3.4 is to promote, and where appropriate, to help coordinate research involving geodetic observation and modeling of earth deformation due to past and ongoing cryospheric changes, with emphasis on present-day deformation taking place in the near field of existing ice sheets and glaciers and the extent to which this deformation is a response to climate change.

Activities 2007–2011

GIA Observation and Modeling

The modeling of glacial isostatic adjustment (GIA) is becoming more complex as both the Earth models [e.g., Klemann et al., 2008; Simpson et al., 2010] and ice history [e.g., van den Berg et al., 2008; Milne et al., 2008] evolve. At the same time, new geodetic observations are acquired and new methods for extracting the geodetic information are being developed [e.g., Tamisiea et al., 2007; Pagli et al., 2007; Hill et al., 2008; Tamisiea et al., 2008]. Observations continue to be used to test and assess available GIA models [e.g., Khan et al., 2008; Groh et al., 2009; Sasgen, 2010].

Present-day mass glacier mass changes and GIA

One of the most difficult tasks facing us is the separation of present-day mass changes and GIA signals. During this period, the GRACE data set achieved much attention, and was used alone or in combination with ground-based data sets to study GIA or separate GIA from present-day effects [e.g., Boehm et al, 2008; Dietrich et al., 2008; Ivins and Wu, 2008; Ivins et al., 2008; Sasgen et al, 2007a; Sasgen et al, 2007b; Sasgen et al, 2008]. In fact, joint inversion studies seem to be generally on the increase [e.g., Tamisiea et al., 2007; Sasgen et al., 2007b, 2008; Dietrich et al., 2008; Hill et al., 2008, 2010; Wu et al., 2009, 2010a,b; Ivins et al, 2010a; Wu, 2010], reflecting the need to disentangle the signatures of GIA from present-day mass change effects. Importantly, relevant ground-based data sets continue to improve [e.g., Dietrich et al., 2008; Groh et al., 2009; Lidberg et al., 2007, 2009, 2010; Milne et al., 2008; King et al., 2009; Scherneck et al., 2010; Whitehouse et al., 2010]. Several sub-commission 3 members published or edited reviews on the topic [King et al., 2010; Wolf et al., 2010].

Deformation due to present-day glacier melting

Ground-based observations on regional or local scales presented us with new specific information on the mass balance of glaciers and how they are impacted by the climate [e.g., Árnadóttir et al., 2008; Khan et al., 2007; Khan et al., 2008; Pagli et al., 2007]. Of great importance is the POLENET project [Wiens et al., 2007]. Now called A-NET (Antarctic network), the network consists of 40 GNSS sites in Antarctica. Its "antipodal sister" is G-NET, consisting now of 46 GNSS sites. Data from these networks are being used to measure solid-Earth deformation in response to melting on seasonal [Bevis et al., 2009a; Kendrick et al., 2010] and longer [e.g., Kahn et al., 2007; Pagli et al., 2007; Bevis et al., 2009b; van Dam et al., 2010; Kahn et al., 2010a, b, c].

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Inter-Commission Project 3.1: Global Geodynamics Project (GGP)

Chairman: David Crossley (USA)
Secretary: Jacques Hinderer (France)

Overview

GGP is listed only under Commission 3 Structure, but it is a Joint Project of Commissions 3 and 2; this report is therefore sent to both Commissions.

1. Introduction

Our report was prepared with knowledge of the report of Gerhard Jentzsch, President of Sub-Commission 3.1 - Earth Rotation and Earth Tides, to the IAG. We thank Gerhard for his remarks that covered several topics involving GGP, thus enabling us to reduce duplication here. Gerhard notes that changes to the IAG structure in 2007 have impacted the functioning of the former Earth Tide Commission (ETC), the International Centre for Earth Tides (ICET), and also GGP.

After the last IUGG Assembly in Perugia 2007, the main task given to GGP was to plan a transition from an Inter-Commission project to an IAG Service, and to prepare a proposal for adoption at the IUGG in 2011. Some progress was achieved on this task up to the IAG meeting in Buenos Aires (2009), with positive encouragement from within IAG. Unfortunately momentum has been lost in the last two years due to issues arising from the move of ICET from the Royal Observatory of Belgium (ROB) in Brussels to the University of French Polynesia (UPF) in Tahiti.

GGP originally (in 1997) chose the database at ICET in Brussels as the vehicle for storing and processing superconducting gravimeter (SG) worldwide data. Through an arrangement between ROB and GFZ (Potsdam), the latter organization became the physical location of the database, but ICET at ROB was the responsible gateway. This arrangement worked well until the retirement of B. Ducarme from ROB (end of 2007), after which ICET was moved to UPF under the Directorship of J.-P. Barriot (see the report of G. Jentzsch).

2. The actual situation for GGP

Before going further, it is appropriate to remind all GGP members, and IAG, that the organization of GGP is skeletal. It consists of a Chair (D, Crossley) and a Secretary (J. Hinderer). There is no other structure – no secretaries, no technical help, and no students dedicated to GGP tasks. We like to think GGP has achieved many things in the past 14 years; if so its success has been due to two factors:

a) the willingness of the various SG groups to send data to ICET on a regular basis. In the early years of GGP, there was extensive discussion of the structure of GGP data, the standards for the data, and the frequency with which it should be made available to other scientists. In 2011 times have changed, and with many new SG users joining the community, some with no background in tidal gravimetry. There are also new requests for quicker release of SG data, so some of the original agreements need to be revisited.

b) the willingness of some organizations to host GGP Workshops, either stand-alone, or as part of meetings such as the Earth Tides Symposia. Examples (not exhaustive) are the ROB (ICET) in Brussels (Melchior/Ducarme/Francis), the University of Jena (Jentzsch /

Kroner), Japanese institutions in Mizusawa and Kyoto (Sato / Tamura / Takemoto), and the Hsinchu SG group in Taiwan (Hwang). Their organizational effort has provided the structure upon which GGP has met and discussed SG data.

The tasks that GGP *can do* are limited to: maintaining the GGP website, planning and scheduling (not frequently even organizing) GGP meetings and workshops, reviewing the statistics of the SG stations sending data to the GGP database, and promoting the use of SG data in the community (e.g. through GGOS meetings) towards achieving various scientific goals.

The tasks that GGP *cannot do*, on a regular basis, are the processing and correction of GGP data from ICET (except for special in-house projects), moderating the interaction between the SG groups and the GFZ database, responding to community demands for help in tidal processing, and doing regular tidal analysis to check the quality of all GGP data. Until 2007 most of these tasks were done by ICET in Brussels.

3. GGP events 2007-2011

As covered in Jentzsch's report, many GGP papers were presented as part of the 16'th International Symposium on Earth Tides in Jena in 2008, the proceedings of which can be found in the Bulletin d'Information Marées Tèrrestre (BIM) on the GGP website http://www.eas.slu.edu/GGP/BIM_recent_issues. Issues 144-146 contain the formalities and papers from the symposium; BIM issues are also available through ICET at http://www.bim-icet.org. Other papers were published in the Journal of Geodynamics (volume 48, 2009). A full report of GGP Business is available through GGP Newsletters #19 and 19a, available at http://www.eas.slu.edu/GGP/ggpnews.html.

A Second Asian SG Workshop was organized in Taiwan by Cheinway Hwang and colleagues in June 2010, and a full report of covering that meeting is contained in Newsletter #20 (available as above). A number of papers from that meeting can be found at http://space.cv.nctu.edu.tw/SG2/programs.html.

GGP Business Meetings and discussions were held at the EGU Meetings from 2008-2010. In 2010 an EGU Session G9.2 "Mass transport involving ground gravity and deformation observations" was organized by C. Kroner and GGP to highlight oral papers on the topic of ground gravity and deformation measurements. We thank C. Kroner for also giving several review talks of GGP science, for example at the 2nd IGFS Meeting in Fairbanks, Alaska, October 2010, and similarly to J.-P. Boy for giving a GGP overview at the AGU Fall meeting in December 2010.

We should not forget the introduction of the new iGrav SG by GWR Instruments (San Diego, CA), the only SG supplier. With almost the same performance as the Observatory instrument (OSG) in a smaller package, it promises to be a popular instrument, due to transportability.

4. Status of the GGP database

As of March 27, 2011, the ICET database contained the following data from stations operating since 2007. The stations are divided into 3 categories.

a) First generation stations – those operational before the official start of GGP (97/7/1). Most stations still operating have kept up to date with sending their data (WU, ST, WE, and CA). Esashi SG stopped at the end of 2008 and was moved to Mizusawa.

b) Second generation stations – those started during the first GGP campaign (97-03). Almost all of these stations have operated well (CB, MB, MC, ME, BH, MO, NY, and SU) with the data almost up to date. We have no data from Matsushiro (MA), and station Tigo Concepcion (TC) had some troubles due to the Chile earthquake in 2010. The SG at Vienna has been moved to the Conrad Observatory (Austria) and was restarted in 2009.

c) Third generation stations – newer stations since 2007. Only 3 of these (HS, PE, and KA) have sent any appreciable amount of data. MunGyung (MG) stopped in 2010 but we never received the previous data. We are waiting on data from AP, BF, CO, DJ, WA, WG, and GE. We hope by the time of the IUGG (June 2011), that at least some of these stations will have responded.

ICET (Ducarme/Barriot) have been processing and correcting 1 minute data covering the period 2007/1/1 – present. This is available at the ICET/GFZ site http://ggp.gfz-potsdam.de/

5. GGP and ICET

In order for GGP to become an IAG service, it was essential that several tasks be organized in a solid and responsible manner for the benefit of IAG, and particularly GGOS as the umbrella project for geodetic and gravity data.

These tasks were identified by Jentzsch as the standardization of 1-minute data, the correction of 1 minute data by ICET, the provision of a calibration history for all the gravimeters within GGP, and the provision of annual tidal analyses of the GGP data by ICET. It was also recognized that the SG data flow had peaked in the early 2000s and some of the new SG stations were unfamiliar with high precision gravity data and their processing. For a number of reasons, the percentage of SG data being sent to ICET has declined in the last few years, despite the efforts of GGP to assist new groups in sending the data to GFZ. As indicated in section 4, it is the newer stations that (as a group) have sent the least data.

GGP data has always been sent directly to GFZ. As indicated above, prior to 2007 other aspects of the GGP data were handled by ICET. Since 2007, and until early 2010, there had been no correction of GGP data by ICET. The automatic program envisaged and presented by J.-P. Barriot in 2007 to do this task has not yet been released to GGP.

The raw 1 minute decimated data usually sent to GFZ includes spikes, disturbances and offsets, which if left in the data renders it unsuitable for tidal analysis. ROB removed these disturbances in a semi-manual way (using TSOFT) and put the processed data on the GFZ website as 'corrected 1-minute data'. ICET at ROB provided a regular tidal analysis of all stations using the corrected 1 minute data as a means of checking the quality of each SG and site. These reports were presented and published at various SG meetings.

In 2010 B. Ducarme resumed the responsibility of correcting the GGP data at ICET in the same manner as prior to 2007. At the 2nd Asian SG Meeting in Taiwan, the ICET report by B. Ducarme and J.-P. Barriot (*attached at the end of this report*) was presented showing a report of tidal analysis of stations that had sent data to ICET. This is a valuable task, as it enables a local tidal model to be used at each station to remove solid Earth and ocean tides from any data set.

If stations do not send 1 minute data to ICET, then their data will not be corrected by this procedure, and the tidal analysis cannot be done. Ducarme (personal communication) has indicated that such analyses will continue at least up to the IUGG meeting in Melbourne (June

2011). J.-P. Barriot detached one technician of his staff who is now able, after training in Brussels, to do the correction of the 1 minute data. However this additional support could be reduced in the future due to the lack of corresponding financial support and it will be necessary then to revisit the ICET commitments.

A smaller, but valuable, role of ICET was as a centre of tidal expertise for those scientists wishing to do tidal analysis, or ocean tide loading, as part of other studies. Frequently scientists were invited to ROB to learn tidal analysis for themselves. Such a service was never envisaged at UPF, (despite the desire of many scientists clamouring to go to Tahiti for such help). GGP has tried to respond to email requests for tidal services, but there have not been the resources to do this in every case. We have always recognized the manpower situation in Tahiti, but the situation with ICET needs resolving to better serve GGP, GGOS, and the scientific community.

6. GGP and GFZ

The GGP database at GFZ also needs some attention. Traditional data uploading and downloading functions are still working well, with most GGP users using the older ICET-oriented portal at GFZ, rather than the newer ISDC portal. Some inconsistencies exists between theses databases. Again the response time of GFZ to GGP inquiries is not always ideal, but the continued involvement of Bernd Ritschel in assisting GGP is much appreciated. G. Jentzsch has also made references to this point, and the lack of response from inquiries to GFZ.

There has been some discussion that a new home for the GGP database could be found within an organization that is able to handle this increasing volume of worldwide gravity data. The recent organization of the absolute gravity database (AGRAV) suggests a potential direction.

7. A seismological view of GGP

Our seismology colleagues are interested in SG data for some purposes (e.g. the Slichter triplet detection). It is instructive to read some remarks from a document online originating from UC Berekely:
"SG data has played a key role in the study of the Slichter mode, but the disadvantages of these instruments are also apparent: (1) Since SGs are very expensive and have strict site condition requirements, they are still sparsely distributed globally; (2) Only a small part of SG data are directly shared on-line, and these data always have a delay of 6 months; (3) the SG data format is not used by seismologists, and the transfer function is not always known. Compared with SGs, STS-1 seismometers also have good performance at ultra low frequency and the wide distribution of the STS-1 makes it an optimal instrument for global stacking. Also, the transfer functions are well known. For these reasons, we are trying to develop a standard procedure to search for the Slichter mode using STS-1 data."

8. Prospects and Challenges

The future of the relationships between GGP, ICET, and GFZ seems fluid. Despite the continued cooperation between B. Ducarme and J,-P. Barriot to ensure ICET a success in Tahiti, there are uncertainties about this direction. Without the full services of ICET, our report remains incomplete, and reduces the prospect of GGP as an IAG Service.

GGP discussion has centered on the following issues:

1) We need to work with the newer stations to increase the geographical coverage of GGP data in the GGP database - for example Onsala (Sweden), Schiltach (Black Forest), GETOC (Wuhan), Lhasa (China), Yebes (Spain), and Apache Point (New Mexico).
2) The current delay in stations sending data to GGP, even delays of only a few months, is a major hindrance to the better and more widespread use of the data. We need to address this topic more urgently and try to get data released immediately it is sent to the GFZ database at the end of each month.
3) More stations should be encouraged (and shown how) to send their raw data directly to IRIS. This has been a long time without finalization. Only Membach and Strasbourg do this regularly.
4) Some GGP members are suggesting a modernized data base with the daily provision of raw data (much like a gravity version of IRIS). This could be monitored for quality control.
5) There have been efforts to work more closely with the AG community with respect to the intercomparisons of AG instruments. GGP has recently completed a survey of possible SG sites where AGs can be regularly sited for a variety of studies.
6) To be an IAG service, GGP needs to deliver a reliable product. The 1 second data probably should go to IRIS (as above). The 1 minute data needs correcting for tidal analysis (ICET, as above). Perhaps GGP could provide a processing of the data for longer term studies (e.g. hydrology, tectonics, polar motion), but this would require a somewhat different kind of processing than regularly done at ICET. The lack of manpower is a major problem.

Considering all these points, GGP will present a proposal to IAG at the IUGG in Melbourne that hopefully will address some of these points.

GGP Data Preprocessing and Analysis Status at ICET

B. Ducarme and J.-P. Barriot

The last update of the GGP data had been made before the last Earth Tides symposium in 2008. The new revision gave the opportunity to process in most of the stations two years of additional data. We welcome the contribution of Hsinchu (HS) and Pecny (PE), who joined recently GGP. A total of 433 months (n in Table 1) from 14 stations have been processed since the beginning of 2010. These stations are marked in blue. Perhaps additional data have been uploaded since our processing as the data base is permanently in evolution. Stations marked in red are late in uploading their raw data. Four stations operated by the Japanese group (CB, ES, KA, NY) did not upload raw data since 2007. MA and TC stopped sending data after 2008/06. The instruments marked with a star are no more operated.

The new data have been analyzed and the results carefully compared with the previous tidal analysis results when available. The responsibles of the 14 reprocessed stations received a report of our investigations. Global tidal analyses have been processed. 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).The number of days used for the global analysis N and the standard deviation STD computed with ETERNA (ANALYZE) are given in Table 1. As the stability of the sensitivity of the superconducting gravimeters is generally better than 0.1%, the STD is a measure of the signal to noise ratio in the station. For 9 stations among the 14 updated ones the STD is lower than 1nm/s^2.

Status of the processed stations

BH: In Bad Homburg the new SG044 is operational for more than 900 days. The STD of this instrument is one of the lowest among all the GGP stations. The new SG C044 is perfectly fitting the results of the CD030-L. There is a slight calibration difference, close to 0.1%, between CD030-L and CD030-H.The phase differences of the different instruments agree within the associated RMS errors.

CA: Cantley started in 1989. It is the longest series of observations. It suffered from technical problem and the STD was multiplied by a factor of two during several months in 2006/2007. This portion of the data was rejected from the global analysis. The change of electronics on January 22 2008 did not affect the calibration. The amplitude factors agree perfectly. The new time lag of 16.3s applied since that epoch provides phases which seem a bit too large compared to previous results. If a precise determination of the true time lag is obtained it will be possible to normalize the data prior to 2008/01/22 to get homogeneous results.

HS: Hsinchu is a new station which has a large STD. The modelling of the tidal factors using recent ocean tides models is questionable as it provides ratios δ_{obs} /δ_{mod} close to 1.01 in the diurnal band and close to 0.995 in the semi-diurnal band. The misfit is thus not related to calibration.

MA: Matsushiro remained a good station and the two last years of data are in perfect agreement with previous data.

MB: Membach continued to run very well as usual. From It is interesting to note a more or less continuous drift of sensitivity of the order of 0.03% to 0.04% between 1998 and 2009.

This variation could probably not be detected by calibration. It confirms that the stability of the superconducting gravimeters is better than 0.1%.

MC : The end of Medicina is a bit noisier than usual. After the change of electronics on 2007/06/12 the calibration factor was modified as well as the time lag. The new time lag of 11.1s is good as the phase lag on M2 is not modified. However a large jump of the amplitude factors of the order of 0.4% is appearing, while the ratio of the new and old calibrations is 1.0043. It is clear that the sensitivity of the voltage output has not been modified. It is the new calibration value which seems questionable as the results obtained with the previous calibration were fitting very well the other GGP stations in Europe as shown in Ducarme et al., 2009.

ME: Metsahovi is also a station which started well before 1997. A comparison of 5 successive analyses covering each 2 years between 2000 and 2009 has shown no shift of sensitivity at the level of 0.05%. The registration prior to the GGP period is in agreement with the GGP data within 0.1%. An adjustment factor of 0.9996 could be introduced for a better fit.
MO: Moxa is an excellent station with very low STD.

PE: Pecny is a new station with exceptionally low STD.. The 1000 registration days provide the same tidal factors as the 6 years of excellent results with the modified ASK228 but the RMS errors on the tidal factors are already lower.

ST: Strasbourg remains an excellent station even if January and December 2009 are perturbed.

SU: In Sutherland the dual sphere instrument was replaced by SG052 after July 2008. The RMS error on the unit weight of the new SG C052 is better than the RMS error of the CD instrument. There was no difference in the tidal factors between CD037-L and CD037-H.
The provisional calibration of the new SG C052 seems to be very slightly too large compared to both components of CD037, but the series of the new instrument is still too short to draw firm conclusions.

TC: Only 7 additional months have been processed in Tigo and there is no special remark.

WE: The dual sphere instrument of Wettzell is excellent. After the change of electronics on April 17, 2007 new calibration values and new time lags have been determined. The amplitude factors δ and the phase differences α of the L and H sensors are now in perfect agreement. In the previous series there was a difference in the δ values between L and H sensors at the level of 0°05%, while the phase differences were in agreement within the associated RMS errors.. It should be noticed that the amplitude factors are now increased by more than 0.1% with respect to the previous values. It confirms the conclusions of Ducarme et al., 2009 based on the previous results. The authors showed that, after tidal loading corrections, the δ_c values for O1 and M2 at Wettzell were 0.1% lower than the mean of 15 European stations. To get homogeneous results it should be necessary to apply a normalisation factor 1.0017 on the previous series of channel L and 1.0012 on channel H.

WU: Wuhan station remains in good shape since its repair at the beginning of 2005. Due to the failure two years of data have been eliminated from the global analysis i.e. 2003-2004. The STD is well below 1nm/s^2.

Ducarme B., Rosat S., Vandercoilden L., Xu J.Q., Sun H.P., 2009 European tidal gravity observations: Comparison with Earth Tides models and estimation of the Free Core Nutation (FCN) parameters. Proceedings of the 2007 IAG General Assembly, Perugia, Italy, July 2 - 13, 2007, Observing our Changing Earth, M.G. Sideris (ed.), Springer Verlag, International. Association of Geodesy Symposia 133, 523-532*(DOI10.1007/978-3-540-85426-5)*.

Table 1: Status of preprocessed and analyzed GGP data

n: number of preprocessed months since 2008

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^2)	remarks
BA	Bandung, Indonesia	T008	00084100	030600	030622*		1104	2.938	
BE	Brussels, Belgium	T003	07790200	000900	000901*		6692	1.641	
BH	Bad Homburg, Germany	CD030_L CD030_U SG044	01300734 02300734 00440734	070400 070400 090800	070422* 070422* 090822	31	2222 2218 909	0.783 0.835 0.558	
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	091100	091122	23	4212 ¶5777	1.221 1.210	
CB	Canberra, Australia	C031	00314204	070400	070422		3429	1.019	
ES	Esashi, Japan	T007	00072849	070400	070322		2274	1.491	→ 20040225
HS	Hsinchu, Taiwan	T048	00482695	081200	081222	33	898	2.249	
KA	Kamioka, Japan	T016	00162828	070500	070522		901	1.310	
KY	Kyoto, Japan	T009	00092823	030600	030622*		1533	3.691	→ 20020731
MA	Matsushiro, Japan	T011	00112834	080600	080622	25	3954	1.008	
MB	Membach, Belgium	C021	00210243	091000	091022	20	4282	0.789	
MC	Medicina, Italy	C023	00230506	100300	100300	34	4458	0.876	
ME	Metsahovi, Finland	T020	00200892	091100	091122	24	4303 ¶4829	1.254 1.154	
MG	MunGuyng, S. Korea								
MO	Moxa, Germany	CD034_L CD034_U	01340770 02340770	100400 100400	100422 100322	27 27	3576 3646	0.679 0.626	
NY	Ny Alesund, Norway	C039	00390005	070400	070422		2413	2.954	
PE	Pecny, CZ	OSG050	00500930	100300	100322	35	1046	0.557	
PO	Potsdam, Germany	T018	00180765	980900	980912*		2250	0.856	
ST	Strasbourg, France	C026	00230306	091200	091222	25	4492	0.744	
SU	Sutherland, South Africa	CD037_L CD037_U SG052	01373806 02373806 00523806	080700 080700 090900	080722* 080722* 090922	08 08 13	2665 2502 385	1.113 1.038 0.713	
SY	Syowa, Antarctic	T016	00169960	030100	030122*		1279	1.387	→ 20001231
TC	Tigo, Concepcion, Chile	RT038	00387621	080600	080622	07	1805	1.158	
VI	Vienna, Austria	C025	00250698	061200	061222*		3402	0.530	
WA	Walferdange, GDL								
WE	Wettzell, Germany	SG103 CD029_L CD029_U	01030731 01290731 02290731	980900 090800 090800	980921* 090822 090822	 29 29	¶726 3784 3750	2.639 0.629 0.642	
WU	Wuhan, China	T004	00322647	090500	090522	35	3300	0.924	
					TOTAL	433			

* instrument stopped

¶ with data before 1997/07

→ end of the global analysis

Inter-Commission Project 3.2: Working Group of European Geoscientists for the Establishment of Networks for Earth Science Research (WEGENER)

Chair: Susanna Zerbini (Italy)

Members

B. Ambrosius (Netherlands), A. ArRajehi (Saudi Arabia), L. Bastos (Portugal), M. Becker (Germany), R. Bingley (United Kingdom), C. Bruyninx (Belgium), L. Combrinck (South Africa), J. Dávila (Spain), J. LaBrecque (USA), S. Mahmoud (Egypt), M. Meghraoui (France), T. Mourabit (Morocco), J.M. Nocquet (France), H. Ozener (Turkey), M. Pearlman (USA), R. Reilinger (USA), W. Spakman (Netherlands), S. Tatevian (Russia), K. Yelles (Algeria), S. Zerbini (Italy).
Representative of Commission 1: Alessandro Caporali (Italy)
Representative of Commission 3: Tonie van Dam (Belgium)

Terms of reference

The evolution of geodetic techniques in the past decade, with unprecedented achievements in the precise detection and monitoring of 3D movements at the millimetre level has opened new prospects for the study of Earth kinematics and hence dynamics. However, those achievements also raised new issues that have to be properly taken into account in the processing and analysis of the data, demanding a careful inter-disciplinary approach.

Areas in Europe, primarily in the broad collision zone between Europe, Africa and Arabia, provide natural laboratories to study crucial and poorly understood geodynamic processes. These have been systematically monitored in the last decade by different research groups using a variety of space geodetic and other techniques. However, in general data analysis has been done from the perspective of one discipline and processing procedures have not always followed a standard approach.

The existence of these geodata, never completely explored, justifies a new insight by using a really integrated approach that combines data from different observational techniques and input from other disciplines in the Earth Sciences. This should lead to the development of interdisciplinary work in the integration of space and terrestrial techniques for the study of the Eurasian/African/Arabian plate boundary deformation zone, and adjacent areas, and contribute to the establishment of a European Velocity Field.

With that purpose it is important to promote stronger international cooperation between Earth-Scientists interested in the study of that plate boundary zone. Towards that goal the WEGENER project aims to:

- Actively encourage the cooperation of all geoscientists Eurasian/African/Arabian plate boundary deformation zone, by promoting the exploitation of synergies;
- Be a reference group for the integration of the most advanced geodetic and geophysical techniques by developing the adequate methodologies for a correct data integration and interpretation;
- Act as a forum for discussion and scientific support for geoscientists from all over the world interested in unraveling the kinematics and mechanics of the Eurasian/ African/Arabian plate boundary deformation zone;

- Promote the use of standard procedures for geodetic data, in particular GPS data, quality evaluation and processing.

The need to involve different research areas demands for collaboration with different IAG Commissions and in particular with Commission 1 and Commission 3. Commission 1 is responsible for regional and global reference frames, for the coordination of space techniques and for satellite dynamics. WEGENER can contribute significantly to each one of these areas and, in particular, to regional and global reference frames by making available, in its study area, quality-tested regional data sets acquired with different space and terrestrial techniques, as well as relevant quality-tested solutions. Additionally WEGENER can contribute by carrying out studies, already being developed by WEGENER member groups, on the definition of effective integrated observational strategies. Commission 3, is responsible for earth rotation and geodynamics. WEGENER will provide its main contribution in the field of geodynamics by studying, regionally, both short and long-term crustal motions.

Objectives

The primary goals of the WEGENER project are to:

- Provide a framework for geodetic/geophysical/geological cooperation in the study of the Eurasian/African/Arabian plate boundary zone;
- Foster the use of space-borne, airborne and terrestrial hybrid techniques for earth observation;
- Define effective integrated observational strategies for these techniques to reliably identify and monitor crustal movements and gravity field variations over all time-scales;
- Facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geoprocesses;
- Organize periodic meetings with special emphasis on interdisciplinary research and interpretation and modeling issues;
- Reinforce cooperation with African and Arabian countries and colleagues, which can both contribute to understanding the kinematics and dynamics of the Eurasian/African/Arabian plate boundary zone and promote the growth of such research in these countries.

Activities

- A GEODynamic Analysis Center (GEODAC) was established at the University of Porto (http://geodac.fc.up.pt). The main objective of GEODAC is to provide automatic analysis of GNSS time series to estimate the station velocity based on the Maximum Likelihood Estimation method and assuming a power-law plus white noise model. It is well known that such an approach provides realistic error bars because it takes into account the temporal correlations that exist in the signal. After free registration, the user can upload his GNSS time-series which will be processed and afterwards the results are presented in figures and tables. The web service uses proprietary software developed at the University of Porto (Bos et al., 2008).
- Strategies are being discussed and developed to integrate geological, geophysical, and geodetic observations to address a broad range of questions related to tectonic, atmospheric, oceanic, and climatic issues of interest to the earth science community (e.g., Zerbini et al. 2007; Zerbini et al. 2010).

– WEGENER members actively fostered the co-operation with the African countries in the framework of AFREF (AFrican REference Frame) and other specific scientific projects. Such collaborations extend to the entire continent since that it is necessary to understand the geodynamics of the different African tectonic units (Nubia, Somalia and other blocks in the East African Rift) in order to properly constrain the interaction between these tectonic plates with Eurasia and Arabia In this respect, new GNSS stations have been installed in several countries by the WEGENER community (e.g., Ethiopia, Eritrea, Morocco, Egypt, Cape Verde, S. Tomé e Príncipe, Malawi, Tanzania, Mozambique, Mauritius). WEGENER PI-driven projects are providing new constraints on fault slip rates throughout the Arabia-Africa-Eurasia zone of plate interaction (e.g., Ferry et al., 2007; Nemer et al., 2008; Sbeinati et al., 2010; Ferry et al., 2011; Reilinger et al., 2009, Vernant et al., 2009, Alchalbi et al., 2009), on the earthquake deformation cycle (Hearn et al., 2009, Ergintav et al., 2009), as well as the kinematics and dynamics of plate-scale interactions (e.g., ArRajehi et al., 2010, McClusky et al., 2010, Perouse et al., 2010), In addition, WEGENER members are collaborating with AFREF Scientific Committee in the definition and implementation of procedures to compute the first AFREF solution. Results for the first two epochs were presented at IAG meetings (e.g., Fernandes et al, 2009).

– In the framework of the IAG GGOS project, WEGENER contributes to the activities of subtask DA-09-02-c (Global Geodetic Reference Frames) of the Group on Earth Observations (GEO).

– Every two years General Assemblies are organized to serve as a high-level international forum, in which scientists from all over the world can discuss multidisciplinary interpretation of geodynamics, and strengthen the collaboration between Countries.

1. The 14th General Assembly with the title "WEGENER: an interdisciplinary approach to Earth science research and modelling" was hosted by the Institute of Physical Geodesy at the Conference Center of the Technische Universität Darmstadt on September 15-18, 2008 (http://www.ipg.tu-darmstadt.de/projekte/wegener2008/home/index.de.jsp). There were 86 participants from 18 nations. The program was articulated around five major sessions: Current plate motions and inter- and intraplate deformations. Focusing on Europe, the Mediterranean and surrounding regions; Contribution of new Earth observation systems and methodologies; The Global Geodetic Observing System (GGOS) and its regional implementations; Open Session: Geosciences from Northern Africa to Central and Northern Europe; Special Session: The Mediterranean: A geohazards focus area. More than 70 oral presentations were made. A special issue of the Journal of Geodynamics compiles 16 selected manuscripts derived from such presentations (JoG, vol. 49, 2010).

2. The 15th General Assembly that celebrated the 30th anniversary of the project was held in Istanbul, Turkey, on September 14-17, 2010 and was hosted by the Geodesy Department of Kandilli Observatory and Earthquake Research Institute of the Bogazici University at the Albert Long Hall Conference Center (http://www. koeri.boun.edu.tr/jeodezi/wegener2010/ . There 96 participants from 15 countries. The program was organized according to the following four main sessions: 30 Years of WEGENER - The Evolution of our Knowledge about the Africa-Eurasia Plate Boundaries; Current Plate Motions, Inter- and Intraplate Deformation with a Focus on Europe, the Mediterranean, Northern Africa and the Middle East; Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis; Open Session with Proposed Focus on International Organization of Geodetic Initiatives Contributing to Earth Sciences. The Journal of Geodynamics agreed upon publishing a special issue

which will include selected manuscripts derived from presentations made during this 15th General Assembly.

- A Wegener session "Geodesy and natural and induced hazards: Progress during 30 years of the WEGENER initiative" co-convened by S. Zerbini, M. Meghraoui and R. Reilinger has been organized and will be held in Vienna, Austria, on April 4 and 5, 2011, during the EGU General Assembly 2011. About 50 abstracts were received. The presentations will describe multidisciplinary studies of natural and human-induced hazards using geodetic techniques (GPS, InSAR, LiDAR, space/air/terrestrial gravity, ground-based geodetic observations), complementary geologic and geophysical observations, and modeling approaches. Also fundamental studies of natural and induced physical phenomena, strategies to develop early warning and rapid response systems, and development programs will be presented.

To keep close contacts among the Directing Board members and to coordinate the activities, directory board meetings are held in association with the annual EGU and AGU meetings. The 16th assembly will take place in September 2012 and will be hosted by the EOST - Institut de Physique du Globe de Strasbourg, France.

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Commission 4 – Positioning and Applications

http://enterprise.lr.tudelft.nl/iag/iag_comm4.htm

President: Sandra Verhagen (The Netherlands)
Vice President: Dorota Grejner-Brzezinska (USA)

Structure

Sub-commission 4.1: Multi-Sensor Systems
Sub-commission 4.2: Applications of Geodesy in 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
Study Group 4.2: GNSS Remote Sensing and Applications
Study Group 4.3: IGS Products for Network RTK and Atmosphere Monitoring

Steering committee

President : Sandra Verhagen (The Netherlands)
Vice-president : Dorota Grejner-Brzezinska (USA)
Chair SC 4.1 : Dorota Grejner-Brzezinska (USA)
Chair SC 4.2 : Günther Retscher (Austria)
Chair SC 4.3 : Marcelo Santos (Canada)
Chair SC 4.4 : Xiaoli Ding (Hong Kong)
Chair SC 4.5 : Yang Gao (Canada)
Member-at-large : Pawel Wielgosz (Poland)
IAG representative : Ruth Neilan (USA)

Overview

Terms of reference

To promote research into the development of a number of geodetic tools that have practical applications to engineering and mapping. The Commission will carry 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 Organisations.

Recognising the central role that Global Navigation Satellite Systems (GNSS) plays in many of these applications, the Commission's work will focus on several Global Positioning System (GPS)-based techniques, also taking into account the expansion of GNSS with Glonass, Galileo and Beidoe. These techniques include precise positioning, but extending beyond the applications of reference frame densification and geodynamics, to address the demands of precise, real-time positioning of moving platforms.

Several Sub-Commissions will deal with precise kinematic GNSS positioning technology itself (alone or in combination with other positioning sensors) as well as its applications in surveying and engineering. Recognising the role of continuously operating GPS reference station network, research into non-positioning applications of such geodetic infrastructure will also be pursued, such as atmospheric sounding. Thereby, other geodetic techniques such as VLBI will be considered as well.

The commission will also deal with geodetic remote sensing, using (differential) InSAR, and GNSS as a remote sensor with land, ocean and atmosphere applications.

Objectives

The main objectives of Commission 4 are:

- Research into (integration of) new navigation and deformation measurement / sensor technologies, and their applications.
- Encourage research and development into new applications in e.g. “precise navigation”, “geodetic remote sensing”, “engineering geodesy”.
- Collaboration with geodetic organizations and services to promote and enable the use of GNSS and geodetic infrastructure for positioning as well as non-positioning applications.

The following activities were planned to reach these objectives:

- Interface with IAG sister organisations and other organizations - e.g. FIG, ISPRS, IEEE, ION
- Promote Geodesy and GGOS to a wide (professional) community
- Offer outreach opportunity through its conferences and seminars (jointly organised with other organisations)
- Forums, collaborative research, and exchange of data through the various sub-components.

Linkages between IAG Commission 4 and FIG, ION, ISPRS

Commission 4, by its rather more “practical” nature than other IAG commissions, has stronger links with sister organisations such as FIG, ISPRS and the U.S. ION. This is reflected in the broad activity of its members, who tend to support conferences organised by these other organisations. Often the officers of Commission 4 are also members of WGs, SGs and committees of the sister organisations. Hence there are a lot of cross-links between organisations. The links with the FIG Commission 5 (“Positioning and Measurements”), FIG Commission 6 (“Engineering Surveys”), ISPRS Commission I (“Image Data Acquisition – Sensors & Platforms”), and ISPRS Commission V (“Close Range Sensing – Analysis and Applications”) are now particularly strong, as evidenced by a permanent series of joint symposia (see below).

Memorandum of Understandings between IAG and FIG initiated and prepared by Chris Rizos and Matt Higgins (FIG)

Memorandum of Understanding between IAG and U.S. ION facilitated by Dorota Grejner-Brzezinska

Collaboration with FIG

Foundation of the FIG WG 5.5 on Ubiquitous Positioning Technologies and Techniques: A collaborative WG with IAG Commission 5 and Commission 6 at the XXIV FIG Congress held in Sydney, Australia, 11-16 April 2010

Joint conferences / sessions:

- FIG Working Week 2008
  - Sandra Verhagen chaired a joint IAG – FIG session on Geodetic Networks, Reference Frames and Systems
  - Sandra Verhagen gave a presentation on behalf of IAG Commission 4 on New Positioning Technologies
  - discussion forum chaired by Sandra Verhagen, Chris Rizos …
- ISPRS Congress 2008, Beijing Dorota Grejner-Brzezinska chaired a special session SS-4: Modern Navigation and Earth Observation that is jointly sponsored by IAG and ISPRS
- ION International Technical Meeting, 26-29 January 2009, Anaheim CA session on "Applications in Surveying, Geodesy, Science and Timing", organized and chaired by Dorota Grejner-Brzezinska
- 2009 6th International Mobile Mapping Symposium co-sponsored/co-organized by IAG, ISPRS and FIG Dorota Grejner-Brzezinska is Science Chair
  - IAG 2009 Scientific Assembly "Geodesy for Planet Earth"
  - session 4 "Positioning and remote sensing of land, ocean and atmosphere" convened by Sandra Verhagen and Pawel Wielgosz, with the following sub-sessions:
    - Session 4.1 "Technology and land applications" convened by Dorota Grejner-Brzezinska and Xiaoli Ding (related to SC 4.1, SC 4.4, SC 4.5 a.o.)
    - Session 4.2 "Modelling and remote sensing of the atmosphere" convened by Marcelo Santos and Jens Wickert (related to SC 4.3 and SG 4.3)
    - Session 4.3 "Multi-satellite ocean remote sensing" convened by Shuanggen Jin and Ole Andersen (related to SG 4.2)
  - session 6 "Joint IAG/FIG/ION/ISPRS session on Navigation and Earth Observation", convenors: Dorota Grejner-Brzezinska and Charles Toth
- 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 13th FIG Deformation Measurement Conference, May 12-15, 2008 in Lisbon, Portugal
- Joint International Symposium on Deformation Monitoring (JIS-DM), including 5th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, 14th FIG Symposium on Deformation Measurements and Analysis, and International Workshop on Spatial Information Technologies for Monitoring the Deformation of Large-Scale Man-Made Linear. November 2-4, 2011 in Hong Kong, P.R. China
- Symposium series (2007 – 2011) on 'Location Based Services and Telecartograpy', joint with ICA.
- FIG/IAG workshop to be held at the 7th Symposium on Mobile Mapping MMT 2011 from June 13-16, 2011 in Cracow, Poland.

Linkages with other IAG commissions and services

Commission 1

- IC-WG 1.1: Environment Loading: Modelling for Reference Frame and positioning applications, Chairs: Tonie van Dam (Luxembourg), Jim Ray (USA) [Joint with Commission 4 and IERS]
- IC-SG1.2 Quality of geodetic multi-sensor systems and networks, Chair: H-G. Kutterer (Germany) [Joint with ICCT, Commission 4]

GGOS

- Sandra Verhagen in steering committee, and participated in the SC meeting in December 2008. Dorota Grejner-Brzezinska is substitute delegate.
- Chris Rizos and Dorota Grejner-Brzezinska contributed to the GGOS Reference document (chapter 4)

ICCT

- IC-SG2: Quality of geodetic multi-sensor systems and networks (see Commission 1, IC-SG1.2)
- IC-SG6: InSAR for tectonophysics, Chair: M. Furuya (Japan) [Joint with Commission 3 and 4]
- IC-SG9: Application of time-series analysis in geodesy, Chair: W. Kosek (Poland) [Joint with Commission 1, 2, 3 and 4]
- Organization of Hotine-Marussi 2009 symposium on Theoretical Geodesy:
  - Sandra Verhagen in scientific committee
  - Session 2 "Geodetic sensors and sensor networks" convened by Sandra Verhagen
  - Poster on behalf of commission 4 "Geodetic sensors and sensor networks – IAG's perspective"
- Organization of QuGOMS in Munich, 2011. Sandra Verhagen in Scientific Committee.

IGS

- Third meeting of International Committee on GNSS: contributions by Chris Rizos and Ruth Neilan.
- IGS is linked to SG 4.3 (see report)

Commission 4 sponsorships

- International Conference on Geo-Spatial Solutions for Emergency Management to be held September 14-16, 2009, Beijing, P.R.China, to celebrate CASM's 50th anniversary.

  Chris Rizos is member of the Steering Committe
- ION International Technical Meeting, January 26-29, Anaheim CA Session on "Applications in Surveying, Geodesy, Science and Timing", organized and chaired by Dorota Grejner-Brzezinska.
- IEEE International Geoscience & Remote Sensing Symposium (IEEE IGARSS 2009), Cape Town, Africa, 13-17 July 2009 Session on GNSS Remote Sensing Applications in Atmosphere, Ocean and Land, see SG4.2 report.
- International Workshop on Geodetic Theory-IWGT 2009, 1-3 June 2009 at Tongji University, Shanghai, China. Yanming Feng was in the technical program committee, see WG 4.5.4 report
- 2nd International Colloquium – Scientific and Fundamental Aspects of the Galileo Programme, October 14-16, 2009, Padua, Italy
- 2010 International Conferenceon Indoor Positioning and Indoor Navigation IPIN from September 15-17, 2010 in Zurich, Switzerland
- 2011 International Conferenceon Indoor Positioning and Indoor Navigation IPIN from September 21-23, 2011 in Guimarães, Portugal
- International Conference on Ubiquitous Positioning, Indoor Navigation and Location-Based Service UPINLBS 2010 from October 14-15, 2010 in Helsinki, Finland; Dorota Brzezinska was one of the keynote speakers at this conference

Highlight: publications

Commission 4 published two papers which are the result of a collaborative effort (co-authored by the different SC and SG chairs), and represent the views, activities, and objectives of the Commission:

- "Geodetic sensors and sensor networks – IAG's perspective" to be presented at Hotine-Marussi 2009 symposium on Theoretical Geodesy, July 2009, Rome, Italy
- "Positioning and applications for planet Earth" to be presented at the IAG2009 Scientific Assembly "Geodesy for planet Earth", September 2009, Buenos Aires, Argentina

Commission meetings

The steering committee had several meetings during the reporting period:

- kick-off meeting at the IUGG 2007 Symposium in Perugia, Italy
- ION GNSS 2007, Savannah, USA
- IAG 2009 Symposium, Buenos Aires, Argentina. During this meeting representatives from FIG (Mikael Lilje, Rober Sarib) were present to discuss collaboration.
- IUGG 2011, Melbourne, Australia
- informal meetings with different members during various conferences and symposia

Sub-Commission 4.1: Multi-Sensor Systems

President: Dorota Grejner-Brzezinska (USA)

Website: http://www.ceegs.ohio-state.edu/IAG-SC41/

Terms of Reference

To coordinate research and other activities that address broader areas of multi-sensor system theory and applications, with a special emphasis on integrated guidance, navigation, positioning and orientation of airborne and land-based platforms. The primary sensors of interest will be GNSS and inertial navigation systems; however the important role of other techniques used for indoor and pedestrian navigation environmental monitoring is also recognized. The Sub-commission will carry out its work in close cooperation with other IAG Entities, as well as via linkages with relevant scientific and professional organizations, such as ISPRS, FIG, IEEE, ION.

Objectives

- To follow the technical advances in navigation sensors and algorithms, including autonomous vehicle navigation, based on
  - positioning sensors and techniques such as GPS (and pseudolilte s), INS, including MEMS IMU, wheel sensors, ultrasonic and magnetic sensors, and
  - positioning methods based on cellular networks and their hybrid with GPS
- To follow the technical advances in mapping sensors, such as CCD cameras, laser range finders, laser scanners and radar devices
- To standardize definitions and measurements of sensor related parameters
- To study and report on the performance of stand alone and integrated navigation systems
- Report on the development, possibilities and limitations of new multi-sensor system technologies.
- To stimulate new ideas and innovation in
  - navigation algorithms, sensor calibration, synchronization and inter-calibration
  - real-time sensor information processing and georeferencing
  - sensor and data fusion
  - automation techniques for information extraction from multi-sensor systems using expert systems
- To study and monitor the progress in new applications (not limited to conventional mapping) of multi-sensor systems (transportation, engineering, car navigation, environmental monitoring personal navigation, indoor navigation, etc.)
- To promote research collaboration and to organize and to participate in professional workshops, seminars, meetings
- To promote research and collaboration with countries with no or limited access to modern multi-sensor technology
- To establish a web page providing information on the SC 4.1 activities, technology updates, and professional meeting calendar.

WG 4.1.1: Alternative integration algorithms

Chair: Dr. Aboelmagd Noureldin (Canada)

Major Developments and Achievements:

1. Development of a unique method based on Particle Filtering for accurately navigating wheel-based platforms in challenging GPS environments. This method has resulted in a patent and the technology is licensed by Trusted Positioning Inc. (Dr. Noureldin and Dr. Kornberg)
2. Development of innovative hybrid INS/GPS integration methods combining the benefits of artificial intelligence (AI) and Kalman filtering (KF) for navigation in urban environments (Dr. Chiang and Dr. Noureldin).
3. Enhancement of multi-sensor system integration using spectral estimation techniques employing robust orthogonal search methods for the development of accurate nonlinear error models of INS (Dr. Kornberg, Dr. McGaughy and Dr. Noureldin).
4. Augmented KF / NN modules for reliable INS/GPS integration for airborne navigation (Dr. Noureldin and Capt. Armstrong).
5. Parallel cascade identification of reliable stochastic nonlinear error model of inertial sensor errors (Dr. Kornberg and Dr. Noureldin).
6. Development of Methods for Attitude and Misalignment Estimation for Constraint Free Portable Navigation. This method has resulted in a patent and the technology is licensed by Trusted Positioning Inc. (Dr. Noureldin)

Research Team:

Name	Position	Department / Institute
Dr. Aboelmagd Noureldin	Chair	Cross-appointment Associate Professor, Departments of Electrical and Computer Engineering, Queen's University and Royal Military College of Canada.
Dr. Kai-Wei Chiang	Vice Chair	Assistant Professor, Department of Geomatics, National Cheng Kung University.
Dr. Michael Korenberg	Member	Professor, Department of Electrical and Computer Engineering, Queen's University.
Dr. Don McGaughey	Member	Associate Professor, Department of Electrical and Computer Engineering, Royal Military College of Canada.
Capt. Justin Armstrong	Member	Canadian Air Force, Department of National Defence, Canada

In addition to the above principal team members, at least 20 postgraduate students were involved on the different phases of the developments.

Publications:

1. Patents

Syed Z., Georgy J., Goodall C., Noureldin A. and El-Sheimy N.: "Methods for Attitude and Misalignment Estimation for Constraint Free Portable Navigation" US Provisional Patent # 61/466,840, Filed: March 23, 2011.

Georgy J. and Noureldin A.: "Method and Apparatus for Improved Navigation of A Moving Platform" US Patent Application No. 13/037,130, Filed: February 28, 2011.

2. Journal Papers

Georgy J. and Noureldin A.: "Tightly Coupled Low Cost 3D RISS/GPS Integration Using a Mixture Particle Filter for Vehicular Navigation" Sensors. (In Print) ID: 7153.

Georgy J., Karamat T., Iqbal U. and Noureldin A.: "Enhanced MEMS-IMU/Odometer/GPS Integration Using Mixture Particle Filter" GPS Solutions, Springer. (In Print)

Georgy J., Noureldin A., and Mellema G.: "Clustered Mixture Particle Filter for Underwater Multi-Target Tracking in Multistatic Active Sonobuoy Systems," IEEE Transactions on System Man and Cybernetics -- Part C: Applications and Reviews. (In Print)

Shen Z., Georgy J., Kornberg M. and Noureldin A.: "Low Cost 2D Navigation Using an Augmented KF/FOS Module for RISS/GPS Integration" Transportation Research – Part C, Elsevier. (In Print) TRC-D-09-00183R1.

Atia M., Noureldin A. and Kornberg M.: "Gaussian Process Regression Approach for Bridging GPS outages in Integrated Navigation Systems" Electronic Letters, IET, V47(1), January 2010.

Iqbal U., Georgy J., Kornberg M., and Noureldin A.: "Nonlinear Modeling of Azimuth Error for 2D Car Navigation Using Parallel Cascade Identification Augmented with Kalman Filtering" International Journal of Navigation and Observation, V2010, 13pp, 2010.

Noureldin A., El-Shafie A. and Bayoumi M.: "Robust Mobile Multi-Sensor Data Fusion Utilizing Dynamic Neural Network for Vehicular Navigation" Information Fusion, Elsevier, V12 (1), pp:48 – 57, 2011.

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Noureldin A., Karamat T., Eberts M. and El-Shafie A. "Performance Enhancement of MEMS Based INS/GPS Integration for Low Cost Navigation Applications" IEEE Transactions on Vehicular Technology, V58 (3), pp: 1077 – 1096, March 2009.

Perreault J., Iqbal U., Okou A. and Noureldin A. "RISS/GPS Integration Utilizing an Augmented KF/NN module" European Journal of Navigation, V6 (3), pp: 15-21, November 2008.

El-Sheimy N, Chiang K-W and Noureldin A.: "Developing a Low Cost MEMS IMU/GPS Integration Scheme Using Constructive Neural Networks;" IEEE Transactions on Aerospace and Electronic Systems, V44 (2), pp: 582 – 594, April 2008.

3. Conference Papers

Atia M, Georgy J, Noureldin A and Kornberg M.: "Embedded Real-Time Realization of Mixture Particle Filter for 3D RISS/GPS Land-Vehicles Navigation," In Proc of ION ITM 2011, San Diego, CA, January 24 – 26, 2011.

Abdelfatah W, Georgy J, Iqbal U and Noureldin A: "Real - Time Realization of 2D RISS/GPS Integrated Navigation on Xilinx´s MicroBlaze Soft-Core Processor for Land Applications," In Proc of ION ITM 2011, San Diego, CA, January 24 – 26, 2011.

Shen Z, Noureldin A and Kornberg M.: "A Real-time Approach to Nonlinear Modeling of Inertial Errors with Application to 3D Vehicle Navigation" In Proc of ION ITM 2011, San Diego, CA, January 24 – 26, 2011.

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WG 4.1.2: Indoor Navigation Systems

Chair: Günther Retscher (Austria)

Almost 70 to 80 % of our daily information is closely related with spatial and temporal aspects. Spatial positioning with time mark exhibits considerable significance in contemporary information services. However, provision of spatial location with both proper reliability and availability is still hindered by a number of challenges and obstacles due to technical and political reasons, and exploration for ubiquitous positioning needs great efforts and becomes our utmost destination. In our research, therefore ubiquitous positioning techniques with alternative sensors and multi-sensor solutions has been investigated.

Nowadays, metropolitan cities in the world are provided with different multimedia services through mobile communications using for example GSM, GPRS and 3G with an affordable service charge. Moreover, popular GPS and WiFi (Wirless Fidelity) integrated mobile devices are readily available on the market to strengthen handset based services and applications. Another function of wireless technologies, in addition to communication, is position determination. Therefore, the integration of GPS/WiFi mobile devices (Mok and Retscher, 2007), wireless communications and positioning technologies, as well as geographic information and mapping systems have created new services to mobile users, namely location-based services (LBS). LBS also play an important role for supporting the wayfinding process in navigation systems (Retscher, 2009a). Guiding services, however, have some limitations. For example, localization accuracy is insufficient for pedestrian's needs in many cases and route suggestions usually rely on road networks and do not meet the demands of walking people, as pedestrians have more degrees of freedom in movement compared to car drivers. Moreover, most of the common services rely only on the positioning with GNSS. This works well in open outdoor environments where the satellite signals can be received, but not in areas surrounded by dense high rise environments, and indoors.

Especially in complex buildings, visitors often need guidance and support. One of the main disadvantages inside buildings affects the sense of orientation: people tend to lose orientation a lot easier within buildings than outdoors especially if not moving along windows. Instead of passive systems that are installed on the user's device and frequently position them as the user moves along, new technologies originated in ubiquitous computing could enrich guiding systems by including information captured from an active environment. This would mean that the user is perceived by a ubiquitous environment and receives location-based information that is suitable for the respective device or is supplied with helpful notes via a public display or similar presentation tools. Additionally to the function of information transmission poles, these smart stations substitute or complement traditional indoor positioning methods by sending coordinates of the station instead of locating the user. Based on the concept of "active landmarks", which actively search for the user and build up a spontaneous "ad-hoc network" via an air-interface, a ubiquitous solution, where an information exchange between different objects and devices is accomplished, was investigated for the use in navigation and location-based services (Retscher, 2009a).

This evolutionary method of ubiquitous guiding in smart environments where sensors at active landmarks are present brings a paradigm shift to contemporary wayfinding. As opposed to conventional navigation systems, which are based on preinstalled software, ubiquitous positioning responds to an individual user at his present location in real-time. Interactivity is facilitated and wayfinding aid is more flexible, which provides new opportunities and challenges to the field of navigation and will require research in positioning techniques with alternative multi-sensors. Thereby intelligent fusion algorithms play also a major role (Retscher, 2007 and 2009b).

The WG members have gained experience in the field of indoor and ubiquitous positioning using different technologies and have good track records in this area of research. At the Vienna University of Technology, Austria, positioning with WiFi and active RFID was investigated intensely (Retscher et al. 2007; Fu and Retscher, 2008). On the other hand, positioning with WiFi, UWB (Ultra-wide Band) and Zigbee was investigated and analysed at the Hong Kong Polytechnic University in cooperation with Sun Yat-Sen University in Guangzhou, China (Mok and Gartner, 2008; Mok et al., 2010; Mok et al., 2011). In addition, the colleagues at RMIT University, Melbourne, Australia, have worked on indoor positioning using MEMS-based INS in combination with RFID (Zhang et al., 2008; Zhu et al., 2009; Zhu, 2010; Zhu et al., 2011). WG members at Melbourne University, Australia, have also investigated positioning with MEMS INS (Kealy et al., 2010) and developed a location information taxonomy for LBS (Kealy et al, 2009). Due to the different expertise of the WG members significant progress for the development of ubiquitous and seamless positioning technologies has already been achieved.

In addition, in 2010 the collaborative FIG WG 5.5 'Ubiquitous Positioning Technologies and Techniques' with IAG has been established (see http://fig.net/commission5/wgroups/wg5_5.htm). The WG is chaired by Allison Kealy and Guenther Retscher. One of the main goals of this WG is to develop an open source platform through which theoretical and practical research into ubiquitous positioning can be enhanced. The platform will be designed in a modular fashion to enable research partners and users to develop their own functionality that can then be easily interfaced and integrated into the platform. Modules will include but not be limited to: performance testing of different types of positioning sensors such as INS, WiFi, RFID, and Zigbee technology; evaluating and data logging of sensors; data integration, algorithm testing and validation either in real-time or post processed; and quality control. Besides the demo platform, demo applications of ubiquitous positioning in combination with analysis of human behaviour are our innovative test and unique output of the collaboration between the two WG's.

In 2007, 2008, 2009 and 2010 the WG 4.1.2 has jointly organized with the ICA Commissions on 'Maps and Internet' and on 'Ubiquitous Cartography' the symposium series on 'Location Based Services and Telecartograpy'. In 2007 the conference was held in Hong Kong, P.R. China; in 2008 in Salzburg, Austria; in 2009 in Nottingham, UK; and in 2010 in Guangzhou, P.R. China. Oral sessions on 'Indoor Positioning' and on 'Positioning in LBS' were held including presentations of members of the WG, e.g. (Retscher and Mok, 2007; Fu and Retscher, 2008; Mok and Gartner; 2008; Zhang et al., 2008). The participating WG members also discussed the future work and collaboration in the working group at these meetings. To continue this successful series of conferences, the WG is actively involved in the organization of the next LBS conference to be held from November 21-23, 2011 in Vienna, Austria (see http://www.lbs2011.org/).

The ION GNSS conference series provided further opportunities for exchanging ideas between WG members and other professionals. Guenther Retscher co-chaired a session on 'Algorithms for Multi-Sensor Fusion' at the ION GNSS 2008 conference which was held in Savannah, Georgia, USA. At the 2009 meeting in Savannah, Allison Kealy represented the WG as technical chair of track B and Guenther Retscher co-chaired a session on 'Multi-sensor Navigation'. Other relevant sessions in track B included 'Algorithms for Multi-sensor Fusion', 'Alternatives and Backups to GNSS' and 'GNSS – Inertial Navigation Systems'. Several papers have been presented, e.g. (Retscher and Fu, 2008; Zhu, 2008; Retscher, 2009b).

For the future work of WG 4.1.2, networking and knowledge exchange between members of the WG will be continued. In addition, co-organization of upcoming conferences in the field of GNSS and LBS is planned.

Publications

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WG 4.1.3: Multi-sensors systems for environmental monitoring applications

Chair: Jan Skaloud

January (2008); Jan Skaloud (group chair) presented several research topics together with WG 4.1 activities at the Department of Geomatics Engineering, University of Calgary.

February (2008): **EuroCOW 2008**

This meeting intended to bring together the world experts, both from public and private sectors, to present and discuss the recent findings and developments on Sensor Calibration and Orientation. The meeting was a highly specialized forum which subject substantially overlapped with the IAG 4.1 topics. During this meeting Jan Skaloud (group chair):

- directed the session on INS/GNSS Technology and Applications
- presided the special Technology update session
- delivered paper "On the calibration strategy of medium format cameras for direct georeferencing"

May (2008): The airborne mapping scanning Scan2map designed in EPFL, Switzerland performed the world-first RTK-LiDAR airborne survey mission. The complete laser point cloud was generated in the real-time with 5 cm – level accuracy. The implemented technology opens the door to new environmental monitoring application.

June (2008): Yannick Stebler (group member) completed his work on GPS/INS Integrity in Airborne Mapping. His approach has been implemented and tested in close-range airborne mapping system suitable for environmental monitoring.

Meeting in Innsbruck, Austria for setting up a joint project related to WG 4.1 research activity. Participants: Jan Skaloud (group chair), Yannick Stebler (group member), Klaus Legat (group member), local industry and faculty members of TU Graz.

July (2008): **ISPRS Congress in Beijing**

The ISPR congress is the largest meeting of the International Society for Photogrammetry and Remote Sensing organized once per four years. IAG is a partner organization of ISPRS and activates within the ISPRS Commission I are closely related to IAG WG 4.1 research topics. During this meeting

- -Philipp Schaer (group member) was selected to deliver oral presentation in the highly competitive session on Integrated Systems for Mobile Mapping. He was the first author of the paper "Towards In-Flight Quality Assessment of Airborne Laser Scanning"
- Julien Vallet (group member) participated at ISPRS Congress in Beijing where he co-authored work on "Oblique Helicopter-Based Lasers Scanning for Digital Terrain Modeling and Visualization of Geological Outcrops."
- Jan Skaloud (group chair) was proposed to chair the ISPRS Commission I working group (WG I-5) on Integrated Systems for Sensor Georeferencing and Navigation. His appointment was later approved by the ISPRS council together with the appointments of Ismael Colomina (group member) as co-chair and Klaus Legat (group member) as secretary.

September (2008): Common meeting of WG 4.1 chair and co-chair was held in Switzerland. The meeting was aimed to update and synchronize the developments on multi-sensor mobile platforms within WG 4.1 leadership.

October (2008): Meeting in Innsbruck, Austria for continuing common research related to WG 4.1 activity. Participants: Jan Skaloud (group chair), Yannick Stebler (group member), Klaus Legat (group member) members of TU Graz.

November (2008): Christian Baumann (group member) spent three weeks in the Institute of Geomatics in Castelldefels, Spain. He was a host of the institute director Dr. I. Colomina (group member). This was a research oriented stay in the domain of sensor integration methods.

Jan Skaloud (group chair) participates at the 6th edition of the Swiss Geoscience Meeting and delivers a talk on the Real-Time Mapping and Monitoring Capability of Geological Features by Airborne Laser Scanning.

December (2008): The real-time analyses of the kinematic laser-scanning coverage and density have been implemented in the mobile laser scanning system Scan2map, EPFL Switzerland. The digital surface model is calculated in the real-time and presented to the operator as hill-shade raster image.

February (2010): **EuroCOW 2010**

This meeting intended to bring together the world experts, both from public and private sectors, to present and discuss the recent findings and developments on Sensor Calibration and Orientation. The meeting was a highly specialized forum which subject substantially overlapped with the IAG 4.1 topics.

March (2010): The group members started a new research project related to robust navigation for unmanned airborne micro-vehicles (<5kg). The project aims integrating redundant low-cost (MEMS) IMUs (RIMU), barometer data and GNSS/EGNOS signals together with high-resolution digital surface models. The new platforms shall carry different type of sensors for environmental monitoring.

April (2010): Group member published a joint journal paper on noise reduction of multiple low-cost IMUs in the journal of Measurement Science and Technology.

June (2010): Several group members participated at the Canadian Geomatics Conference held in Calgary, Alberta. This meeting brought together experts in the field of geomatics from Canada and the world.

September (2010): WG chair J. Skaloud presented invited lecture at the University of Calgary entitled Optimizing Computational Performance for Real-Time Mapping with Air-borne Laser Scanning. His visit initiated new exchange of airborne data and experience between group members.

Several group members participated at ION-GNSS in Portland, Oregon, the largest annual meeting in the field of satellite positioning.

November (2010): The group members met in Barcelona (Spain) to review the started project on robust navigation for micro-UAV platforms and to conduct a test-flight with a UAV helicopter platform equipped with hyper-redundant navigation systems comprising GNSS receivers (3), MEMS-IMUs(4), control tactical-grade IMU, barometer, thermo sensors, and terrain guidance.

January (2011): A new micro-UAV platform has been acquired for a joint environmental monitoring project between group members. This platform can carry up to 0.5kg payload and has a flying autonomy of ~30 minutes.

February (2011): There was a group meeting in Portugal between group members for analyzing and synthesizing the flight-results from November 2010.

March (2011): Two group members met in Switzerland for test and analysis of the capacity of a new MEMS-IMU at tactical-grade quality that is not yet in production.

Sub-Commission 4.2: Applications of Geodesy in Engineering

President: Günther Retscher (Austria)

Website: http://info.tuwien.ac.at/ingeo/sc4/sc42.html

Terms of reference

Rapid developments in engineering, microelectronics and the computer sciences have greatly changed both instrumentation and methodology in engineering geodesy. To build higher and longer, on the other hand, have been key challenges for engineers and scientists since ancient times. Now, and for the foreseeable future, engineers confront the limits of size, not merely to set records, but to meet the real needs of society minimising negative environmental impact. Highly developed engineering geodesy techniques are needed to meet these challenges. The SC will therefore endeavour to coordinate research and other activities that address the broad areas of the theory and applications of engineering geodesy tools. The tools range from conventional terrestrial measurement and alignment technology (optical, RF, etc.), Global Navigation Satellite Systems (GNSS), geotechnical instrumentation, to software systems such as GIS, decision support systems, etc. The applications range from construction engineering and structural monitoring, to natural phenomena such as landslides and ground subsidence that have a local effect on structures and community infrastructure. The SC will carry out its work in close cooperation with other IAG Entities, as well as via linkages with relevant scientific and professional organisations such as ISPRS, FIG, IEEE, ION.

Objectives

- To monitor research and development into new technologies that are applicable to the general field of "engineering geodesy", including hardware, software and analysis techniques.
- To study advances in dynamic monitoring and data evaluation systems for buldings and other manmade structures.
- To study advances in monitoring and alert systems for local geodynamic processes, such as landslides, ground subsidence, etc.
- To study advances in geodetic methods used on large construction sites.
- To study advances in the application of artificial intelligence techniques in engineering geodesy.
- To document the body of knowledge in this field, and to present this knowledge in a consistent frame work at symposia and workshops.
- To promote research into several new technology areas or applications through the SC4.2 Working Groups.

Initially it was planned to establish the following four Working Groups:

WG 4.2.1: Measurement Systems for the Navigation of Construction Processes

Chair: Wolfgang Niemeier (Technical University Braunschweig, Germany)

WG 4.2.2: Dynamic Monitoring of Buildings

Chair: Gethin Roberts (IESSG, Nottingham University, UK)

WG 4.2.3: Application of Artificial Intelligence in Engineering Geodesy

Chair: Alexander Reiterer (Vienna University of Technology, Austria)

Co-Chair: Uwe Egly (Vienna Univ. of Technology, Austria)

WG 4.2.4: Monitoring of Landslides and System Analysis

Chair: Gyula Mentes (Geodetic and Geophysical Research Institute of HAS, Hungary)

Co-Chair: Paraskevas Savvaidis (University of Thessaloniki, Greece)

The reports of the activities of WG 4.2.3 and WG 4.2.4 can be found below. These two WGs are very active. WG 4.2.3 has currently 8 members and WG 4.2.4 23 members. WG 4.2.4 has changed its title recently to "Investigation of Kinematic and Dynamic Behaviour of Landslides and System Analysis". WG 4.2.1 and WG 4.2.2, however, were not established in the reported period.

In the last two years SC 4.2 was involved in the organization of the following conferences:

1. **8th Conference on Optical 3-D Measurement Techniques**

   July 9-12, 2007 in Zurich, Switzerland
2. **4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 13th FIG Deformation Measurement Conference**

   May 12-15, 2008 in Lisbon, Portugal
3. **9th Conference on Optical 3-D Measurement Techniques**

   July 1-3, 2009 in Vienna, Austria
4. **6th International Symposium on Mobile Mapping Technology (MMT'09)**

   July 21-24, 2009 in Presidente Prudente, São Paulo, Brazil

The established WG's have supported these four conferences and were represented by WG members and/or chairs.

The sub-commission is also involved in the organization of the following upcoming meetings:

1. **7th International Symposium on Mobile Mapping Technology (MMT'11)**

   June 13-16, 2011 in Cracow, Poland
2. **Joint International Symposium on Deformation Monitoring (JIS-DM), including 5th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, 14th FIG Symposium on Deformation Measurements and Analysis, and International Workshop on Spatial Information Technologies for Monitoring the Deformation of Large-Scale Man-Made Linear**

   November 2-4, 2011 in Hong Kong, P.R. China

WG 4.2.3: Application of Artificial Intelligence in Engineering Geodesy

Chair: Alexander Reiterer

AI, in general, is the study and design of intelligent agents, where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. Many real-world problems require the agent to operate with incomplete or *uncertain information*. Methods used for uncertain reasoning are probabilistic in nature, such as Bayesian networks, which represent a general tool that can be used for a large number of problems, for example, reasoning (using the Bayesian inference algorithm), learning (using the expectation-maximization algorithm), planning (using decision networks), and perception (using dynamic Bayesian networks). Probabilistic algorithms can also be used for filtering, prediction, smoothing and finding explanations for streams of data, helping perception systems to analyze processes that occur over time. AI techniques also include classifiers and statistical learning methods.

In the last years, Artificial Intelligence (AI) has become an essential technique for solving complex problems in Engineering Geodesy.

Current applications using AI methodologies in engineering geodesy are:

- geodetic data analysis,
- deformation analysis,
- navigation,
- deformation network adjustment,
- optimisation of complex measurement procedure.

The work of the WG 4.2.3 can be summarized as follows:

- networking and knowledge exchange between members of the WG,
- organisation of a meetings,
- organisations of two international workshops
- public relation in form of an website (http://info.tuwien.ac.at/ingeo/sc4/wg423/wg_423.html).

In 2008 the WG has organized the "First International Workshop on Application of Artificial Intelligence in Engineering Geodesy – AIEG2008" in Vienna/Austria. The meeting was co-sponsored by Leica Geosystems and FWF (Austrian Science Fund). About 20 experts from the US, from Germany, Italy and Austria have participated. The program consisted of presentations and tutorials. The workshop was an exciting opportunity to discuss the state of the art and recent developments of AI application in engineering geodesy. The two key notes were given by Prof. Dorota A. Grejner-Brzezinska from the Ohio State University (USA) and by Dr. Chmelina Klaus from Geodata (Austria). Oral presentations have been focused on the application of artificial neuronal networks, knowledge-based systems, intelligent sensor fusion, decision-support systems, etc. The workshop proceedings have been published in one Volume which has about 120 pages.

In 2009 the WG has organized a special session at the "9th Optical 3-D Measurement Techniques 2009" in Vienna. The session "Applications of Artificial Intelligence in Optical 3D-

Systems" has presented research work of different origin and content, e.g. basic research, application oriented research, etc.

In 2010 the WG has organized the "Second International Workshop on Application of Artificial Intelligence and Innovations in Engineering Geodesy – AIEG2010" in Braunschweig/Germany. The meeting was co-sponsored by Inmetris3D and Trimble. About 40 experts from Germany, Italy, Greek, Turkey and Austria have participated. The program consisted of presentations and tutorials. The key note was given by Prof. Hansjörg Kutterer from the Leibniz University Hannover. Oral presentations have been focused on the application of vector machines, artificial neuronal networks, intelligent sensor fusion, decision-support systems, etc. The workshop proceedings have been published in one Volume which has about 110 pages.

For an easy communication within the WG a central data exchange unit and a mailing list have been installed.
In 2010 some members of the WG have composed a paper about methods of AI in geodesy. The paper will be published in 2011 in the Journal of Applied Geodesy.

Publications:

Reiterer A., U. Egly (Eds.): Application of Artificial Intelligence in Engineering Geodesy. Proceedings for the First Worksop on AIEG, 2008. http://info.tuwien.ac.at/ingeo/sc4/wg423/AIEG2008.pdf

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Reiterer A., U. Egly, T. Vicovac, T. Mai, S. Moafipoor, D. Grejner-Brzezinska, C. Toth: Application of Artificial Intelligence in Geodesy – A Review of Theoretical Foundations and Practical Examples. Journal of Applied Geodesy. Accepted for Publication.

IAG WG 4.2.4: Investigation of Kinematic and Dynamic Behaviour of Landslides and System Analysis

Chair: Gyula Mentes

Surface mass movements can cause a lot of damages. Forecasting landslides is of crucial importance due to the potentially serious consequences to the society. It is a difficult and complex task which needs understanding of the relationships between landslide generating processes (geological, geophysical, hydrological, meteorological, etc.) and movements of the sliding block and its surroundings. In addition to the continuous recording geophysical, hydrological, meteorological, etc. parameters, there is an urgent need for continuous 3D geodetic measurements to determine the complex movements of the landslide prone area to understand the kinematic and dynamic behaviour of landslides. There is only a chance to develop an early warning system in exact knowledge of the moving process of the landslide area and all of other physical parameters. According to these requirements the working group laid a special emphasis on the following research areas:

- detection of potential landslides on large scale
- an efficient and continuous observation of critical areas
- a knowledge-based derivation of real time information about actual risks in order to support an alert system (Kahmen et al., 2007).

The main task of the working group in the last four years was the development of 3D geodetic measurement techniques. In the most cases different geodetic measuring methods were used simultaneously on the test sites, both to get more precise information about the movements and to test and compare the single measuring systems. For detection of landslide prone areas InSAR technique was used (Riedel and Walther, 2008). The InSAR technique was also combined with terrestrial geodetic measuring techniques 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.

In Germany at the Institute of Physical Geodesy of the Darmstadt University of Technology and at the Braunschweig University of Technology ground-based microwave interferometry was used to monitor surface displacements in a quarry (Niemeier and Riedel, 2010; Rödelsperger et al., 2010). Time domain reflectometry (TDR) for the detection of surface displacements in boreholes and reflectorless video tacheometry (VTPS) and a low cost GNSS sensor array for 3D determination of surface movements were tested by the researchers of the Chair of Engineering Geology and Chair of Geodesy of Munich University of Technology and Institute of Geodesy of UniBw Munich (Thuro et al., 2010). At the Institute of Geodesy and Geophysics of the Vienna University of Technology and at the Geodetic Institute of the Darmstadt University of Technology automatic tacheometer measurement system was used for landslide monitoring and an adaptive Kalman-filtering method was developed to predict displacements (Schmalz et al., 2010) with the aim to develop an early warning system.

All members carried out measurements at different types of landslide areas: in mountainous and hilly regions, on streambanks. This makes possible to better understand the general relationships between movements and geological, geomorphological, hydrological, meteorological, etc. factors and their role in triggering landslides. The investigated test sites were: Steinlehnen test site in Austria (Northern Tyrol), Baota test site in China, the Aggenalm Landslide in the Bavarian Alps in Germany, Touzla overpass, Kristallopigi landslide, Basilikos landslide, Gkrika Cuts, Prinotopa site, Anthohori entrance, the Big Cut in Greek, the high loess banks of the River Danube at Dunaföldvár and Dunaszekcső in Hungary, Corvara test site in Italy.

All the participants collected their data in GIS (see e.g. Lakakis et al., 2009a; Mentes, 2008a and 2008b) and used these data to develop Spatial Decision Support Systems (SDSS) (e.g. Lakakis et al., 2009b) and early warning systems. To get reliable information about the landslide behaviour with the use of all available information Support Vector Machine (SVM) modelling was developed (Riedel and Heinert, 2008). An Adaptive Kalman-Filtering method was developed for the Calibration of Finite Difference Models of Mass Movements and for prediction of displacements on the basis of real time measurements (Schmalz et al., 2010).

In Hungary two characteristic landslide prone areas were investigated. Both test sites are streambanks along the River Danube. At the first test site in Dunaföldvár landslides occurred several times. Here continuous borehole tilt measurements have been carried out since 2002. Relationships between regional tectonics, subsurface structures and mass movements were investigated based on remote sensing data, gravity and tilt measurements in cooperation between the Geodetic and Geophysical Research Institute of the Hungarian Academy of

Sciences and the Berlin University of Technology, Institute of Geosciences, Department of Hydrogeology and Bureau of Applied Geoscientific Remote Sensing (Mentes, 2008a, 2008b; Mentes et al., 2009; Újvári et al., 2008). At this test site the relationships between hydrological effects (water stage of the River Danube, ground water table and precipitation) and streambank movements were also investigated in detail.

The other test site at Dunaszekcső in Hungary gave a good opportunity to investigate the whole process of the landslide mechanism, since a large landslide occurred at this test site on February 12, 2008. The high bank on this area was sliding slowly with increasing velocity since September of 2007 till February 12, 2008. On this day there was an abrupt sliding. About 500.000 m^3 loess was sliding toward to the Danube. The movements before, during and after the sliding process were monitored by GPS and borehole tilt measurements. The study of the movement is a good possibility to understand the kinematics and dynamics of the slope (Újvári et al., 2009) and therefore the investigations are continued. The high bank is still moving and a next slide event is expected to take place on the South part of the test site in the near future.

The Institute of Geodesy and Geophysics of the Vienna University of Technology in cooperation with the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences develops measurement methods and their mathematical background for detecting very small displacements by accelerometers and borehole tiltmeters with very high resolution (1 nrad). These small movements are not detectable by geodetic methods but their early detection is very important for forecasting of a possible landslide. The most important issue of this research is that how can be the small movements caused by the initial phase of a landslide separated from the background noise (Kahmen et al., 2007; Mentes, 2008b and 2008c).

In this period the inactive members of the working group were replaced for other members working actively in landslide research. As the presented examples showed the member of the working group actively cooperated with each other and achieved new scientific results. If the work of the group can be continued in the next period, then a workshop will be organized in Sopron, Hungary.

Publications:

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Working Group 4.2.5 – Ubiquitous Positioning Systems (Joint with FIG Working Group 5.5)

Chair: Allison Kealy

Objectives

The challenge of delivering ubiquitous positioning capabilities i.e. geopositioning in all environments, has raised numerous philosophical, technical and operational questions, many of which are currently under investigation by a vast, multi-disciplinary, international research community. This working group has been established as a response to these questions and aims to draw together these international efforts under a common umbrella project of ubiquitous positioning.

Terms of Reference

This group will focus on the development of shared resources that extend our understanding of the theory, tools and technologies applicable to the development of ubiquitous positioning systems. It has a major focus on:

- Performance characterization of positioning sensors and technologies that can play a role in the development of ubiquitous positioning systems.
- Theoretical and practical evaluation of current algorithms for measurement integration within ubiquitous positioning systems.

– The development of new measurement integration algorithms based around innovative modeling techniques in other research domains such as machine learning and genetic algorithms, spatial cognition etc.
– Generating formal parameters that describe the performance of current and emerging positioning technologies that can inform FIG and IAG members.

Report on activities

In 2009, the FIG working group WG5.5 collaborative with IAG working group 4.2.5 – Ubiquitous Positioning Systems - held two international workshops. These workshops kicked off a longer term practical study into understanding the signals used in ubiquitous positioning systems. Low-cost MEMS inertial navigation sensors (INS) were the focus of these tests. With the overall aim of characterizing the operational environment for mobile users (using a range of low-cost MEMS INS) the first workshop was held at the University of New South Wales, Sydney. The second workshop was held at the Ohio State University with the aim of acquiring benchmarking datasets for GNSS/INS systems that could be used by the broader research community.

To evaluate the performance of low-cost MEMS INS within the context of bridging GPS outages and maintaining the availability of a position solution, a time synchronisation software package has been developed as a generic data capture platform for ubiquitous positioning, and allows for the addition of new sensors by simply configuring a few parameters describing the communications interface, data output format, field descriptions and data conversion factors. The program uses the GPS pulse per second (PPS) when it is available to synchronize the incoming data while native kernel32 is used between GPS time updates. This software package will soon be available on a resources website currently under development by this working group.

The aim of the second workshop was to generate representative datasets that could be used in benchmarking the performance of MEMS INS as well as providing a data resource for the research community involved in the development of GPS/INS sensor fusion algorithms. A range of MEMS INS with small variations in the manufacturer performance specifications and a navigation grade INS were used in these tests. The datasets collected and all associated information will also be made freely available to the broader FIG/IAG research community on the working group website.

Meetings:

A kick-off meeting was held in December 2009 in Sydney, Australia to confirm the terms of reference, initiate participation and outline work packages to be completed in the first year of this working group. The working group was formally launched at the FIG meeting in April 2010 and a second meeting for current participants was held in May 2010 at the Ohio State University, USA. Working group activities planned for 2011 include participation in the FIG Working Week in Marrakech, Morocco, the ION GNSS conference in Portland, Oregon, the IUGG Symposium in Melbourne, Australia, the IGNSS conference in Sydney, Australia, the International Mobile Mapping Symposium in Krakow, Poland in June 2011, and the Location-Based Services Symposium in Vienna, Austria

Sub-Commission 4.3: Remote Sensing and Modelling of the Atmosphere

President: Marcelo Santos (Canada)
Vice-President: Jens Wickert (Germany)

Terms of Reference

The objective of Sub-Commission 4.3 (SC 4.3) is to coordinate research dealing with the treatment, interpretation and modelling of measurements collected in the atmosphere for the purpose of improvements in geodetic positioning as well as for better understanding the atmosphere itself. Even though GNSS techniques are seen here as the primary research tools, other sensors also bring important information on the atmosphere and as such should be considered in the context of this Sub-Commission. Dedicated satellites, having on-board GNSS receivers, can also contribute to atmospheric studies by exploring the atmosphere-induced bending of GNSS signals while propagating through the atmosphere, to furnish round-the-clock weather data, monitor climate change, and improve space weather forecasts. Geodetic positioning can benefit and contribute to atmospheric models, such as Numerical Weather Prediction (NWP) models. Novel advancements in modelling the atmosphere as applied to positioning, error sources, instrumentation, dedicated missions, and real- or near real-time data access should also be contemplated. SC4.3 will foster linkages with sister scientific and professional organizations, such as IAG, ISPRS, FIG, IEEE and ION.

Meetings

As a sub-Committee activity, two Symposia were organized during IAG Assemblies. One of them during the IAG General Assembly, Buenos Aires, Argentina, Aug 31 – Sep 4, 2009, with title "Remote Sensing of the Troposphere." The other being organized for the IUGG General Assembly, 28th June to 7th July, 2011, Melbourne, Australia, with the title "Space geodesy-based atmospheric remote sensing." (joint with IAMAS)

Study Group 4.3.1 - Ionosphere Modelling and Analysis

Chair: Michael Schmidt (Deutsches Geodätisches Forschungsinstitut, Munich, Germany), schmidt@dgfi.badw.de

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Terms of Reference

The general objective of this study group is the development of strategies for establishing ionosphere models which can be used for both, the correction of electromagnetic measurements and the study of ionospheric features and their spatial-temporal evolution. Thus, our overall intention is the combination of physics, mathematics and statistics to derive a high-resolution multi-dimensional ionosphere model.

Research Activities:

– At DGFI a multi-dimensional ionosphere model was developed within the last years which can be used for modelling ionospheric target functions such as the electron density and the vertical total electron content (VTEC) globally, regionally or locally. Depending on the chosen area spherical harmonics, endpoint-interpolating B-splines, trigonometric B-splines, Chapman functions, etc. can be used for the spatial representation. For the temporal representation empirical orthogonal functions, B-splines, a Fourier series, etc. can be chosen. The unknown coefficients of the resulting spatio-temporal multi-dimensional ionosphere model based on tensor products of the different kinds of base functions are estimable from a combination of ground-based GNSS measurements, dual-frequency altimetry and COSMIC/FORMOSAT-3 GPS measurements; data gaps can be handled efficiently by a regularization procedure using prior information.

– Much of the ionospheric modelling efforts in South Africa have been concentrated on practical applications and for contributions towards improvements to the International Reference Ionosphere (IRI). The main areas that the group has concentrated on in the last 2 years are (1) improvements to the South African Bottomside Ionospheric Model (SABIM), (2) the development of a neural network based global foF2 model, (3) the variability of F1 and F2 layer parameters and (4) the development of an ionospheric map for South Africa.

– The research work on ionosphere at NCU is to carry out studies of the structure and dynamics of near-Earth space plasma distribution and investigation of space weather under different solar-geophysical conditions. The proposed research will be carried out by ionosphere profiling and modeling and on the base of ionosondes, low-orbital (American TRANSIT and Russian TSIKADA/PARUS) and high-orbital (American GPS and Russian GLONASS) navigational satellite systems.

– The DLR at Neustrelitz is establishing an ionosphere weather service via the project SWACI (http://swaciweb.dlr.de) which is essentially supported by the German state government of Mecklenburg-Vorpommern. The service includes the provision of data products deduced from ground- and space-based GNSS measurements. Whereas ground-based GNSS measurements provide VTEC maps and corresponding derivatives, spaced-based measurements provide vertical electron density profiles and 3D reconstructions of the topside ionosphere/plasmasphere systems. All retrieval techniques are model assisted:

- The DLR model NTCM is used as a background model for creating TEC maps by data assimilation.
- A Chapman layer based model is assisting the retrieval of vertical electron density profiles from radio occultation measurements onboard CHAMP and GRACE satellites.
- The PIM model is used as a background model for 3D reconstructions of the topside ionosphere/plasmasphere systems using navigation data from the CHAMP satellite

- With its standard X/S-band dual frequency observing sessions Very Long Baseline Interferometry (VLBI) provides consistent ionospheric delays from 1979 until today. The network of geodetic/astrometric VLBI guided by the International VLBI Service of Geodesy and Astrometry (IVS) consists of sites with a globally distribution, which take part in routine observing sessions more or less sparsely. At DGFI first considerations have been carried out evaluating a potential contribution of slant total electron content (STEC) from IVS data to a combined model of the ionosphere.
- In the last 2 years the Institute of Geodesy and Geophysics (IGG) of TU Vienna has successfully accomplished the development of combined global VTEC models from GNSS and altimetry. To achieve this goal spherical harmonics of degree 15 were used. Global Ionosphere Maps (GIMs) with spatial resolution of 2.5^o latitude, 5^o longitude and temporal resolution of 2 hours are estimated. Next VTEC measurements derived from FORMOSAT-3/COSMIC occultation data were combined with the GIMs by recursive parameter estimation. Different empirical weighting methods were applied. The results clearly show improvement of VTEC maps in the time when occultation measurements are carried out in regions with low number of GNSS stations, i.e. mainly on ocean.
- At the Middle East Technical University (METU) B-spline functions were used to model VTEC on the basis of real GPS observations collected over Turkey. For 2D case, VTEC is modeled in sun-fixed reference frame while 3D approach including the time to represent the temporal variations the modelling was performed in an Earth-fixed reference frame. Iteratively re-weighted least squares (IRLS) with a bi-square weighting function as a robust regression algorithm was carried out for the parameter estimation procedure in order to reduce the effects of outliers. Another iterative method, i.e. Conjugate Gradient Least Squares (CGLS) method was performed to bring about regularization effect for ill-conditioned problems in large equations.
- In a second project at METU an efficient algorithm with Multivariate Adaptive Regression Splines (MARS) was developed for regional spatio-temporal mapping of the ionospheric electron density using ground-based GPS observations. MARS is able to handle very large datasets and is an adaptive and flexible method, which can be applied to linear and non-linear problems. The base functions are directly obtained from the observations and have space partitioning properties resulting in an adaptive model that provides solutions in region with rare observations without regularization. Since the fitting procedure is additive it does not require gridding and is able to process large amounts of data with large gaps. The performance and adaptivity of the MARS algorithm were applied to real GPS data over Europe.
- The work at Goddard Space Flight Centre (NASA/GSFC) was concentrating on the validation of the International Reference Ionosphere (IRI) using in situ measurements from GRACE K-Band ranging and CHAMP planar langmuir probe (PLP). The ionospheric delay derived by combination of dual frequency K-Band ranging measurements of GRACE infers the electron density integrated between the two satellites along the orbit with a baseline length of approximately 220 km at the altitude of around 450 km. We

compared the GRACE KBR and PLP measurements with the electron density derived from IRI and validated the recent advances in IRI.

- The research activities within SG4.3.1 will be bundled in a special issue of Journal of Geodesy, which will be published hopefully next year. General Topic of the Special Issue reads: Geodetic contributions to ionosphere research. List of individual papers:
  1. Schmidt, M.: Introduction
  2. Hernandez-Pajarez, M., J.M. Juan, J. Sanz, A. Aragon-Angel, A. Gracia-Rigo, D. Salazar: The Ionosphere: effects, modelling and benefits in the Space Geodetic techniques
  3. Bilitza, D., L.-A. McKinnell, B. Reinisch, T. Fuller-Rowell: The International Reference Ionosphere (IRI) today and in the future
  4. Dettmering, D., M. Schmidt, R. Heinkelmann, M. Seitz: Combination of different satellite observation data for regional ionosphere modeling
  5. Alizadeh M.M., H. Schuh, S. Todorova, M. Schmidt: Global Ionosphere Maps of VTEC from GNSS, Satellite Altimetry and FORMOSAT-3/COSMIC Data
  6. Brunini, C., F. Azpilicueta, M. Gende, E. Camilion, A. Aragón-Ángel, M. Hernández-Pajares, J.M. Juan, J. Sanz, D. Salazar: Ground- and space-based GPS data ingestion into the NeQuick model
  7. A. Krankowski, I. Zakharenkova, A. Krypiak-Gregorczyk, I.I. Shagimuratov, P. Wielgosz: Ionospheric electron density observed by FORMOSAT-3/COSMIC over the European region and validated by ionosonde data
  8. N. Jakowski, M.M. Hoque, C. Mayer: A new global TEC model for estimating transionospheric radio wave propagation errors
  9. Tsai, L.-C., K. Kevin Cheng, C. H. Liu: GPS radio occultation measurements on ionospheric electron density from low Earth orbit
  10. Lee, C.-K., S.-C. Han, D. Bilitza, J.-K. Chung: Validation of the International Reference Ionosphere models using in situ measurements from GRACE K-Band ranging and CHAMP planar langmuir probe

Meetings:

- TUJK, Annual Scientific Meeting, 2007-11-14/16, Ankara, Turkey (Karslioglu, Nohotcu, Schmidt, Heinkelmann)
- EGU 2008, General Assembly, 2008-04-14/18, Vienna, Austria (Schmidt, Alizadeh, Heinkelmann)
- URSI 2008, General Assembly, 2008-08-07/16, Chicago, USA (Schmidt, Tsai, Bilitza, McKinnell)
- EGU 2009, General Assembly, 2009-04-19/24, Vienna, Austria (Schmidt, Dettmering, Tsai, Alizadeh, Bilitza, Krankowski, Wielgosz, Han)
- Splinter Meeting of IAG SG 4.3.1, 2009-04-23, TU Vienna, Austria (Schmidt, Dettmering, Tsai, Alizadeh, Bilitza, Krankowski, Wielgosz)
- Real-time IRI Task Force Workshop, 2009-05-04/06, Colorado Springs, USA (Schmidt, Bilitza)

– A. Krankowski, M.O. Karslioglu and myself organize the session G5.1 Monitoring and modelling of the ionosphere from space-geodetic techniques at EGU 2011 in Vienna. The topic of the session is closely related to the objectives of the IAG Study Group.

Publications:

Adewale A.O., Oyeyemi E.O., and McKinnell L.A., "Comparisons of observed ionospheric F2 peak parameters with IRI-2001 predictions over South Africa", Journal of Atmospheric and Solar Terrestrial Physics, 71(2), doi:10.1016/j.jastp.2008.10.014, pp. 273-284, 2009.

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McKinnell L.A., and Friedrich M., "A neural network based model for the auroral zone", Journal of Atmospheric and Solar Terrestrial Physics, doi:10.1016/j.jastp.2007.05.003, 69, pp. 1459 – 1470, 2007.

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Working Group 4.3.1 - Atmospheric refractivity, TEC and Ionospheric Scintillation

Chair: Lucilla Alfonsi (INGV, Italy)
Co-Chair: Sybille Vey (TU Dresden)

Terms of Reference

To collect experimental data to derive information on precipitable water vapour, TEC and ionospheric scintillation by means of GPS monitors/receivers, at high and mid latitudes, and to study the tropospheric and ionospheric impact on precise positioning operations, during both quiet and disturbed conditions at middle and high latitudes.

Report on activities

During the first months of the WG the work has been mainly dedicated to the first attempts of exchange data and expertise on ionospheric imaging and mitigation of ionospheric effects on GNSS signals. A feasibility study on the use of Antarctic measurements, run by both geodetic and ionospheric teams, for water vapour reconstruction is currently in progress by using the GPS data collected at the Italian station "Mario Zucchelli" (Terra Nova Bay, Antarctica).

Recently available, global tropospheric models for water vapour retrieval were implemented in the analysis of geodetic observations with the purpose of improve the estimation process of zenith total delay with GPS data. Comparisons with old models are being carried out and alternative techniques for water vapour content estimation, such as radiosonde. In particular, common data sets from different techniques and overlapping observations periods have been identified and adopted as test benchmarks on which cross checking can be performed and integrated water vapour can be computed. Analysis is currently in progress. A collaboration with the geodetic groups dealing with Mediterranean GPS data is planned to start multidisciplinary studies also at middle latitudes. From 2009 to 2011 the WG work has been dedicated to exchange data and expertise on ionospheric imaging and mitigation of ionospheric effects on GNSS signals at high and low latitudes. The use of Antarctic measurements, run by both geodetic and ionospheric teams, for water vapour and ionospheric electron density reconstruction is the core of an Action Group, titled "GPS for Weather and Space Weather Forecasting", endorsed by SCAR (Scientific committee for Antarctic Research) on July 2010. Collaboration with the geodetic groups dealing with Mediterranean GPS data has produced a prototype of real-time imaging of the Mediterranean ionosphere called MIRTO (Mediterranean Ionosphere With Real-Time Tomography).

Publications

L. Alfonsi, Y. Ping, C.N. Mitchell,G. De Franceschi, V. Romano, P. Sarti, M. Negusini, A. Capra, GPS imaging of the antarctic ionosphere: a first attempt. Presentation during the *SCAR Open Science Conference (St. Petersburg, July 2008)*. The work presents the potentialities of using the geodetic data also for producing ionospheric imaging, for the first time, over Antarctica.

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P. Sarti, M. Negusini, C. Lanconelli, A. Lupi, C. Tomasi, gps and radiosonde derived precipitable water vapour content and its relationship with 5 years of long-wave radiation measurements at "mario zucchelli" station, terra nova bay, antarctica. Poster at the *SCAR Open Science Conference (St. Petersburg, July 2008).* The work presents the long time series of water vapour content computed with GPS at Terra Nova Bay and its relation with long wave radiation.

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Luca Spogli, Lucilla Alfonsi, Giorgiana De Franceschi, Vincenzo Romano, Marcio Aquino, Alan Dodson, climatology of the ionospheric scintillations: first results over the auroral and cusp European regions. Poster at *V European Space Weather Week (Brussels,17-21 November, 2008).* The work deals with the use of GPS high rate data to investigate the scintillation scenario due to irregularities of perturbed ionosphere from cusp to auroral region during high solar activity.

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De Franceschi, G., L. Alfonsi, V. Romano, L. Spogli, M. Aquino, A. Dodson. GPS ionospheric scintillation monitoring and investigation at high latitude. *Invited talk to the AGU Fall Meeting (San Francisco, 15-19 December 2008), Session G44A: Synergy Between GNSS/GPS Observation Systems and Climate, Meteorological, and Ionospheric Applications II.* A review on scintillation and plasma dynamics deduced by ionospheric imaging over polar regions is presented.

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Alfonsi, L., Monitoring and investigations of high latitude ionospheric irregularities using GPS signals Dayside Cusp and Polar Cap Ionosphere: Present knowledge and future planning, Oslo (Norway), April 2009.

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Aquino M., Monico J.F.G., Dodson A.H., Marques H., De Franceschi G., Alfonsi Lu., Romano V., Andreotti M., Improving the GNSS Positioning Stochastic Model in the Presence of Ionospheric Scintillation, *Journal of Geodesy (2009),* doi: 10.1007/s00190-009-0313-6.

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Working Group 4.3.3 – Numerical Weather Predictions for Positioning

Chair: Thomas Hobiger (Kashima Space Research Center, Japan)

Terms of Reference

To study various technical aspects of using Numerical Weather Prediction (NWP) model data to map the effect of troposphere on space geodetic signals. To concatenate the terminology used by both meteorological and geodetic communities. To test and sediment procedures related to ray-tracing through NWP data layers. To suggest quality control criteria to be used for assessing the quality of tropospheric data and results obtained from them. To evaluate state of the art and report the progress achieved during the time-life of the WG on the use of NWP for positioning.

Report on activities

In order to draw conclusions about the best way for ray-tracing based on numerical weather data, two radiosonde profiles (kindly provided by A. Niell) were selected as basis for all investigations. At first, the focus was set on zenith hydrostatic (ZHD) and wet delays (ZWD) whereas six independent solutions were submitted for comparison. As for the hydrostatic components all solutions agreed within 1 mm, including the model by Saastamoinen (1972), which has been computed additionally. The wet delays showed larger scattering between the different solutions, likely caused by different interpolation strategies of the water vapour constituents. Some groups linearly interpolate relative humidity before converting it to water vapour pressure, other groups prefer to interpolate water vapour pressure levels using an exponential scheme. Nevertheless, all submitted solution were found to be within +/- 1 mm from the average over all results.

After comparison of zenith delays, a second call was made to submit ray-traced dry and wet slant delays, based on the same profiles under the assumption of spherical symmetry. In total, four WG members followed this call and submitted their results for elevations angles ranging from 3 to 90 degrees, in steps of one degree. In general, all solutions agreed well with each other, having only larger differences (~1 cm) at the very low elevation angles (i.e. below 10 degrees). These differences are thought to be caused by the different ray-tracing operators used for the calculation of the ray-path. In general, it could be stated that smaller integration steps are preferred rather than ray-tracing in coarse steps. Better modeling of asymmetric delays due to the Earth's ellipticity as well as proper consideration of bending angle effects have been pointed out as well.

Activities through 2009 involved (a) comparison of ray-traced delays based on radiosonde data (i.e. vertical profile), with submissions from A. Niell, MIT, USA, J. Boehm, VUT, Austria, T. Hobiger, NICT, Japan, R. Ghoddousi-Fard, UNB, Canada, F. Nievinski , UNB, Canada, S. de Haan, KNMI, Netherlands; (b) comparison of ZHD w.r.t. Saastamoinen Model; (c) basically good agreement in across all submissions; (d) differences due to: interpolation of water vapour pressure resp. rel. humidity, choice of ray-tracing model and Earth geometry.

Activities through 2010. "Ray-tracer workshop" organized by IAG SC 1.1. WG3 and IAG WG 4.3.3 held at the Vienna University of Technology in April, 2010. It involved a full 3D ray-tracing comparison. Good agreement between different ray-tracers was obtained. Remaining problem: Different weather model, resulting in totally different ray-traced delays. Suggestions based on the 2nd comparison campaign (from ray-tracer WS):

- Recommendation 1: Ray-tracing should be done at least up to 76 km as upper limit of the troposphere. The US Standard Atmosphere 1976 or the COSPAR International Reference Atmosphere are sufficient as extension for both slant and zenith directions.
- Recommendation 2: A latitude dependent formulae for the radius of curvature of the Earth needs to be applied. (The use of constant radius is not recommended.) The best suggestion for this case will be the more realistic Euler's formula, if ellipsoidal heights are not used directly.
- Recommendation 3: For converting geo-potential to geometric heights, it is recommended to use an expression for normal gravity from (NIMA (2000) or from the Federal Meteorological handbook No 3 (OFCM, 2007).

Meetings and communication:

A kick-off meeting was held during AGU Fall Meeting 2007 and a mailing list was established to distribute information between the WG members. Additionally, the WG homepage[1] has been set-up in "wiki" style, allowing the members to modify the content and upload results directly.

Relevant papers

Böhm, J., B. Werl, and H. Schuh (2006), Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for Medium Range Weather Forecasts operational analysis data, J. Geophys. Res., 111, B02406, doi:10.1029/2005JB003629

Böhm, J., A. Niell, P. Tregoning, and H. Schuh (2006), Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data, Geophysical Research Letters, Vol. 33, L07304,doi:10.1029/2005GL025546 download from AGU

Böhm, J., R. Heinkelmann, and H. Schuh (2007), Short Note: A global model of pressure and temperature for geodetic applications, Journal of Geodesy , doi:10.1007/s00190-007-0135-3 download from JoGeod

Ghoddousi-Fard R., P. Dare and R.B. Langley (2009), Tropospheric delay gradients from numerical weather prediction models: effects on GPS estimated parameters, GPS Solutions, download from GPSSol

Hobiger T. , R. Ichikawa, T. Kondo, and Y. Koyama (2008), Fast and accurate ray-tracing algorithms for real-time space geodetic applications using numerical weather models, Journal of Geophysical Research, vol. 113, no. D203027, pp. 1–14, download from AGU

Hobiger T., R. Ichikawa, T. Takasu, Y. Koyama, and T. Kondo (2008), Ray-traced troposphere slant delays for precise point positioning, Earth, Planets and Space, vol. 60, no. 5, pp. e1–e4 download from EPS (free e-paper).

Hobiger T., Ichikawa R., Koyama Y., Kondo T. (2009), Computation of troposphere slant delays on a GPU, IEEE Transactions of Geoscience and Remote Sensing, accepted, doi10.1109/TGRS.2009.2022168.

Kouba, J. (2007), Implementation and testing of the gridded Vienna Mapping Function 1 (VMF1), Journal of Geodesy , doi:10.1007/s00190-007-0170-0 download from JoGe

Nievinski, Felipe G. (2009). Ray-tracing Options to Mitigate the Neutral Atmosphere Delay in GPS. M.Sc.E. thesis, Department of Geodesy and Geomatics Engineering Technical Report No. 262, University of New Brunswick, Fredericton, New Brunswick, Canada, 232 pp.

Urquhart, Landon (2011). Assessment of Tropospheric Slant Factor Models: Comparison with Three Dimensional Ray-Tracing and Impact on Geodetic Positioning. M.Sc.E. thesis, Department of Geodesy and Geomatics Engineering Technical Report No. 275, University of New Brunswick, Fredericton, New Brunswick, Canada, 166 pp.

Nafisi,V., L. Urquhart, M. C. Santos, F. G. Nievinski, J. Böhm, D. D. Wijaya, H. Schuh, A. A. Ardalan ,T. Hobiger, R. Ichikawa, F. Zus, J. Wickert, P. Gegout. (2011). "Comparison of ray-tracing packages for troposphere delays." Submitted to IEEE Trans. on Geoscience and Remote Sensing

[1] http://www.hobiger.org/wg433/tiki-index.php

Sub-Commission 4.4: Applications of Satellite and Airborne Imaging Systems

President: Prof. Xiaoli Ding (Hong Kong)
Vice-President: Dr. Linlin Ge (Australia)
Secretary: Prof. Makoto Omura (Japan)

Objectives

The main objectives of the Sub-Commission are to promote collaborative research in the development of satellite and airborne imaging systems, primarily including Synthetic Aperture Radar (SAR) and Light Detection And Ranging (LiDAR) systems, for geodetic applications, and to facilitate communications and exchange of data, information and research results through coordinated efforts.

Terms of Reference

(1) Development of methods, models, algorithms and software for geodetic applications of satellite and airborne imaging systems;

(2) Study of effects of field and atmospheric conditions on satellite and airborne imaging systems;

(3) Integration of satellite and airborne imaging systems with other geodetic/geospatial technologies such as GPS and GIS;

(4) Development and promotion of new geodetic applications of satellite and airborne imaging systems; and

(5) Development of collaboration with sister organisations such as FIG and ISPRS, and liaison with image data providers.

Working Groups

The SC has currently the following Working Groups:

WG 4.4.1: Quality Control Framework for InSAR Measurements

Chair: Prof. Xiaoli Ding

Terms of Reference:

To study quality measures and quality control procedures and formulate a quality control framework for InSAR measurements.

WG 4.4.2: Imaging Systems for Monitoring Local Area Surface Deformation

Chair: Prof. Makoto Omura

Terms of Reference:

To study satellite and airborne imaging systems such as InSAR and LiDAR for monitoring local area ground surface deformations such as volcanic and seismic activities, and ground subsidence associated with city development, mining activities, ground liquid withdrawal, and land reclamation.

Research Activities of the Working Groups

InSAR is a very active field of research in the geodetic research communities. The current research issues that the members of the SC are working on include

- The development of more effective methods/algorithms for InSAR solutions;
- The quality control and assurance of InSAR measurements;
- The study and mitigation of biases in InSAR measurements such as the atmospheric effects;
- Integration of InSAR and other geodetic technologies such as GPS and GIS; and
- New and innovative applications of the technology in geodetic studies.

Examples of some of the major research projects that the SC is working on include

- The development of new InSAR approaches such as multi-temporal InSAR (MT-InSAR) techniques. For example, a MT-InSAR technique named Temporarily Coherent Point InSAR (TCP-InSAR)) has been developed that has a number of advantages in applications especially in areas with a small number of SAR acquisitions only are available. Other work includes the development of some new and more effective interferograms filters, some phase unwrapping techniques, and the modeling of detectable deformation gradients when applying InSAR;
- Study of atmospheric effects on InSAR measurements. The effects of both the troposphere and ionosphere on InSAR measurements have been studied to understand their spatial and temporal variations and statistical properties. Various methods have also been studied for mitigating the effects including those based on external data such as GPS, ground and remote sensing meteorological measurements and meteorological models. Study has also been carried out to map the atmospheric water vapour variations and the ionospheric TEC anomalies with InSAR measurements. An interesting case study was conducted with InSAR to map the ionospheric TEC anomalies associated with the Wenchuan earthquake in 2008.
- A large number of projects have been carried in applying InSAR to study various geophysical phenomena associated with earthquakes, and engineering and mining activities. This includes a major collaborative project carried out to study ground deformations associated with mining activities and urban subsidence in many parts of the world. The project involves researchers from a number of countries. Members of the SC have also been working on ground deformations associated with major earthquakes such as the Mw 8.0 Wenchuan earthquake in China that occurred on 12 May 2008, and the Mw 9.0 Fukushima earthquake in Japan that occurred on 11 March 2011. Co-seismic ground deforma-

tions are mapped with InSAR measurements and used for calculating the fault structures of the earthquakes.

Conferences

Members of the SC have been active in both participating and organizing scientific meetings/conferences relevant to the activities of the SC. The following represent a sample of the meetings organized (or co-organized):

- A session on InSAR at the 13th FIG Symposium on Deformation Measurements and Analysis and 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering in Lisbon, Portugal, 12-15 May 2008.
- A special session on SAR at the Japanese Geoscience Union Meeting 2008 in Chiba city, Japan, 25-30 May 2008.
- A session on Earth Observation at the 26th ISTS (International Symposium on Space Technology and Science) in Hamamatsu, Japan, 1-8 June 2008.
- A special session on InSAR, Geodetic Remote Sensing, at the AOGS (Asia Ocean Geophysics Society) conference in Busan, South Korea, 16-20 June 2008.
- A special session, Modern Geodetic Techniques for Surface Deformation Monitoring, at the WPGM (Western Pacific Geophysics Meeting) in Cairns, Australia, 29 July – 1 August 2008.
- 2008 Earthquake Research Institute, University of Tokyo, Workshop on Monitoring and Analyzing Earthquakes, Volcanoes and Ground movements by using SAR and Infra-red Sensors in Tokyo, Japan, 16-17 September 2008.
- A session on SAR at the Japanese Geoscience Union Meeting 2009 in Chiba, Japan, 16-21 May 2009.
- A session on Earth Observation at the 27th ISTS (International Symposium on Space Technology and Science) in Tsukuba city, Japan, 5-12 July 2009.
- Sessions at the IAG Scientific Assembly, Buenos Aries, Argentina, 31 August – 4 September 2009.
- International Conference on Geo-spatial Solutions for Emergency Management (GSEM 2009), Beijing, 14-16 September, 2009.
- International Workshop Spatial Information Technologies for Monitoring the Deformation of Large-Scale Man-made Linear Features, Hong Kong, 11-12 January 2010.
- A special Session, Advanced Interferometric SAR Techniques and their Engineering and Geological Application, Progress in Electromagnetic Research Symposium (PIERS), Xián, 22-26 March2010.
- Asia Pacific Space Geodynamics Program (APSG) Workshop 2010: Progress in Space Geodesy and Earth Environment Change, Shanghai, 16-20 August, 2010.
- International Symposium on Precision Engineering Survey Theory and Spatial Information Technology for High-Speed Railway (HSRPES 2010), Chengdu, 20-22 August 2010.
- 1st International Conference on Sustainable Urbanisation, Hong Kong, 15-17 December 2010.
- Lidar and Radar Mapping: Technologies and Applications, Nanjing, 26-29 May 2011.

- International Symposium on Deformation Measurements, Hong Kong, 1-3 November 2011.
- IAG Symposium: Geodetic Remote Sensing, International Union of Geodesy and Geophysics (IUGG), Melbourne, 28 June – 7 July 2011.
- IEEE International Geoscience and Remote Sensing Symposium (IGARSS) in Sendai, Japan, 1-5 August 2011.

Special Issues

The SC is currently working on the following journal special issues:

- Special issue on InSAR and LiDAR in Journal of Geodesy
- Special issue on urban remote sensing in International Journal of Remote Sensing

Sub-Commission 4.5: High-Precision GNSS

President: Yang Gao (Canada) www.ucalgary.ca/~point/iag.html

Working Groups

WG4.5.1 Quality Measures for Network Based GNSS Positioning
Chair: Xiaolin Meng (The University of Nottingham, UK)

WG4.5.2 Precise Point Positioning and Network-RTK
Chair: Sunil Bisnath (York University, Canada) http://www.yorku.ca/sbisnath/iag/

WG4.5.3 Correction Models for Ultrahigh-Precision GNSS Positioning
Chair: Wu Chen (The Hong Kong Polytechnic Univ., Hong Kong)

WG4.5.4 Data Processing of Multiple GNSS Signals
Chair: Yanming Feng (Queensland University of Technology) http://www.gnss.com.au/iagwg454.html

Academic Activities

- WG4.5.2. "Precise Point Positioning and Network-RTK" forms a small, active, global group of members from academia and the public and private industry.
- A white paper "Current state of Precise Point Positioning and future prospects and limitations" presented at IUGG 24th General Assembly IAG Commission 4 session.
- A paper on "Precise Point Positioning: Past, Present, and Future" published in GPS World's Innovation.
- A working group website created for WG4.5.2: http://www.yorku.ca/sbisnath/iag/.
- A number of PPP and closely associated network RTK papers were presented at the ION GNSS 2008 conference in Savannah, Georgia, USA.
- Members at The University of Calgary has published and presented several papers on their research progress made in the area of GNSS biases and PPP ambiguity resolution central to the development next generation RTK technology
- Research results on Precise Point Positioning at The University of Calgary have been transferred in the form of software system to academic and industry sectors to support research activities and product development.
- Members at the University of New Brunswick have created a PPP software comparison website: http://gge.unb.ca/Resources/PPP/.
- WG4.5.1. "Quality Measures for
- 4 "Data Processing of Multiple GNSS Signals" forms a membership with members from academia and the private industry.
- A website has been created for WG4.5.4 "Data Processing of Multiple GNSS Signals": http://www.gnss.com.au/iagwg454.html, which provides a list of 145 papers.
- WG4.5.4 Chair Yanming Feng gave a keynote speech on "Three carrier Ambiguity Resolution: Generalized Problems, Models, Solutions and Performance" at International Workshop on Geodetic Theory 2009.

- WG4.5.4 members present four papers at ION GNSS 2008 session 6D "Multiple-frequency GNSS algorithms".
- WG4.5.4 members published fourteen journal papers and seven conference papers.
- SC4.5 has made significant contributions in advancing high precision GNSS technologies in the past four years through various academic activities from timely research publications, white papers, special journal issues, group discussions to the organization of numerous conference and technical sessions. Its members have also made many technical presentations to the industry sector to accelerate the dissemination and commercialization of new technological advances in high precision GNSS, including the launch of a PPP software centre for public access. Today PPP has become a widely recognized technology for high precision GNSS and its commercial uses are increasing with strong market demands. PPP is considered one of the most significant advances for precision positioning since the advent of RTK technology. Network RTK has also been further enhanced with many new progresses particularly in the area of RTK with multi-constellation signals and quality control of RTK solutions. SC4.5 will continue its contribution to the advance of future high precision GNSS technologies.
- WG4.5.1 created a website on "Quality Measures for Network Based GNSS Positioning".
- WG4.5.2 developed a PPP software centre: http://gge.unb.ca/Resources/PPP/ to promote the PPP concept and the evaluation of different PPP software packages.
- WG4.5.2 continued promotion of PPP for precision positioning, data and user algorithm development and testing: observables, multi-GNSS, error modeling, ambiguity resolution, etc. and evaluation of current network RTK positioning performance
- WG4.5.3 updated the publication list for research papers on multiple GNSS data processing.
- WG4.5.3 edited a special issue for Journal of GPS on data processing of multi-GNSS signals
- WG4.5.3 created a website to publish the reference list for research publications in the field of multiple GNSS data processing, currently with more than 100 papers (http://www.gnss.com.au/iagwg454.html)
- Network Based GNSS Positioning" forms a membership with members from academia and the private industry.
- A link to previous WG of IAG has been set up to integrate existing findings with this group: www.network-rtk.info/
- Members at The University of Nottingham conducted systematic studies on the quality issues of network RTK positioning and a systematic approach has been designed to quantify the quality of the RTK corrections in real time and relevant data processing and quality assessment platform has been developed. A number of papers have been published in journals (e.g. Journal of Applied Geodesy, GPS World) and international conferences (e.g. ION, ENC and FIG).
- Members at The University of Newcastle upon Tyne have conducted a series of field tests using the Ordnance Survey's facility aiming at creating best practice guidance to the surveyors using NRTK.
- Around 200 people attended the ground breaking Launch Day of the Network RTK Best Practice Guidelines that was organised by the University of Newcastle upon Tyne. This report can be downloaded from the website of The Survey Association (TSA) at http://www.tsa-uk.org.uk/guidance.php.

- Member at in Position worked on the combination of different GNSS into one seamless positioning network and solution. The use of observations of different GNSS constellations is relatively straight-forward as long as similar receiver types are used throughout the network configuration. Especially for an arbitrary mix of receivers of different manufacturers the overall concepts for processing GNSS observations in real-time need adaptation.
- New concepts for processing multiple receiver observation information and quality control techniques are desperately required. The publications concentrate the options for optimal use of a multi-GNSS receiver together with other GNSS receivers not supporting the complete set of GNSS. The computation scheme developed allows an arbitrary mix of GNSS receivers. Results based on post-processing and real-time processing have been published on various conferences (see literature list)
- WG4.5.WG4.5.3 developed a wiki-page "Three Carrier Ambiguity Resolution", which is currently under review.

Conferences, Workshops, Technical Sessions

- SC4.5 helped organize several technical meetings and workshops including International Technical Meeting on GNSS – "The Next Generation GNSS - Innovation and Applications" to be held in Beijing, August 7-9, 2009; Chinese Technical Application Association for GPS (CTAAGPS) on New Navigation Technologies and Innovations, Beijing, December 18-20, 2008; Scientific Workshop on Hazard Monitoring by Geosciences, Wuhan, China, May 22, 2008.
- SC4.5 President Yang Gao gave invited talks at several technical meetings such as IGS Workshop 2008, Florida, USA, 2-6 June 2008; CTAAGPS Annual Meeting on New Navigation Technologies and Innovations, Beijing, China, December 18-20, 2008.
- A session on PPP vs DGPS central to IAG Commission 4 "Positioning and Applications" held at the International Union of Geodesy and Geophysics 24th General Assembly, Perugia, Italy, 2-13 July 2007.
- WG4.5.2 organized a PPP workshop in June 2008, Niagara Fall, Canada: http://gge.unb.ca/Research/GRL/GNSS/NiagaraFallsPPP2008.htm.
- WG4.5.1 co-organised LBS 2009 Workshop in Nottingham
- WG4.5.4 co-organized International Workshop on Geodetic Theory 2009, Tongji University on behalf of AIG Commission IV, 1-2 June 2009.
- WG4.5.2 organized a PPP and network RTK session at the upcoming ION GNSS 2009 conference in Savannah, USA.
- SC4.5 helped organize CPGPS 2010 Technical Forum on Satellite Navigation and Positioning, August 18-20, 2010, Shanghai, China. IAG is a sponsor of the conference.
- SC4.5 helped organize 2nd Annual China Satellite Navigation Conference, May, 2011, Shanghai, China.
- WG4.5.1 co-organized the International Workshop on Geodetic Theory 2009 at Tongji University, June 1-2, 2009. IAG is the sponsor of the workshop.
- WG4.5.3 involved in the organization of LBS 2010 in Guangzhou, September 20 -22, 2010, as the vice chair for this conference.
- WG4.5.2 organized a technical session on "Precise Point Positioning and Network RTK" at ION GNSS 2010, Portland, Oregon, USA, September 20-24, 2010.

- WG4.5.3 organized a special session on "Data Processing of Multiple GNSS Signals" for IGNS2011, Canberra, Australia.
- WG4.5.1 co-organize "2011 International Symposium on Image and Data Fusion" http://isidf2011.casm.ac.cn.
- WG4.5.1 organize a workshop on "Network RTK Quality Control and Engineering and Environmental Applications" in Nottingham , July 2011.
- WG4.5.3 organize a joint workshop (e.g. with CPGPS) on "Data Processing of Multiple GNSS Signals"
- WG4.5.1 helped organize 6th International Symposium on LBS and TeleCartography, The University of Nottingham, 2009
- WG4.5.1 helped organize 7th International Symposium on LBS and TeleCartography, Guangzhou, China, 2010
- WG4.5.1 helped organize 8th International Symposium on LBS and TeleCartography, Vienna, Austria, 2011
- WG4.5.1 helped organize a special session at IEEE Intelligent Vehicles Symposium, Baden-Baden, Germany, June 5-9, 2011.
- WG4.5.1 helped organize ISPRS - The 2011 International Symposium on Image and Data Fusion, Tengchong, China, 2011

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Study Group 4.2: GNSS Remote Sensing and Applications

Chair: Shuanggen Jin (Shanghai Astron. Observ./Uni. Texas at Austin, USA)

Terms of Reference:

Nowadays, the Global Navigation Satellite System (GNSS), which is a very powerful and important contributor to all scientific questions related to high precision positioning on Earth's surface, has been widely used as a mature technique in geodesy and geodynamics. Recently, the versatility and availability of reflected and refracted signals from GNSS gave birth to many new GNSS applications for various environmental remote-sensing in atmosphere, ocean and land. Many countries have initiated efforts in this area of researches and applications. The focus of this Study Group (SG4.1) is to facilitate collaboration and communication, and to support joint researches with new GNSS remote sensing techniques. Specific objectives will be achieved through closely working with members 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/extend developments of current GPS reflected signal sensor and Radio occultation techniques and their applications;
- To improve the existing estimation algorithms and data processing for GPS reflected signals and Radio occultation;
- To coordinate data collection campaigns and to compare with terrestrial and satellite observations, in order to encourage research and development into the crucial measurement and applications;
- To investigate applications in atmosphere, ocean and land as well as space sciences.

Website:

http://www.geosensings.com/iag-sg4.1

Activities

2011

- **7-9 August 2011,** Shuanggen Jin organized an international workshop on GNSS Remote Sensing for Future Missions and Sciences, Shanghai, China
- **12-16 September 2011**, Shuanggen Jin Chaired one session “Remote Sensing using GNSS and other sensors” at Progress In Electromagnetics Res. Symp. (PIERS 2011) and gave one talk, Suzhou, China
- **8-12 August 2011**, Shuanggen Jin Chaired one session “Exploration and Science of Venus at Asia Oceania Geosciences Society (AOGS 2011) and gave one talk, Taipei, Taiwan.

- **25-29 July 2011**, Shuanggen Jin Chaired one session "GNSS Remote Sensing in the Atmosphere, Ocean and Hydrology at the IEEE Int. Geosci. & Remote Sens. Symp (IGARSS 2011) and present two invited papers, Vancouver, Canada.
- **28 June-7 July 2011**, Shuanggen Jin participated in the XXV IUGG General Assembly (IUGG 2011) with one oral talk, Melbourne, Australia.
- **24-26 June 2011,** Shuanggen Jin Chaired one session "Remote Sensing and Climate Change" at the 19th International Conference on GeoInformatics and presented one paper, Shanghai, China
- **15-18 May 2011**, Shuanggen Jin participated in Chinese Satellite Navigation Conference (CSNC 2011) with one paper, Shanghai, China

2010

- **26-28 October 2010**, Shuanggen Jin was a Advisor Board Member, MarineTech Summit-2010 (MTS-2010), Dalian, China.
- **25-28 October 2010**, Shuanggen Jin attended the GGOS/IAU Workshop on Observing and Understanding Earth Rotation and chaired one session with two presentations, Shanghai, China.
- **4-8 October 2010**, Shuanggen Jin gave one invited talk at the URSI-F Symposium on Microwave Remote Sensing of the Earth, Oceans, and Atmosphere, Florence, Italy.
- **3 October 2010**, Jose M. Sánchez Reales (Ph.D student, University of Alicante, Spain) is welcomed to visit the Shanghai Astronomical Observatory, Chinese Academy of Sciences, China from October 2010 to April 2011.
- **18-20 August 2010**, Shuanggen Jin attended the CPGPS Technical Forum on Satellite Navigation & Positioning and Chaired one Session with one talk, Shanghai, China.
- **11 May 2010**, Shuanggen Jin gave a seminar talk on GNSS, Gravity and Geodesy at the Center for Space Research, University of Texas at Austin, Austin, Texas, USA.
- **9-25 April 2010**, Shuanggen Jin visited gave several talks at Shanghai Astronomical Observatory, CAS, Wuhan University, University of Science and Technology of China, Nanjing Aeronautics & Astronautics University, Hehai University, Institute of Geodesy and Geophysics, CAS, etc.

2009

- **31 August-4 September 2009**, Shuanggen Jin attended the International Association of Geodesy (IAG) Scientific Assembly, Buenos Aires, Argentina and Chaired one sub-session "Multi-satellite Ocean Remote Sensing" as well as presented two papers.
- **8-10 August 2009**, Shuanggen Jin attended International Technical Meeting on GNSS (ITM-GNSS)-Innovation and Application, Beijing, China with one presentation and Chaired one session.
- **13-17 July 2009**, Shuanggen Jin and Attila Komjathy Chaired one Joint IAG/IEEE/ION/ ISPRS session "GNSS Remote Sensing of Atmosphere, Ocean and Land" at the IEEE Geoscience and Remote Sensing Symposium (IGARSS), Cape Town, South Africa and presented two papers.
- **19-24 April 2009**, Shuanggen Jin Chaired one session "GPS/Gravity Applications in Active Tectonics and Geophysics" and Co-Convened one session "Secular changes of the Planetary Earth system and its Physical Mechanism" at the European Geosciences Union (EGU) General Assembly, Vienna, Austria.

2008

- **15-19 December 2008**, Shuanggen Jin Chaired one session "High-Rate and Low-Latency Data for Earth Science Applications", American Geophysical Union (AGU) Fall Meeting, San Francisco, USA.
- **24-25 September 2008**, GNSS Reflectometry Course and Workshop organized by the European Space Agency was held at ESTEC in Noordwijk, The Netherlands.
- **29 July-1 August 2008**, Dr. Shuanggen Jin Co-Convened one session "Towards the synergy of geodesy, environment and atmosphere" at the Western Pacific Geophysics Meeting (WPGM) of American Geophysical Union (AGU), Cairns, Australia and presented one paper.
- **5-12 July 2008**, Dr. Attila Komjathy Convened one session "Ionospheric Remote Sensing by GPS" at the joint 2008 IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (Commission G, Ionospheric Radio and Propagation), San Diego, CA, USA.
- **June-July 2008**, Shuanggen Jin had worked as Research Scientist at the Department of Reference Systems and Geodynamics, Royal Observatory of Belgium, Brussels, Belgium.
- **16-20 June 2008**, Shuanggen Jin participated in the fifth Annual Assembly of Asia Oceania Geosciences Society (AOGS), Busan, South Korea and Chaired one session "GPS/Gravity and Applications in Active Tectonics and Geophysics" and Co-chaired on session "Geodetic Techniques (GNSS, VLBI, SLR...) and Its Applications on Atmosphere/Geodynamics" as well as presented two papers.
- **5-8 May 2008**, Dr. Susan Skone of SG4.1 member Chaired one session **"**Earth Observation & Remote Sensing" at the Position Location and Navigation Symposium 2008 (PLANS2008), Monterey, California, USA.
- **13-18 April 2008**, Dr. Shuanggen Jin attended the European Geosciences Union (EGU) General Assembly, Vienna, Austria, where he Chaired one session "Monitoring of the lower atmosphere and ionosphere by space geodetic techniques" and presented one paper "Retrieval of Ionospheric slab thickness and its variations from 3-D GPS observations".
- **28-30 January, 2008**, Dr. Susan Skone of SG4.1 member Co-Chaired one session "Atmospheric Effects" at the 2008 National Technical Meeting, San Diego, CA, USA.
- **5-7 January 2008**, Dr. Shuanggen Jin attended the Second CPGPS Youth Forum on "The Next Generation GNSS - Opportunities and Challenges", Guangzhou, China as member of Technical Committee and Co-Chaired one session as well as presented the paper "GPS models/combinations and its applications: Progresses and Challenges".

2007

- **1 November 2007**, Dr. Shuanggen Jin's paper "Ionospheric slab thickness and its seasonal variations observed by GPS" was published in the Journal of Atmospheric and Solar-Terrestrial Physics, 69(15), 1864-1870, doi: 10.1016/j.jastp.2007.07.008.
- **29 October-4 November, 2007**, Shuanggen Jin visited/collaborated with the University of Bath and University of Oxford, and attended the International Navigation Conference & Exhibition, Royal Institute of Navigation (RIN), London, UK.
- **1-4 October 2007**, The GNSS Remote Sensing Session was held at the 1st Colloquium Scientific and Fundamental Aspects of the Galileo Programme, Toulouse, France. Dr. J. Garrison of SG4.1 member presented the paper "Considerations in Utilizing Galileo

Signals for GNSS-R Ocean Sensing" and Prof. G. Ruffini of SG4.1 member presented the paper "Soil Moisture Monitorization Using Galileo Reflected Signals".

- **October-November 2007**, Report initial activities of SG4.1 to Commission 4.
- **October-November 2007**, Expand members to join the Study Group (SG4.1).
- **September-November 2007**, Made a website for the SG4.1 to show the terms of reference, objectives and members list, report activities and progress as well as related linkage, etc.: http://www.gnss.googlepages.com/IAG-SG4.1
- **14-16 September 2007**, Dr. Shuanggen Jin invited Prof. Dr. Jeffrey T. Freymueller (University of Alaska, Fairbanks, USA) to visit the Korea Astronomy & Space Science Institute, Daejeon, South Korea and then he attended 21st COE conference at the University of Tokyo, Japan.
- **31 July-4 August 2007**, Dr. Shuanggen Jin attended the 4th Assembly of Asia Oceania Geosciences Society (AOGS), Bangkok, Thailand and chaired one session "Geodesy, Geodynamics and Geohazards" as well as presented three papers.
- **1-9 July 2007**, Dr. Shuanggen Jin attended the IUGG XXIV General Assembly, Earth: Our Changing Planet, Perugia, Italy and presented three papers with two oral presentations.

Journal publications

Afraimovich, E.L., A.B. Ishina, M.V. Tinin, Y..V. Yasyukevich, and S.G. Jin (2011), First evidence of anisotropy of GPS phase slips caused by the mid-latitude field-aligned ionospheric irregularities, Adv. Space Res., 47, doi: 10.1016/j.asr.2011.01.015.

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Cardellach E, A. Rius (2008) A new technique to sense non-Gaussian features of the sea surface from L-band bistatic GNSS reflections, Remote Sensing of Environment, 112(6), 2927-2937

Gleason S, Hodgart S, Sun Y, Gommenginger C, Mackin S, Adjrad M, Unwin M (2005) Detection and Processing of Bistatically Reflected GPS Signals from Low Earth Orbit for the Purpose of Ocean Remote Sensing. IEEE Transactions on Geoscience and Remote Sensing, 43(6): 1229- 1241.

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Jin, S.G., and O. Luo (2009), Variability and climatology of PWV from global 13-year GPS observations, IEEE Trans. Geosci. Remote Sens., 47(7), 1918-1924, doi: 10.1109/TGRS.2008.2010401.

Jin, S.G., O. Luo, and S. Gleason (2009), Characterization of diurnal cycles in ZTD from a decade of global GPS observations, J. Geod., 83(6), 537-545, doi: 10.1007/s00190-008-0264-3.

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Jin S.G., O.F. Luo, and P. Park (2008), GPS observations of the ionospheric F2-layer behavior during the 20th November 2003 geomagnetic storm over South Korea, J. *Geodesy*, 82(12), 883-892, doi: 10.1007/s00190-008-0217-x.

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Komjathy A, Armatys M, Masters D, Axelrad P, Zavorotny V, Katzberg S (2004) Retrieval of Ocean Surface Wind Speed and Wind Direction Using Reflected GPS Signals. Journal of Atmospheric and Oceanic Technology, 21(3): 515-526.

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Study Group 4.3: IGS Products for Network RTK and Atmosphere Monitoring

Chair: Robert Weber (Austria)

Website:

http://mars.hg.tuwien.ac.at/Research/SatelliteTechniques/IAG_Study_Group_43/iag_study_group_43.html

Objectives

- To promote the use of IGS products for Network RTK and Atmosphere Monitoring
- To identify the current needs of near real-time atmospheric monitoring and Network-RTK in terms of IGS product quality, delivery time and spatial resolution
- To investigate options how to provide IGS products in standard real-time formats

Terms of Reference

The International GNSS Service (IGS) provides GPS & GLONASS station data and derived products like satellite orbits, clock corrections, electron content models and tropospheric delays of superior quality and within different time frames in support of Earth science research and multidisciplinary applications. Special applications like Network RTK in order to allow for fast access of a globally consistent reference frame for all position applications and near/real-time atmospheric monitoring for weather prediction require GNSS products with greatly reduced delays. Soon these products will be made available to the user community by means of the IGS RT Project in near-real via Internet and other available streaming technologies.

This Study Group identifies the needs of near real-time atmospheric monitoring in terms of orbit and clock-correction quality and investigates if the suite of IGS real-time products match the requested quality and spatial resolution necessary for correction data within regional RTK networks. Another topic deals with the coding of IGS products and models to be useful as a state space representation of error sources within the real-time standard formats RTCM and RTCA.

This Study Group is directly linked to IAG sub-commissions 4.3 and 4.5 as well as to the International GNSS Service (IGS).

Research Activities

In the period 2008 till mid 2009 the influence of IGU (IGS Ultra Rapid) products on the fast calculation of Zenith Wet delays has been studied in depth. An operational system to provide ZWD-estimates to Meteorological Offices has been set up. In conclusion the predicted part of the IGU orbits can be used for close to real time ZWD estimation. IGU satellite clock corrections are usually not suitable for this purpose due to their low resolution (15 minutes) and the 6h –update rate accompanied by frequent clock mis-modelling. It is recommended to obtain real-time clock corrections delivered by the upcoming IGS RT project. Close to Real-Time Ionospheric Models utilizing IGS TEC maps as well as the potential of increasing the spatial resolution of the ionospheric delay information have been studied in 2009 and 2010 within the project OEGNOS.

From 2009 onwards TU-Vienna contributed to the IGS RT Working Group by means of real-time GPS clock and orbit information. This product is in principal based on the IGS IGU orbits and the combined RT-streams will complement the IGU product line in the near future. The IGS RT correction stream is thought to support RTK as well as PPP applications. To take advantage of this new IGS product for RT applications the RTCM format has to be upgraded to support State Space Representation. This upgrade process is currently under progress and shall lead to a new version of the RTCM standard in 2011. This study group has tested both the combined IGS RT data streams as well as individual Analysis centre solutions as source for RT-PPP solutions (see publication list below)

A list of reports as well a complete publication list can be obtained from the SG 4.3 Website accessible via http://mars.hg.tuwien.ac.at/Research/SatelliteTechniques/IAG_Study_Group_43/iag_study_group_43.html

Scientific Meetings

Members of the SG have been active in both participating and organizing a number of scientific sessions at the AGU, EGU and IGS-conferences relevant to the goals of this SG. As these meetings are not co-sponsored by IAG the complete list is not given here but can be obtained from the Study-Groups Website

Publications and Presentations

Boehm J. and R. Weber, *Neutral Atmosphere Delays in GNSS Analysis.* European Journal of Navigation, Vol. 7, No. 2, pp. 4-9, 2009.

Bröderbauer V., Opitz M. and R. Weber: *Automated quasi-realtime prediction of GNSS clock corrections*, Österreichische Zeitschrift für Vermessung und Geoinformation (VGI), Heft 2 (2007), 95. Jahrgang; S. 53 -58.

Hobiger T., Kondo T., Koyama Y., Ichikawa R., and R. Weber: *Effect of the Earth's oblateness on the estimation of global vertical total electron content maps*; Geophysical Research Letters, **34** (2007), 11.

Karabatic A. and R. Weber: *Near real-time zenith wet delay estimation*"; IGS Analysis Center Workshop 2008, Miami.

Karabatic A. and R. Weber: *Potential contribution of GNSS data based tropospheric zenith delay to weather forecasts in alpine areas*; AGU Fall Meeting San Francisco, San Francisco.2010

Karabatic A., Weber R., Leroch S. and Th. Haiden: *GNSSMET - Contribution of tropospheric zenith delays derived from GNSS data for weather forecast in alpine areas*; EGU 2008, Vienna..

Opitz M. and R. Weber: *Real Time Monitoring of IGS Products within the RTIGS Network*; in: Proceedings of the IGS Analysis Center Workshop, Darmstadt, 2008.

Thaler G., M. Opitz M. and R. Weber: *Real Time Monitoring of GPS-IGU orbits and clocks as a tool to disseminate corrections to GPS-Broadcast Ephemerides*; European Geosciences Union, General Assembly Vienna,2009.

Thaler G. and R. Weber: *Use of RTIGS data streams for validating the performance of the IGS Ultra-Rapid products*"; European Geosciences Union, Vienna, *2010*.

Thaler G., Karabatic A. and R. Weber: *Consistency check of improved real-time clock and orbit products by means of PPP*; ENC GNSS 2010, Braunschweig, Deutschland, 2010.

Weber R. and S. Englich: *Scientific Applications in Geodesy and Geodynamics - Innovations offered by the new Galileo signals*; Proceedings 1st Colloquium Scientific and Fundamental Aspects of the Galileo Program, Toulouse, France;01.10.2007 - 04.10.2007; Proceedings of Colloquium.

Weber R., Opitz M. and G. Thaler: *Real-Time quality control of IGS clocks and orbits*; IGS Analysis Center Workshop 2008, Miami.

Weber R. and A. Karabatic: *Potential Improvements in GNSS-based Troposphere Monitoring by use of up-coming GALILEO-signals,* in: Proceedings 2nd Colloquium - Scientific and Fundamental Aspects of the Galileo Program, 2009.

Weber R., Karabatic A., Leroch S., and Th. Haiden: *GNSSMET – Quasi Real tropospheric zenith delays derived from GNSS data for weather forecast*; Final Report, 120 pages, University of Technology, Vienna,2010.

Weber R., Moeller G., and A. Karabatic: *Bestimmung atmosphärischer Feuchteänderungen aus GNSS - Beobachtungen und deren Assimilation in das operationelle Wetterprognosesystem ALADIN-AUSTRIA.* Projekt GNSSMET-AUSTRIA Final Report, 2011

The Inter-Commission Committee on Theory (ICCT) of the International Association of Geodesy

Final Report

Period covered: 2007–2011

http://icct.kma.zcu.cz

President: Nico Sneeuw (Germany)
Vice President: Pavel Novák (Czech Republic)

Structure

IC-SG1: Theory, Implementation and Quality Assessment of Geodetic Reference Frames
IC-SG2: Quality of Geodetic Multi-Sensor Systems and Networks
IC-SG3: Configuration Analysis of Earth Oriented Space Techniques
IC-SG4: Inverse Theory and Global Optimization
IC-SG5: Satellite Gravity Theory
IC-SG6: InSAR for Tectonophysics
IC-SG7: Temporal Variations of Deformation and Gravity
IC-SG8: Towards cm-accurate Geoid – Theories, Computational Methods and Validation
IC-SG9: Application of Time Series Analysis in Geodesy

Overview

Terms of reference

The Inter-Commission Committee on Theory (ICCT) was formally approved and established after the IUGG XXI Assembly in Sapporo, 2003, to succeed the former IAG Section IV on General Theory and Methodology and, more importantly, to interact actively and directly with other IAG entities.

The main objectives of the ICCT are:

- to be the international focal point of theoretical geodesy,
- to encourage and initiate activities to further geodetic theory,
- to monitor research developments in geodetic modelling.

The structure of the ICCT is specified in the IAG by-laws. The ICCT Steering Committee consists of the President, the Vice-President and representatives from all IAG Commissions:

- President: Nico Sneeuw (Germany)
- Vice-President: Pavel Novák (Czech Republic)
- Representatives:
- Commission 1: Zuheir Altamimi (France)

- Commission 2: Pieter Visser (The Netherlands)
- Commission 3: Richard Gross (USA)
- Commission 4: Sandra Verhagen (The Netherlands)

After the IUGG General Assembly in Perugia (held in July 2007), a structure of nine ICCT Study Groups was created. They are denoted as IC-SG1 to IC-SG9, see the list above. The new structure, terms of reference, objectives and program of activities for the 2007-2011 period were presented in the Geodesist's Handbook 2008 published in the *Journal of Geodesy* (J Geod 82: 783-792, November 2008).

Website

During the fall of 2007, the new ICCT Website was also established at: http://icct.kma.zcu.cz. The website is located at the web server of the Department of Mathematics, University of West Bohemia in Pilsen, and is powered by the MediaWiki Engine (similar to that used for the Wikipedia, a free, web-based multilingual encyclopaedia project). Due to this setup, the content of the ICCT Website can easily be edited by any authorized personnel (members of the ICCT Steering Committee and Chairmen of the Study Groups). Thus, the website can be used by for fast and easy communication of ideas among the members of the Study Groups. During 2008 the latest Study Group was established (IC-SG9), i.e., there are currently nine active Study Groups within the ICCT.

Steering Committee

During the 2007-2009 period, the ICCT Steering Committee organized two meetings. The ICCT Splinter Meeting was held during the IAG International Symposium on *Gravity, Geoid and Earth Observation* in Chania (June 2008). The agenda of the meeting included these issues: the information of the ICCT President on the structure of the ICCT, organization of the Hotine-Marussi Symposium in 2009, the new website of the ICCT and short reports of the present chairmen of the ICCT Study Groups. The second meeting of the ICCT Steering Committee was organized during the VII Hotine-Marussi Symposium in Rome (July 2009). The committee was almost complete with the ICCT President, Vice-President, three of four commission representatives and six of nine Study Group Chairmen attending the meeting. The business meeting took place at the Academia Nazionale dei Lincei in Rome on July 8, just in the middle of the VII Hotine-Marussi Symposium. The program of the meeting included the evaluation of the first part of the Hotine-Marussi Symposium and the mid-term report of the ICCT to the IAG. The SG Chairmen attending the business meeting presented shortly reports of their Study Groups for the 2007-2009 period and outlined plans for the next two-year period (until 2011).

Hotine-Marussi Symposium

The highlight of the ICCT activities in 2009 was the organization of the VII Hotine-Marussi Symposium in Rome, 6-10 July 2009. The conference was organized by the ICCT with the strong support from the local organizing committee under the leadership of Mattia Crespi, University La Sapienza in Rome. The five-day program of the Symposium consisted of eight sessions covering research areas of all nine ICCT Study Groups, namely:

- Geodetic sensor systems and sensor networks (Verhagen)
- Estimation and filtering theory, inverse problems (Kutterer, Kusche)

- Time series analysis and prediction of multi-dimensional signals (Kosek, Schmidt)
- Geodetic boundary-value problems and cm-geoid computational methods (Wang, Novák)
- Satellite gravity theory (Mayer-Gürr, Sneeuw)
- Earth-oriented space techniques and their benefit for Earth system studies (Seitz, Gross)
- Theory, implementation and quality assessment of geodetic reference frames (Dermanis, Altamimi)
- Temporal variations of deformation and gravity (Spada, Crespi, Wolf)

Additionally, a special session was organized at the Academia Nazionale in commemoration of Antonio Marussi (Sansò). The program of the conference consisted of 52 oral presentations (12 of them invited) and approximately of 50 posters. In total, 112 participants from 20 countries attended the VII Hotine-Marussi Symposium.

Further meetings

The Hotine-Marussi Symposium was not the only scientific meeting with the visible presence of the ICCT. Since 2008 the ICCT president has co-organized and co-convened) a session on recent developments in geodetic. The ICCT Vice-President was a member of the Scientific Committee of the IAG Scientific Meeting held in Buenos Aires, September 2009. The ICCT was also present through its Study Groups at other meetings, see their respective reports below. The Study Group 1 organized the IAG School on Reference Systems that was held June 7–12 2010 at the facilities of the Aegean University at Mytilene, Island of Lesvos, Greece. The Study Groups 2 and 3 jointly organized the 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11), 13–15 April 2011 in Munich.

This report

The activities of the ICCT are related namely to the research carried out by members of its Study Groups. Their final reports specify the areas investigated by the members of the Study Groups, achieved results (publications and presentations) and plans for the future work. All the SG Chairmen (but one) submitted their reports that can be found at the following pages. Based on the content of the reports, it can be concluded that the Study Groups are active, although the level of mutual co-operation and/or interaction between its members is not necessarily the same for all the Study Groups.

IC-SG1: Theory, Implementation and Quality Assessment of Geodetic Reference Frames

Chair: A. Dermanis (Greece)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group IC-SG1 since its creation in 2007.

Primary Objectives of the Study Group

The primary objective of this SG has been the following:

- Study of models for time-continuous definitions of reference systems for discrete networks with a non-permanent set of points and their realization through discrete time series of station coordinate functions and related earth rotation parameters.
- Understanding the relation between such systems and reference systems implicitly introduced in theories of earth rotation and deformation.
- Extension of ITRF establishment procedures beyond the current linear (constant velocity) model, treatment of periodic and discontinuous station coordinate time series, understanding of their geophysical origins and related models.
- Understanding the models used for data treatment within each particular technique, identification of possible biases and systematic effects and study of their influence on the combined ITRF solution. Study and improvement of current procedures for the merging of data from various space techniques.
- Statistical aspects of reference frames, introduction and assessment of appropriate quality measures.

Current Membership Structure

Chair:

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Members:

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Activities of the Study Group

IAG School on Reference Systems

The main and most important activity of the Study Group has been the organization of the First IAG School on Reference Systems, on June 7–12 2010. The School was hosted by the Department of Geography of the Aegean University in Mytilene, Lesvos Island, Greece. The School has been realized thanks to the generous financial support of the School of Rural and Surveying Engineering, Faculty of Engineering, Aristotle University of Thessaloniki.

The scope of the School has been twofold: First, to introduce young researchers to the theoretical-methodological and operational problems within the various aspects and techniques of establishing global reference frames. Secondly, to give the opportunity to more experienced researches working on a particular field within global reference frame establishment, to gain a more general perspective and deeper understanding of the various tools and aspects within neighbouring research fields. Furthermore, the School aspired to provide a forum for discussion and exchange of experiences and ideas for researchers working on adjacent fields in order to facilitate a wider understanding of the various problems and peculiarities. This has been achieved by providing adequate time for discussion within the lectures.

The School was attended by 58 students from 19 countries. Some came from as far as Australia, North America and South Korea. The participation may be judged as unusually large in comparison to that of other IAG Schools, thus reflecting the great interest in the topic and the need for more Schools in the future, preferably in other parts of the world.

The topics covered were *"Basic Concepts of Reference Systems in Geodesy, Astronomy and Geophysics"* (A. Dermanis), *"SLR Data Analysis for Terrestrial Reference Frame Development"* (E. Pavlis), *"Models and Strategies for Global VLBI Networks"* (T. Herring), *"Models and Strategies for Global GNSS Networks"* (T. Herring), *"Models and Strategies for Global DORIS data analysis"* (P. Willis), *"Reference Frame Combination and Time Series Analysis"* (Z. Altamimi) and *"Height Systems"* (M. Sideris). In addition to the taught material the students had the opportunity of familiarization with software currently used for the analysis of data either within each particular space technique or for the implementation of the International Terrestrial Reference Frame.

More details of the School, including the program, a detailed description of each lecture, as well as the lecture notes and other distributed material can be found at the School web page: http://www.topo.auth.gr/IAG2010_RefSchool/

Study Group Webpage

A web page of the study group has been established at the address:

http://der.topo.auth.gr/sgrf.

The web page contains the terms of reference, objectives, membership and program of activities of the study group.

Meetings of the Study Group

Due to very limited overlap of the presence of members in the various scientific meetings no actual meeting of the study group has been realized.

Conference Sessions

VII Hotine-Marussi Symposium, Rome July 06-10, 2009

Session 7: Theory, implementation and quality assessment of geodetic reference frames. Conveners: A. Dermanis, Z. Altamimi.

IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), Paris 4-8 October 2010.

Session 1: Theory and realization of global terrestrial reference systems. Conveners: Claude Boucher, David Coulot.

Future Activities

A number of theoretical problems remain unsolved and can be the subject of future research. To mention a few:

- Inclusion of non-linear periodic terms in the ITRF coordinate model.
- Comparison of the various strategies for ITRF formulation, taking into account the non-validity of the Gauss-Markov model (systematic biases and coloured noise).
- Development of efficient models for geophysical effects and the corresponding data reduction.

The most important activity though is the organization of IAG Schools on Reference Systems in a more-or-less regular basis.

Publications

Abbondanza Claudio, Zuheir Altamimi, Pierguido Sarti, Monia Negusini and Luca Vittuari (2009), Local effects of redundant terrestrial and GPS-based tie vectors in ITRF-like combinations, Journal of Geodesy 83, 1031-1040

Altamimi Z., D. Coulot, X. Collilieux, Status of the ITRF development and SLR contribution, Proceedings of the 16th International Laser Ranging Workshop, Poznan, Poland, Oct. 2008, vol. 2, page 35-42, Space Research Centre, Polish Academy of Sciences, Space Research Centre, Polish Academy of Sciences, 2009

Altamimi Z., X. Collilieux, B. Garayt, ITRS Centre, chapter 3.5.5., IERS annual report 2007, BKG, 2008

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Altamimi Z., X. Collilieux, C. Boucher, Preliminary analysis in view of the ITRF2005, Dynamic Planet: Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, International Association of Geodesy Symposia, vol. 130, page 685,691, Springer, IAG, 2007

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IC-SG2: Quality of Geodetic Multi-Sensor Systems and Networks

Chair: H. Kutterer (Germany)

Introduction and Primary Objectives of the Study Group

Modern geodetic observations are usually embedded in an integrated approach based on multi-sensor systems and networks. The fields of application are as manifold as the sensors in use. For example, total stations, GPS receivers and terrestrial laser scanners are applied in engineering geodesy for structural monitoring purposes together with permanently installed equipment. Geometric and physical space-geodetic sensors may serve as a second example since they are used for the determination of global reference frames. This report comprises some relevant research in theory (uncertainty modeling and propagation, recursive state-space filtering) and applications (design, implementation and validation of multi-sensor systems) which has been carried out during the last four years.

Membership Structure

H. Kutterer (Germany, Chair)
O. Akyilmaz (Turkey)
H. Alkhatib (Germany)
A. Eichhorn (Germany)
I. Neumann (Germany)
V. Schwieger (Germany)
J. Wang (Australia)
Y. Yang (China)

Activities of the Study Group

The field of uncertainty modeling and propagation is of interest in many disciplines. It also concerns international standardization activities in the field of metrology. Here, an approach is broadly used which is based on stochastics – more or less on Bayesian theory in a very technical way (ISO, 1995; ISO, 2007). As this approach relies on a special interpretation of uncertainty – and is more or less restricted to uncertainty measures for scalar measurement results – alternative approaches are of increased interest. Alkhatib et al. (2009) consider the joint modeling and propagation of two major types of data uncertainty – random variability and imprecision – of vector quantities. For the modeling of random variability a Bayesian approach in combination with Monte-Carlo simulations is used. In contrast, imprecision is modeled using fuzzy theory which allows a more flexible concept of uncertainty propagation. The analysis of fuzzy data is described, e.g., in Viertl (1996); see Neumann (2009) for some recent developments in Geodesy. Note that Koch (2008a, b) studied uncertainty propagation in a rigorous Bayesian framework. Meanwhile, extended studies which are based on real data from Terrestrial Laser Scanning (TLS) revealed non-normality in observed TLS profile time series (Kutterer et al., 2010) which has to be modeled accordingly.

For state-space filtering recursive algorithms are of major interest as they provide the basis for real-time applications. The classical Kalman filter is the most prominent example. In order to take deviations from the normality and linearity assumptions into account, several extensions have been studied. Alkhatib et al. (2008) compare the so-called extended Kalman filter (use of functional 2nd order terms), the unscented Kalman filter (use of so-called sigma points to approximate a non-normal distribution) and the particle filter (Monte-Carlo solution of a Bayesian state-space filter). Meanwhile, this work has been extended with respect to both efficiency and the use of adaptive parameters in the system equations (Alkhatib et al., 2011). Vennegeerts and Kutterer (2009) consider efficiency issues of the algorithmic variance-co-variance propagation of geometric mass data (3D point clouds) which are observed using a kinematic multi-sensor system (GPS, INS, terrestrial laser scanner). Work in the field of data-driven modeling of time-variable systems based on a Neuro-Fuzzy approach for application in Earth orientation prediction is presented by Akyilmaz et al. (2010).

Kutterer and Neumann (2009, 2010) develop a Kalman filter extension and a recursive least-squares estimation with respect to data imprecision. Here, the set-theoretical overestimation is the main problem as in recursive formulations some information on data dependencies gets lost. In case of fuzzy data – defining fuzzy vectors by the so-called minimum principle – this yields true supersets of the correct fuzzy state-space vectors. Hence, the obtained uncertainty measures are only upper bounds of the true ones. In linear estimation problems this problem is easily overcome if the observation data uncertainty is strictly referred to originally independent uncertain influence quantities. Hence, the same idea has been applied to state-space recursion which has consequently been resolved for the uncertainty propagation. In this case it is also possible to introduce adaptive system parameters.

The theoretical developments on uncertainty modeling and state-space filtering have been supported by R&D work on kinematic multi-sensor systems using a terrestrial laser scanner as the main sensing device (see, e.g., Paffenholz et al., 2010).

Ongoing Activities

Together with IC-SG3, IC-SG2 has been organizing QuGOMS 2011 (1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems) in Garching/Germany. This IAG-sponsored workshop will take place in 2011, April 13-15, and it is co-sponsored by FIG – IAG Springer proceedings are scheduled. Closely related methodological issues in engineering geodesy and Earth system observation will be addressed by ten invited speakers and about 40 contributed papers. Its main purpose is to gather experts in this field to stimulate new discussions on theory and methodology for geodetic observation and monitoring; requests from the applications are taken into account.

Publications

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IC-SG3: Configuration Analysis of Earth Oriented Space Techniques

Chair: F. Seitz (Germany)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group IC-SG3 since its creation in 2007. Activities of the study group Configuration Analysis of Earth Oriented Space Techniques are focussed on the application and combination of modern space-based Earth observation systems for studies related to Earth system science. A multitude of simultaneously operating satellite systems with different objectives is available today. Various sensors offer a broad spectrum of information on geodynamic processes within and/or between individual components of the Earth system in different temporal resolutions and on different spatial scales. The general objective of this study group is the development of strategies how the available information from complementary and redundant observation systems can be combined and analysed in order to answer up-to-date scientific questions in the context of geodetic Earth system research.

Primary Objective of the Study Group

The observations of most space-based geodetic observation techniques are influenced by various dynamical processes in the Earth system that are involving transports and redistributions of masses as well as the exchange of energy and angular momentum. In order to separate the observations into contributions of individual processes, a combination of sensors that are unequally sensitive to different processes is indispensable. Based on this background the development of strategies for multi-sensor approaches is the primary goal of the study group. Investigations deal with the question in which way heterogeneous data sets can be combined in an optimal way in order to identify and quantify the contributions of particular processes. This way the study group aims on fostering and improving the understanding of the Earth system by creating more reliable information on processes and interactions in the subsystems of the Earth. This is especially necessary in view of studies related to global change.

Among the most important tasks are the compilation and assessment of background information for individual systems and sensors (mode of operation, sensitivity, accuracy, deficiencies) as well as theoretical studies, which (new) information on the Earth system can be gained from a combination of different observation methods. Furthermore the work comprises theoretical studies on combination strategies and parameter estimation. The study group provides a forum for researchers from various fields of space geodesy and geophysics in order to discuss theoretical and computational aspects of sensor combination. Special attention of the research is turned to methodology and data analysis.

Common research the study group is reflected by various common publications and presentations of its members (see below). The activities are also supported by third party funds in the form of two major projects: The Deutsche Forschungsgemeinschaft (DFG) and the International Graduate School of Science and Engineering (IGSSE) of the Technische Universität München support the research activities on the field of the study group with a total of four positions and scholarships for PhD students for periods between 2 and 3 years. These funds resulted from common project proposals of the SG members **F. Seitz, M. Schmidt, F. Meyer** and **K. Hedman.**

Current Membership Structure

F. Seitz (Germany, Chair)
S. Abelen (Germany)
J. Dickey (USA)
K. Hedman (Sweden)
F. Meyer (USA)
M. Motagh (Germany)
M. Schmidt (Germany)
M. Seitz (Germany)
A. Singh (India)
X. Wang (Germany) (until 2009)

Activities of the Study Group

Conference Contributions of SG Members

Abelen, S., K. Hedman, F. Seitz: Contributions from different Water Storage Compartments to total Storage Change from Multi-Sensor Analysis. *German Geodetic Week*, Cologne, Germany, 7.10.2010.

Abelen, S., F. Seitz, A. Güntner, **M. Schmidt**: Analysis of regional variations in soil moisture by means of remote sensing, satellite gravimetry and hydrological modeling. *IUGG XXV General Assembly*, Melbourne, Australia, 28.6.-7.7.2011.

Abelen, S., F. Seitz, A. Güntner, **M. Schmidt**: Signals of soil moisture variations in remote sensing and gravity field observations. *IUGG XXV General Assembly*, Melbourne, Australia, 28.6.-7.7.2011.

Abelen, S., F. Seitz, M. Schmidt, A. Güntner: An inter-comparison of soil moisture variations detected by satellite remote sensing, satellite gravimetry, and hydrological modeling. *EGU General Assembly*, Vienna, Austria, 3.-8.4.2011 (Poster).

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Schmeer M., Bosch W., Drewes H., **Schmidt M.**: Analysis of Atmospheric Density Variations - MaSiS: Separation of Mass Signals by Common Inversion of Gravimetric and Geometric Observations, *Joint International GSTM and DFG SPP Symposium*, Potsdam, Germany, 2007 (Poster).

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Schnitzer, S., A. Menzel, **F. Seitz**: Estimation of mass loss due to soil erosion in the Loess Plateau in China: A comparison of the erosion model RUSLE, multi-temporal DEMs and GRACE satellite gravimetry. *EGU General Assembly*, Vienna, Austria, 2011 (Poster).

Seitz, F.: Configuration analysis of Earth oriented space techniques: Status report of the study group IC-SG3 of IAG's Inter Commission Committee on Theory. *VII Hotine-Marussi Symposium*, Rome, Italy, 2009.

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Seitz, F., M. Motagh: Geodetic methods for monitoring water overexploitation: Results from geometric and gravimetric observation techniques. *AGU 2009 Fall Meeting*, San Francisco, USA, 2009 (Poster).

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Seitz M., Blossfeld M., Sánchez L., **Seitz F.**: Understanding and treating seasonal signals of station positions in the ITRF computation. *EGU General Assembly 2010,* Vienna, Austria, 2010 (Poster)

Seitz M., Heinkelmann R., Blossfeld M.: Combination of VLBI and GPS in order to improve TRF and EOP solutions. *Workshop VLBI and GNSS: New Zealand and Australian perspectives*, Auckland, New Zealand, 2010.

Singh, A., F. Seitz, Ch. Schwatke, **M. Schmidt**, A. Güntner: Changing hydrology of the Aral Sea: Results from satellite altimetry, GRACE satellite gravimetry and hydrological modeling. *EGU General Assembly*, Vienna, Austria, 2011 (Poster).

Wang, X., Peters, T.: Determination of mass transport in the Earth system from satellite constellation flights . *IAG International Symposium on Gravity, Geoid and Earth Observation 2008*, Chania, Greece, 2008 (Poster).

Study Group Webpage

The webpage of the group is http://icct.kma.zcu.cz/index.php/IC_SG3

Meetings of the Study Group

International Seminar on Signals of Climate Variability on Continental Hydrology from Multi-Sensor Space and In-situ Observations and Hydrological Modeling (CLIVAR-Hydro), TU München, Munich, Germany, 11-12.10.2010 (Organizer: **F. Seitz**)

*The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS), TU München, Munich, Germany, 13-15.4.2011. Co-organized by IC-SG2 and IC-SG3 (Organizers: H. Kutterer, **F. Seitz**)*

Conference Sessions

German Geodetic Week, Bremen, Germany, 2.10.2008:

- Session 5: GGOS – Global Geodetic Observing System (Convenor: **F. Seitz**)

VII Hotine-Marussi Symposium, Rome, Italy, 6-10.7.2009:

- Session 6: Earth oriented space techniques and their benefit for Earth system studies (Convenors: **F. Seitz**, R. Gross)

IEEE International Geoscience and Remote Sensing Symposium, Cape Town, South Africa, 12.-17.7.2009:

- Sessions: Sessions: Ionospheric Effects In Polarimetric and Interferometric SAR Imagery I and II; Interferometry – Moving Targets (Convenor: **F. Meyer**)

German Geodetic Week, Karlsruhe, Germany, 24.9.2009:

- Session 5: GGOS – Global Geodetic Observing System (Convenor: **F. Seitz**)

3rd ALOS PI Symposium, Kona, Hawaii, USA, 9.-13.11.2009:

- Session: Ionosphere (Convenor: **F. Meyer**)

EGU General Assembly 2010, Vienna, Austria, 4.5.2010:

- Session G12: Observing and Understanding Earth Rotation and its Geophysical Excitation (Convenors: A. Brzezinski, **F. Seitz**, D. Salstein,)

EGU General Assembly 2010, Vienna, Austria, 5.5.2010:

- Session G2: The Global Geodetic Observing System: Tying and Integrating Geodetic Techniques for Research and Applications (Convenors: P. Sarti, R. Gross, E. Pavlis, **M. Seitz**)

EGU General Assembly 2010, Vienna, Austria, 6.5.2010:

- Session G6: Space geodetic techniques and the Earth's atmosphere (Conveners: **M Schmidt,** R. Pacione , M. Karslioglu , A. Martellucci)

German Geodetic Week, Cologne, Germany, 7.10.2010:

- Session 5: GGOS – Global Geodetic Observing System (Convenor: **F. Seitz**)

IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Honolulu, Hawaii, USA, 26.-30.7.2010:

- Sessions: Ionospheric Effects In Polarimetric and Interferometric SAR Imagery I and II (Convenor: **F. Meyer**)

Committee on Earth Observing Sensors (CEOS) Synthetic Aperture Radar Calibration/Validation Workshop, Zurich, Switzerland, 23-27.8.2010:

- Session : Calibration Methods (Convenor: **F. Meyer**)

EGU General Assembly 2011, Vienna, Austria, 5.4.2011

- Session G5.1: Monitoring and modelling of the ionosphere from space-geodetic techniques (Conveners: **M Schmidt**, M. Karslioglu , A. Krankowski, D. Dettmering , P. Wielgosz)

EGU General Assembly 2011, Vienna, Austria, 6.4.2011:

- Session G2.3: Observing and Understanding Earth Rotation and its Geophysical Excitation (Convenors: **F. Seitz**, D. Salstein, A. Brzezinski)

EGU General Assembly 2011, Vienna, Austria, 7.4.2011

- Session G2.2: The Global Geodetic Observing System: Tying and Integrating Geodetic Techniques for Research and Applications (Convenors: R. Gross, E. Pavlis, **M. Seitz**, D. Behrend)

Future Activities

All members of the SG intend to continue their common activities on the field of Earth observation by means of multi-satellite in the upcoming years. It is intended to propose further projects in order to raise funds for PhD positions on the basis of the common work. It is also planned to organize a summer school in which all collaborating PhD students at the institutions of the SG members shall participate. Furthermore it is intended to repeat the successful Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS), that has been organized jointly by SG2 and SG3 in Munich in April 2011, in regular intervals. The results of the SG activities shall be published in highly-ranked scientific journals.

Publications

Abelen, S., Seitz, F., Schmidt, M., Güntner, A. (2011): Analysis of regional variations in soil moisture by means of remote sensing, satellite gravimetry and hydrological modelling**.** IAHS Red Book Series, in press.

Anderssohn, J., Wetzel, H.U., Walter, T.R., **Motagh, M.**, Djamour, Y., Kaufmann, H., (2008). Land subsidence pattern controlled by old alpine basement faults in the Kashmar Valley, northeast Iran: Results from InSAR and leveling. *Geophysical Journal International*, 174, 1, 287-294.

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Göttl F, **Seitz F** (2008) Contribution of non-tidal oceanic mass variations to polar motion determined from space geodesy and ocean data. In: Observing our Changing Earth, Sideris MG (ed.), *IAG Symposia*, 133, 439-446, Springer, Berlin.

Marcus, S. L.; **Dickey, J. O**.; Willis, J. K.; **Seitz, F.** (2009): Earth oblateness changes reveal land ice contribution to interannual sea level variability; *Geophysical Research Letters*, 36, 23, L23608.

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Motagh M, Walter T, Sharifi M, Fielding E, Schenk A, Anderssohn J, Zschau J (2008) Land subsidence in Iran caused by widespread water reservoir overexploitation. *Geophys. Res. Lett*., 35, L16403, doi: 10.1029/2008GL033814.

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Seitz, F. (2009)**:** Configuration analysis of Earth oriented space techniques**,** Mid-term report of ICCT IC-SG3; in: Drewes, H.; Hornik, H. (eds.) Travaux de l'Association Internationale de Géodésie 2007-2009, Vol. 36, 188-191.

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IC-SG4: Inverse Theory and Global Optimization

Chair: C. Kotsakis (Greece)

[no final study group report available at time of writing]

IC-SG5: Satellite Gravity Theory

Chair: T. Mayer-Gürr (Germany)

[no final study group report available at time of writing]

IC-SG6: InSAR for Tectonophysics

Chair: M. Furuya (Japan)

Introduction

This document is a summary report of the work undertaken by the ICCT Study Group "InSAR for Tectonophysics" since its creation in 2007. Against a backdrop of a series of SAR satellite missions, ERS1/2, JERS, Envisat/ASAR, ALOS/PALSAR, Radarsat-1/2, TerraSAR/X, and planned future missions (e.g. Sentinel-1 and DESDyni), many interesting and exciting results have been presented from this SSG as illustrated in the publication list. Those results include the following research areas, related to geodetic measurement and analysis of SAR/InSAR data and their application to tectonophysical problems: (1) SAR/InSAR data analysis for tectonophysics, (2) retrieval and separation of atmospheric and crustal deformation signal, (3) modeling and interpretation of SAR/InSAR data, (4) combination of InSAR data with other measurement sources.

Primary Objectives of the Study Group

The primary objective of this SG has been to be a focus of activities related to geodetic measurement and analysis of SAR/InSAR data and their application to tectonophysical problems.

Current Membership Structure

Masato Furuya (chair), Hokkaido University, Japan, furuya@mail.sci.hokudai.ac.jp
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Activities of the Study Group

Conference Contributions of SG Members

Each of the SC members have presented their papers at a number of international meetings, which include American Geophysical Union, European Geoscience Union, Asia Oceania Geosciences Society, IEEE International Geoscience and Remote Sensing, the ESA's FRINGE and Envisat workshop, ALOS-PI meeting and the IAG's 2008 GGEO meeting.

Conference Sessions

Earth Observation by Satellite Altimetry and InSAR at GGEO 2008 meeting

Future Activities

New satellite-based SAR missions, C-band Sentinel-1 by ESA and L-band ALOS2 by JAXA, are approved to be launched in ~2013. Exploiting these new data as well as archived data, we will further be able to develop advanced analysis techniques and acquire more exciting scientific results. We plan to hold conference sessions in future international meetings.

Publications

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Baer, G; Funning, GJ; Shamir, G; Wright, TJ (2008) The 1995 November 22, M-w 7.2 Gulf of Elat earthquake cycle revisited, Geophys J Int, 175(3), pp1040-1054. doi:10.1111/j.1365-246X.2008.03901.x

Barisin, I; Leprince, S; Parsons, B; Wright, T (2009) Surface displacements in the September 2005 Afar rifting event from satellite image matching: Asymmetric uplift and faulting, Geophys Res Lett, 36, . doi:10.1029/2008GL036431

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IC-SG7: Temporal Variations of Deformation and Gravity

Chair: D. Wolf (Germany)

[no final study group report available at time of writing]

IC-SG8: Towards cm-accurate Geoid – Theories, Computational Methods and Validation

Chair: Y.M. Wang (USA)

Primary Objectives of the Study Group

The Inter-Commission Study Group (SG 8) focuses on the theories and computation methods for cm-accurate geoid. Geoid computation is a sophisticated process which involves the fundamental theory (geodetic boundary values problem), computation methods and data acquisition. The geoid accuracy depends on a precise theory, adequate computation methods and high quality data. Since the creation of the SG, the focus has been placed on the following topics:

- Optimal combination of global gravity models with local gravity data.
- Rigorous calculation of the topographic effects on gravity and the geoid, refinement of the topographic and gravity reductions.
- Studies on harmonic downward continuations.
- Non-linear effect of the geodetic boundary value problems on geoid determination.
- The effect of topographic density variations on the Earth's gravity field, especially the geoid.
- Effect of time varying gravity on the geoid

Current Membership Structure

Y.M. Wang (USA, Chair)
W. Featherstone (Australia)
N. Kühtreiber (Austria)
H. Moritz (Austria)
M.G. Sideris (Canada)
M. Véronneau (Canada)
J. Huang (Canada)
M. Santos (Canada)
J.C. Li, (China)
D.B. Cao (China)
W.B. Shen (China)
Z. Martinec (Czech Republic)
R. Forsberg (Denmark)
O. Anderson (Denmark)
H. Abd-Elmotaal (Egypt)
H. Denker (Germany)
B. Heck (Germany)
K. Seitz (Germany)
W. Freeden (Germany)
E. Grafarend (Germany)
J. H. Kwon (South Korea)
L. Sjöberg (Sweden)
P. Dumrongcha (Thailand)
D. Roman (USA)
J. Saleh (USA)
D. Smith (USA)

Activities of the Study Group

This document presents the status report of IC-SG 8 since its creation in 2007. During the period 2007-11 the SG established its terms of reference, organized its membership structure, adopted an Internet site, and proposed focus items. There are many activities within as well as outside the SG, this report can only cover the main activities of SG members. The material presented here has been compiled from information and feedback obtained from individual SG members. Important developments by research outside the SG are also included.

Moritz (2011) outlined the contemporary perspective of the height anomaly determination assuming the Earth's surface is known. In the approach, the gravity anomaly is replaced by gravity disturbance, and Hotine/Koch's formula takes place of the Stokes's integral.

Flury and Rummel (2009) refined the formulation for the separation between the quasigeoid and geoid. They showed that the refinement may improve the geoid by a decimetre dm in high mountainous region. From a different angle, Sjöberg (2010) developed a strict formula for the separation.

Grafarend et al (2010, 2011) investigated the application of the ellipsoidal harmonics in modelling the Earth's gravity field. Sjöberg (2008, 2009) continues his research in the topographic effects on geoid computations. He has questioned the usefulness of the terrain correction in geoid computations. His conclusion induces an interesting discussion between the author and Vermeer (2007).

Heck and Seitz (2007) presented solutions of the inverse Stokes and inverse Hotine problems to order of f^2 for an ellipsoid boundary. Heck (2009, 2011) also presented solutions of fixed and internal geodetic boundary value problems. Wild and Heck (2008) also studied the topographic and isostatic reductions for satellite gradiometry.

Huang and Novák (2008) revisited their one step geoid computation that combines the Stokes integral and the harmonic downward continuation, aimed to avoid the step function caused by computation blocks. Huang et al (2009) also computed a gravimetric geoid in combination with mean see surface height to determine the Labrador Current. Regarding the geoid modeling, Huang and Véronneau (2010) develop the three different methods of combining the satellite and terrestrial gravity data using the Stokes kernel kernel modification techniques. Ince et al. (2010) compare CGG05, EGM08 and US2009 geoid models over the Great lakes region and conclude the accuracy of the three geoid models is about 5 cm in this region.

Abd-Elmotaal and Kühtreiber (2007a, b) compared the method of Stokes kernel modification and the window technique used in geoid computation. The optimal combination of surface gravity data with a global coefficient model is also investigated (Abd-Elmotaal and Kühtreiber (2008). The method of optimal combination of the deflections of the vertical and the surface gravity anomaly is also proposed by Kühtreiber and Abd-Elmotaal (2007).

Ellmann (2009) showed a large difference (9 cm standard deviation) between the geoids computed by using different kernel modifications. The difference is almost one order larger than the cm-geoid requirement. Similar results are obtained by other researchers. This draws attention to how to use the kernel modification methods properly in geoid computations. Li and Wang (2011) investigated the stability of the modified Stokes kernels to different computation cup size and modification degrees using Alaska as a test area. They found that some methods are more stable than others.

Modeling the topographic potential using the high degree spherical harmonic series has been in progress since the publication of EGM08. Novák (2009) and Wang (2009) presented their topographic potential in spherical harmonic series to degree and order 2700 under the spherical approximation. The coefficients models are used in geoid determinations (Wang et al., 2010).

Effect of varying topographic density to geoid has been one of the important aspects of the cm-geoid determination. Investigation by Kingdon et al (2007, 2008, 2009, and 2010) is an example of this effort. More research along this line is expected, when more accurate density profiles become available.

Kwon and Jekeli (2009), Hong et al (2009) assessed data requirements for precise geoid computation using gravity and topographic data in South Korea. By using 30" elevation model of the North America, Wang (2009) studied omission error due to limited grid size used in geoid computations. He concluded that the omission error is below 1 cm for extreme cases, if 1' grid size is used. However, the omission error in gravity may reach in tens of mGals.

Local geoid computations over various countries and regions are as follows, but not limited to: Featherstone (2007,2010); Claessens et al (2011); Amos et al (2009); Huang and Veronneau (2010), Ince et al (2010); Biltzkow et al. (2008); Avalos et al (2008); Abd-Elmotaal (2008); Wang et al (2010). The geoids serve directly and indirectly as vertical datums in many countries.

To validate relative accuracy of the geoid, Smith et al (2010) proposed a plan using all possible means of survey gravity, vertical gravity gradient, GPS/leveling, deflections of the vertical along a line in Texas. The survey is planned to complete in the summer of 2011.

Meetings of the Study Group

During the period covered the SG had one meeting during the IAG Science Assembly, Geodesy for Planet Earth, Buenos Aires, August 31-September 3, 2009.

Conference Sessions

During the period covered the SG had one conference session during The VII Hotine-Marussi Symposium: Geodetic boundary value problems and cm-geoid computational methods, Rome, July 6-10, 2009.

Future Activities

The Earth's surface is measured by remote-sensing technology in high resolution with high accuracy, so that the foundation of geoid determination is changing from the free-boundary problems to the much easier fixed-boundary values problems. It is the time to replace the gravity anomaly by gravity disturbance, to use the Hotine/Koch formula instead of Stokes's integral, and to use the ellipsoid, rather than the geoid as the reference surface in geoid computations. The SG plans to have a meeting at IUGG 2011 in Melbourne, Australia to discuss whether we should encourage group member to advocate the changes.

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IC-SG9: Application of Time-series Analysis in geodesy

Chair: W. Kosek (Poland)

Introduction

This report presents a status report of the work undertaken by the ICCT Study Group 9 since its creation in 2009.

Primary Objectives of the Study Group

The primary objectives of this study group are as follows:

- Study of the nature of geodetic time series to choose optimum time series analysis methods for filtering, spectral analysis, time frequency analysis and prediction.
- Study of Earth rotation and gravity field variations and their geophysical causes in different frequency bands.
- Evaluation of appropriate covariance matrices for the time series by applying the law of error propagation to the original measurements, including weighting schemes, regularization, etc.
- Determination of the statistical significance levels of the results obtained by different time series analysis methods and algorithms applied to geodetic time series.
- Comparison of different time series analysis methods in order to point out their advantages and disadvantages.
- Recommendations of different time series analysis methods for solving problems concerning specific geodetic time series.

Current Membership Structure

W. Kosek (Poland) – chair
M. Schmidt (Germany)
J. Vondrák (Czech Republic)
W. Popinski (Poland)
T. Niedzielski (Poland)
J. Böhm (Austria)
D. Zheng (China)
Y. Zhou (China)
M.O. Karslioglu (Turkey)
O. Akyilmaz (Turkey)
L. Fernandez (Argentina)
R. Gross (USA)
O. de Viron (France)
S. Petrov (Russia)
M. van Camp (Belgium)
H. Neuner (Germany)

Study Group Webpage

The webpage of the group is http://www.cbk.waw.pl/~kosek/ICSG9.

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Communication and Outreach Branch (COB)

http://www.iag-aig.org

President: József Ádám (Hungary)
Secretary: Szabolcs Rózsa (Hungary)

Activity Report

1. Introduction

The period of 2007-2011 is the second 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) with the MTA-BME Research Group for Physical Geodesy and Geodynamics of the Hungarian Academy of Sciences (MTA), Budapest, Hungary.

The Communication and Outreach Branch is one of the components of the Association. According to the new Statues (§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 2008 (Ádám and Rózsa, 2008; Rózsa, 2008), respectively.

In the past period of the second term (since the 2007 IUGG General Assembly in Perugia till July, 2009) the COB's Steering Committee held a meeting in Vienna, Austria, 18 April, 2008. Helmut Hornik IAG Assistant Secretary General visited us at the COB office in Budapest in 25-26 February, 2009 in order to update and synchronize the database of the IAG Individual Members. Another meeting of the COB's Steering Committee is planned for June 2011 in Budapest (or in Melbourne).

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 ("Topic of the Month"). Moreover a section introducing Geodesy to the wider public has been added to the website, and all the printed information material can be downloaded, too.

3. The IAG Newsletters

Altogether 46 IAG Newsletters have been published from March 2007 till December 2010 and can be accessed on the IAG new website in HTML, HTML print version and in PDF formats. We strive to publish only relevant information by keeping the Newsletter updated on a per-monthly basis. The 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. Selected content of the electronic Newsletters were compiled and have been sent regularly to Springer for publication for 35 issues of the Journal of Geodesy (Vol 81/5 – 84/12). Starting from the double issue 82/11-12 the volume of the Springer IAG Newsletters is limited to 3-4 pages due to a change in the editorial policy to improve the impact factor of the journal. Hence we strived to publish only new and/or relevant material as a service to the IAG community.

4. Outreach Activities

The COB has been active in the publishing of information material in the reporting period. A new 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, 2009). It has a chapter on the Global Geodetic Observing System, and provides information on the IAG components (Commissions, Inter-Commission Committee, Services, etc.).

Another shorter version of the brochure has been published for the JB GIS, too (Rózsa and Ádám, 2010). Both of the brochures can be downloaded from the opening page of the IAG website, together with the updated IAG leaflet (Ádám and Rózsa, 2007).
J. Ádám (2008) prepared a summary on "Update of the History of the International Association of Geodesy".

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 finalized through a long review process;
e) one short 4 pages IAG booklet was prepared for the Joint Board of Geoinformation Societies (JBGIS);
f) some works were made in preparation and for finalizing The Geodesist's Handbook 2008 (Drewes et al., 2008), and
g) 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: Markus Rothacher (Switzerland)
Vice Chair: Ruth Neilan (USA)
Vice Chair: H.P. Plag (USA; until March 2010)

Structure

Bureau on Networks and Communications
Bureau on Conventions and Standards
Working Group on Data and Information Systems
Working Group on Satellite and Space Missions
Working Group on Outreach
Working Group on ITRS Standardization
Working Group on Contribution to Earth System Modelling
GGOS Coordinating Office
GGOS Portal
GGOS Science Panel
GGOS Themes
GGOS in the Group on Earth Observation (GEO)

Overview

The idea of a Global Geodetic Observing System (GGOS; originally called IGGOS, Integrated Global Geodetic Observing System) goes back to the IAG Section II Symposium in Munich in 1998. In 2003 at the XXIII IUGG General Assembly in Sapporo the new IAG structure was implemented and with it the GGOS Planning Group was set up. Four years later, at the XXIV IUGG General Assembly in 2007, GGOS was accepted by the IAG Council as a full component of the IAG structure. More details may be found in (Beutler et al., 2009). Table 1 summarizes the major events that happened since, i.e., in the report period 2007-2011. In the following the most important developments are described in some more detail.

Table 1: Major GGOS Events 2007-2011

Date	Event
July 2007	XXIV IUGG General Assembly in Perugia, Italy: GGOS accepted as a full component of the IAG by the IAG Council
January 2009	Establishment of the Bureau on Networks and Communication, Bureau on Standards and Conventions, and the GGOS Portal
July 2009	The book "Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020" published as the basis for the present and future development of GGOS
January 2010	GGOS Coordinating Office starts its work
February 2010	GGOS Retreat in Miami: the three GGOS Themes for integrated products are initiated

December 2010	GIAC (GGOS Inter-Agency Committee) is established
December 2010	GGOS Working Group on Contributions to Earth System Modelling established
January 2011	GGOS Web pages online
February 2011	GGOS Retreat: new vision, mission and goals for GGOS, new GGOS Terms of Reference are set up
June 2011	XXV IUGG General Assembly in Melbourne, Australia: New GGOS chair is appointed by the IAG Executive Committee. Action plans exist for the major components of GGOS.

GGOS 2020 Book

In early 2006 an effort was started to write a book describing the background of GGOS and its perspectives for the year 2020. The final version of this book called "GGOS 2020 book" was published in 2009. This book was realized under the leadership of Hans-Peter Plag and Mike Pearlman with contributions of the GGOS Science Panel as well as a large group of experts in various neighbouring fields of geoscience (Plag et al., 2009). It marks a milestone in the development of GGOS. The full reference is given below.

Building up the GGOS Organizational Structure

The first two years after the establishment of GGOS as a full component of the IAG (the Global Geodetic Observing System of the IAG) were mainly used to build up the structure necessary for GGOS to work. The components to be established were already lined out in the GGOS 2020 book (see Figure 1).

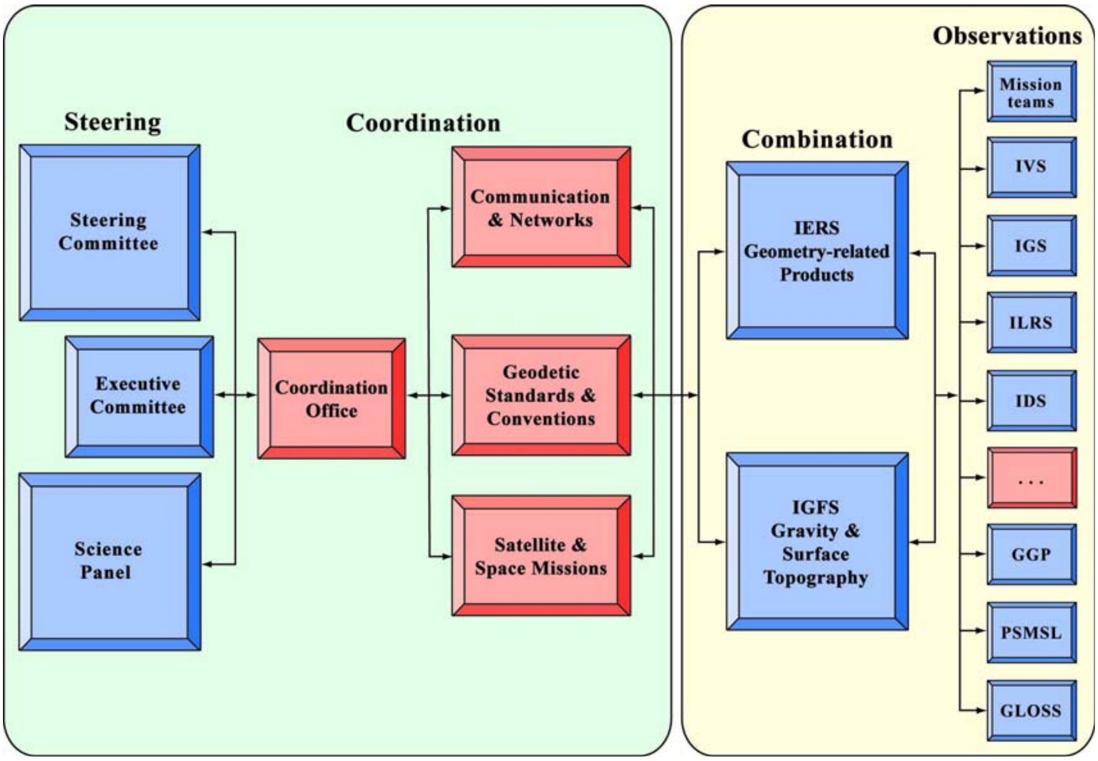

Figure 1: GGOS Structure proposed in the GGOS 2020 Book (Plag & Pearlman, 2009), Chapter 10

In January 2009 the following components could successfully be established:

- Bureau for Networks and Communication: Cambridge Center for Astrophysics / NASA (Director: M. Pearlman)
- Bureau for Standards and Conventions: Research Group on Satellite Geodesy in Munich (FGS: FESG, DGFI, IAPG; director: U. Hugentobler, now D. Angermann)
- GGOS Portal: BKG (Federal Agency of Cartography and Geodesy, Frankfurt; director: Bernd Richter)

For the planned GGOS Bureau for Satellite and Space Missions no leading institution was found and, therefore, the GGOS WG on Satellite and Space Missions was kept. The chair was decided to be C.K. Shum, Ohio State University (OSU). Since 2010, this GGOS WG is led by Isabelle Panet (IGN, Paris) and Roland Pail (TU Munich).

An institution responsible to operate the GGOS Coordinating Office (CO) could be found in the beginning of 2010, when the Italian Space Agency (ASI) volunteered to act as the GGOS CO with Giuseppe Bianco as the director. The GGOS CO is now successfully organizing a lot of the day-to-day activities of GGOS and is also responsible for the GGOS web pages (www.ggos.org) and works closely together with the GGOS Portal at BKG.

With the GGOS CO the organizational structure of GGOS could be completed. In addition, a new GGOS Working Group, the WG on Contributions to Earth System Modeling, was created in 2010 chaired by Maik Thomas at the Deutsches GeoForschungsZentrum (GFZ) in Potsdam. With this new GGOS WG there are now five working groups in GGOS (see Table 2).

An overview of the present structure is also given in Figure 2.

Table 2: Present GGOS Working Groups

GGOS WG	Chair(s)
WG on Data and Information Systems	Bernd Richter, Carey Noll
WG on Satellite and Space Missions	Isabelle Panet, Roland Pail
WG on Contributions to Earth System Modeling	Maik Thomas
WG on ITRS Standardization	Claude Boucher
WG on Outreach	Giuseppe Bianco

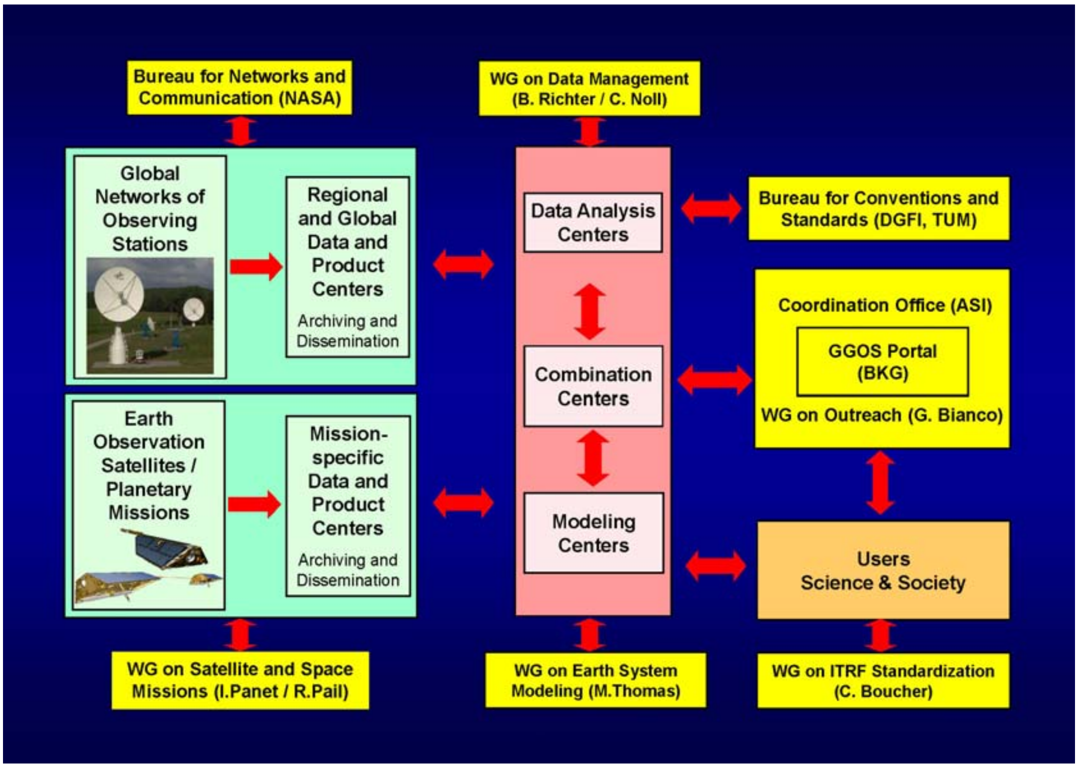

Figure 2: Present GGOS Structure

New GGOS Core Sites

In the period from 1970-1990 a rather rapid development of the global space geodetic infrastructure took place, initiated among others by the NASA Crustal Dynamics Project (CDP). During the years to follow further developments were taking place but only at individual stations, by individual institutions and for individual techniques. Some stations were even decommissioned during this time period. With the arguments of GGOS at hand and due to technique-specific initiatives (e.g. IVS2010, SLR), a new era of building up improved infrastructure has started. Figure 3 summarizes the present status of the GGOS core sites. It can be seen that a substantial progress was taking place during the last few years. In VLBI alone, it is expected that more than 20 new telescopes will become operational in the next several years. This gives an indication that the goal of establishing around 40 global GGOS core sites, as recommended in the GGOS 2020 book, is indeed feasible with the joint effort of GGOS and the IAG Services and the support of the national institutions responsible for the geodetic infrastructure.

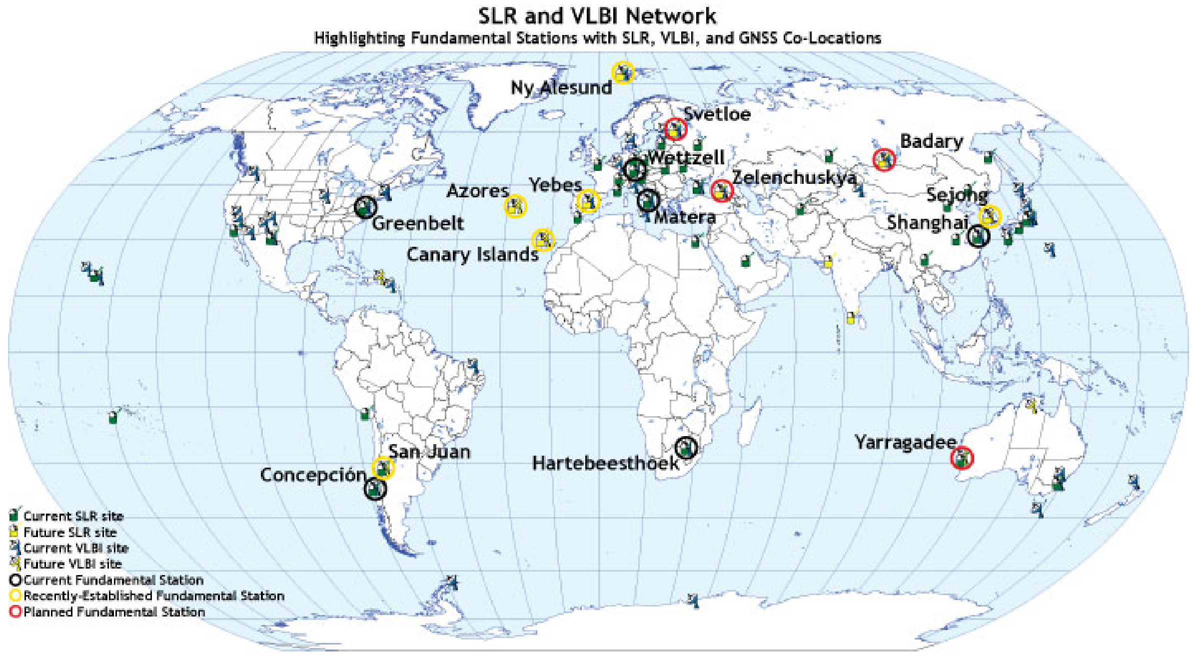

Figure 3: Increasing number of GGOS core sites in the global networks (NASA, 2011)

GGOS Outreach

Besides the GGOS 2020 book several other articles, books and white papers were published during the period 2007-2011.

- Chapter by Blewitt et al., 2010, in the book "Understanding Sea-Level rise and Variability" (Church et al, 2010)
- White papers for the Ocean'09 meeting (Shum et al., 2009; Plag et al., 2009; Scott et al., 2009; http://www.oceanobs09.net/)
- Springer book containing the final report of the German Geotechnologies Project (Flechtner et al., 2011)
- Papers about GGOS (Plag et al., 2010; Plag et al., 2009; …)

In addition, leaflets, posters, one-page stories, and a GGOS booth were produced and presented at various meetings, especially at GEO Plenaries and Ministerial Summits.
Finally, with the help of BKG (Federal Agency of Geodesy and Cartography) the GGOS portal (see below) could be established and new web pages were generated by the GGOS Coordinating Office (ASI).

Retreats, Workshops and Sessions

During the past four years quite a number of GGOS retreats, GGOS workshops and meetings were organized. They are listed in Tables 3 and 4 with their internet link. Whereas the GGOS retreats were held to make progress in the organization and further development of GGOS, the workshops were focussing on specific scientific themes of relevance to GGOS. In addition, GGOS sessions were proposed and held at almost every AGU and EGU Meeting.

Table 3: Retreats organized by GGOS

GGOS Retreat	Place	Date
GGOS Retreat 2007	Oxnard, California	February 19-21, 2007
GGOS Retreat 2008	Bertinoro, Italy	March 25-28, 2008
GGOS Retreat 2010	Miami, USA	February 1-4, 2010
GGOS Retreat 2011	Zurich, Switzerland	February 2-4, 2011

Table 4: Workshops organized or co-organized by GGOS

GGOS Workshop	Place	Date	Web page
The GGOS Contribution to GEOSS and an Observing System for Geohazards and Disaster Prevention	Frascati, Italy	November 5-6, 2007	http://earth.esa.int/work-shops/2007Geohazards/
Unified Analysis Workshop 2007	Monterey, USA	December 5-7, 2007	http://www.iers.org/
IGCP 565 Workshop 1: Science of geodetic monitoring of the hydrological cycle	San Francisco, USA	December 11, 2008	http://www.igcp565.org/_work-shops/SanFrancisco/
Understanding Glacial Isostatic Adjustment	Espoo, Finland	June 23-26, 2009	http://dynaqlim.fgi.fi/files/GGOS_DynaQlim.htm
Towards a Roadmap for Future Satellite Gravity Missions	Graz, Austria	September 30-October 2, 2009	http://www.igcp565.org/_work-shops/Graz/
Unified Analysis Workshop 2009	San Francisco, USA	December 11-12, 2009	http://www.iers.org/
IGCP 565 Workshop 2b: From Satellite Gravity Observations to Products	San Francisco, USA	December 12-13, 2009	http://www.igcp565.org/_work-shops/SF_2009/
IGCP 565 Workshop 3: Separating Hydrological and Tectonic Signals in Geodetic Observations	Reno, USA	October 11-13, 2010	http://www.igcp565.org/_work-shops/Reno_2010/
Observing and Understanding Earth Rotation	Shanghai, China	October 25–28, 2010	http://202.127.24.12/dct/

GGOS Themes

In view of the complexity of the Earth system as a whole, GGOS decided to start with a small set of integrated and interdisciplinary themes/products of high importance to science and society. The three themes selected are:

- Theme 1: Global Unified Height System (Chairs: M. Sideris, J. Ihde)
- Theme 2: Geohazards (global Earth surface deformations and strain rates for geohazards assessment and disaster prevention) (Chairs: T. Dixon, R. Gross)

– Theme 3: Understanding and Forecasting Sea-Level Rise and Variability (Chairs: C.K. Shum., P. Woodworth)

These themes are described in more details in a later section of this report.
GEO activities

GGOS, representing the IAG in the Group on Earth Observation (GEO), has been contributing to the GEO activities by participating in the GEO Committees and Working Groups and in the GEO Plenaries and Ministerial Summits and by proposing own tasks or subtasks within GEO. The two major subtasks within GEO for which GGOS is responsible are the subtask on "Global Geodetic Observing System" and on "Global Geodetic Reference Frames". These will also be part of the GEO Work Plan 2011-2015, that will be the last GEO work plan before the end of the GEO 10-Year Implementation Plan for GEOSS, the Global Earth Observing System of Systems. Details are given below.

GIAC

In November 2009 a group of national geodetic institutions met for the first time to discuss the establishment of an Intergovernmental Committee for GGOS. This initiative was started by Reiner Rummel (TU Munich) and Dietmar Grünreich (BKG), because the global ground infrastructure for space geodesy is far from ideal and not sustainably financed. Since the GGOS concept builds on long-term observation series, the sustainability of the existing IAG Services and the infrastructure they use is a key issue that needs to be approached.

The Frankfurt Declaration written during this meeting states "The overall goal of this initiative is to improve the sustainability of IAG Services in general and in particular, the long term coverage of the in-situ space geodetic networks in time and distribution and to increase the visibility and effectiveness of Geodesy to global geo-observation programs".

In the time to follow it was decided that before going through the very difficult work of forming a GGOS Intergovernmental Committee (GIC), a GGOS Inter-Agency Committee (GIAC) should be formed. This happened at a meeting of the GIAC Planing Group in San Francisco on December 9, 2010. By now, around 15 major institutions signed the Frankfurt Declaration and became member of GIAC.

GIAC will support GGOS in attaining its goals by working towards an appropriate intergovernmental agreement that facilitates planning, securing, and maintaining geodetic infrastructure and operation of the Services based on the needs of science and society, and by promoting GGOS to international entities that require intergovernmental representation.

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Bureau on Networks and Communications

Chair: M. Pearlman (USA)

Role of the Bureau

The role of the Bureau is to promote the further development of sustained infrastructure needed to satisfy the long-term (10-20 years) requirements for the reference frames and the monitoring of global change signals. GGOS provides observations of variations in Earth shape, gravity field and rotation, which are fundamental for monitoring of climate and global change. The global geodetic reference frame, the International Terrestrial Reference Frame (ITRF) provides the foundation for most Earth metric observations and for observations in the lunar and planetary systems. GGOS provides observations of variations in Earth shape, gravity field and rotation, which are fundamental for monitoring of climate and global change. These observations depend on sustained geodetic ground networks with stations of sufficient measurement quality and global distribution.

The reference frame requirement is to establish an ITRF with an accuracy of 1 mm and a stability of 0.1 mm/year, which represents an improvement of 10-20 beyond the current quality. The main driver for this requirement is the monitoring of sea level, but other applications are not far behind (Plag, H-P and Pearlman, M.R., 2009). These requirements will be met with a ground network of globally distributed stations with co-located VLBI, SLR, GNSS, DORIS, and may include other systems such as gravimeters, seismometers, tide gauges, etc. These have been termed GGOS Fundamental Stations (see Figure 4).

In this role the Bureau will plan and advocate for the implementation of:

- Ground-based network of Fundamental Stations with co-located VLBI, SLR, GNSS, DORIS required to establish an ITRF that has an accuracy of 1 mm and a stability of 0.1 mm/year, which represents an improvement of 10-20 beyond the current quality;
- Implementation of a ground-based GNSS network to make the ITRF of this quality available everywhere on the surface of the Earth for 24 hours a day;
- Implementation of the ground-based tracking network to support planned missions;
- Integration of techniques including gravity field, tide gauges, etc to support GGOS themes.

Progress

- Bi-annual meetings at AGU and EGU the services to exchange information and plans;
  - Files have been implanted to provide on-line access to network station and data product information including local ties, mis-closure files, etc. See: http://observing-system-portal.bkg.bund.de/lang_en/nn_261332/sid_10CCEAF2FA145E6 BF8AE876363 B45F00/GGOS-Portal/EN/GGOS-Products/GGOS-Products.html
- Simulation underway to scope the size and properties of the co-location network
  - Thirty globally distributed, well positioned, co-location stations with modern technology and proper conditions will be required to define the reference frame that will meet to requirements;

  - Half of these co-location stations must track GNSS satellites with SLR to calibrate the GNSS orbits;
  - Dense network of GNSS ground stations to distribute the reference frame globally so that users anywhere on the Earth may refer their measurements in the reference frame 24 hours a day.
- IAG services continue to upgrade their technologies and expand their networks
  - SLR: KHz ranging; increased automation, improved electronics;
  - VLBI: new VLBI 2010 design includes much wiser band width, faster slewing;
  - GNSS: multiple constellations, more frequencies, SLR retro-reflectors;
  - DORIS: new ground beacons, additional satellites.
- Co-location network is expanding with the addition of the Yarragadee site, work underway at Metsahovi, and serious discussions underway at several other sites (see Figure 5);
- The first version of a GGOS Site Requirements Document for co-located (Fundamental) sites is now available, see: http://cddis.gsfc.nasa.gov/docs/GGOSSiteRequirements_ v1.pdf
- Work continues on intersystem vector measurements at co-located sites with the IERS WG on Site Survey and Co-location; these vectors are critical for inter-relating the measurements from the separate techniques;
- Call for Participation for participation in the GGOS network has been prepared and is awaiting a decision by the GGOS Steering Committee and the GIAC;
- Outreach activities have been underway with talks given at AGU, EGU and AOGS, and visits with group interested in implementing a Fundamental Stations including groups in Colombia and Brazil;
- Proposal pending at NASA/HQ to support the completion of prototype VLBI 2010 and SLR systems with a follow-on phase to build and implement a number of units;

Plan

- Continue advocating for the establishment of that GGOS Network of Fundamental Stations; continue the items in process above;
- Continue the simulation activities to quantify the anticipated evolution of the reference frame as a function of phased deployment; systematic errors, additional space objects, tracking scenarios, GRASP satellite for co-location in space, etc.
- Complete the prototype SLR and VLBI and a prototype new technology Fundamental Station at GSFC;
- Issue the Call for Participation periodically to enhance participation and the establishment of partnerships to implement Fundamental Stations.

Deliverables

Although this is a task of promoting and advocating, the goal of this task with the help of the GIAC is:

- Implementation of new technologies at the space geodesy ground stations
- Additional co-located ground stations to expand global coverage

- Improved data quantity and quality for more accurate and stable reference frame and more accurate orbit determination to support active missions
- Improved integrated data products such as the ITRF, sea level, unified global height model, etc.

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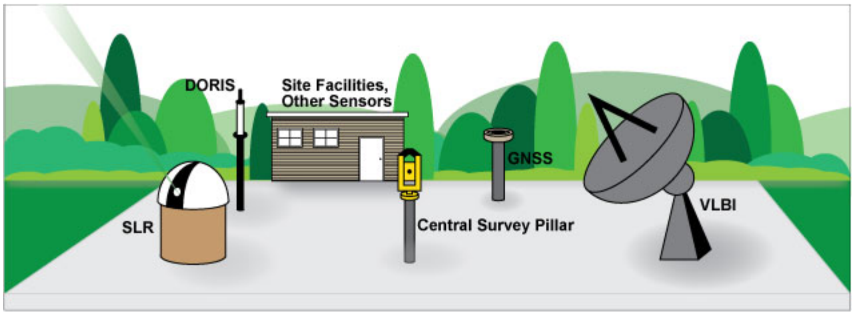

Figure 4: Fundamental Station

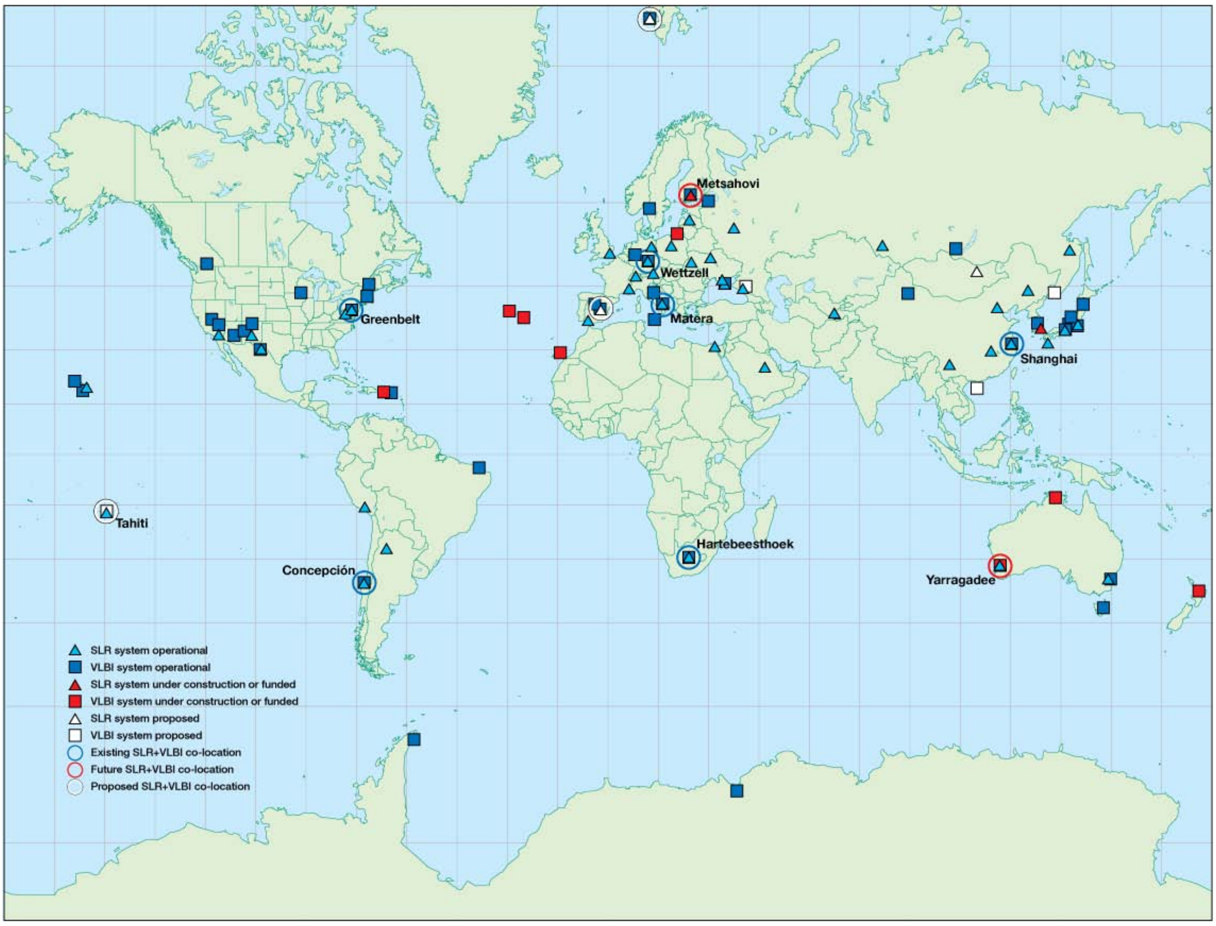

Figure 5: Co-located VLBI and SLR Network. Nearly all stations have GNSS and some have DORIS

Bureau on Conventions and Standards

Chair: U. Hugentobler (Germany)

GGOS WG on Conventions, Models, Analysis

The GGOS WG on Conventions, Models, Analysis (CMA) – the predecessor of the GGOS Bureau on Conventions and Standards – was led by H. Drewes. Objectives of the WG were to ensure the consistency between all (geometric and gravimetric) products by using common standards, conventions and models in data analysis, parameterisation and representation; to improve the geodetic algorithms, parameterisation and physical models to the point, where an overall accuracy and consistency of products better than 1 ppb can be achieved; to stimulate and coordinate efforts aiming at a combined analysis of all space geodetic observation techniques, integrating all parameters common to more than one space geodetic technique.

An extended form was prepared by the WG in order to review the used constants, conventions, models and parameters used by the IAG Services and Commissions and distributed in 2007. The form polled questions on used numerical constants, geodetic conventions, geophysical models, and estimated parameters. Activities included the participation at and contribution to the GGOS Unified Analysis Workshop on December 5-7, 2007, in Monterey, CA. Activities in 2007 and 2008 focused on the analysis of effects produced by the use of different conventions and models on the different estimated parameters in the context of GGOS-D, a cooperative project supported by the German Federal Ministry of Education and Research performed by four institutions (Helmholtz-Zentrum Potsdam Deutsches GeoForschungs-Zentrum, Deutsches Geodätisches Forschungsinstitut, Federal Agency for Cartography and Geodesy, University of Bonn). Further activities were performed in conjunction with research projects related to mass transports and Earth rotation.

GGOS Bureau on Conventions and Standards

The GGOS Bureau on Conventions and Standards was installed in 2009 – as the successor of the CMA – after the acceptance of the corresponding proposal submitted by the Forschungsgruppe Satellitengeodäsie (FGS) by the GGOS Steering Committee Meeting in December 2008. The Bureau is jointly operated by Forschungseinrichtung Satellitengeodäsie (FESG) and Institut für Astronomische und Physikalische Geodäsie (IAPG) of Technische Universität München, Munich, Germany, and the Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany. Members of the Bureau were initially U. Hugentobler (Chair), D. Angermann (Secretary), J. Bouman, M. Gerstl, T. Gruber, B. Richter, P. Steigenberger.

Objectives of the Bureau are to keep track of the strict observance of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in the generation of products issued by the IAG Services; to review examine and evaluate standards, constants, resolutions and conventions adopted by IAG or its components and propose necessary updates; to identify gaps, inconsistencies, and deficiencies in standards and conventions and to initiate steps to close them; to propose the adoption of new standards and conventions as far as necessary; and to propagate standards and conventions to the wider scientific community and promote their use.

Actions of the Bureau included the compilation of the relevant resolutions, review of the IERS Conventions, comments to numerical constants of IERS Conventions 2010, presentations on standards and conventions and activities of the Bureau at the IAG Scientific Assembly, September 2009, Buenos Aires, Argentina, at the Unified Analysis Workshop 2009, December 2009 in San Francisco, CA, at the Plenary Meeting of ISO TC211, May 2010, in Southampton, UK, and at the IAG Commission 1 Symposium Reference Frames for Applications in Geosciences, October 2010 in Paris.

In order to improve balance between Bureau members affiliated to geometric and gravimetric research fields and to improve the performance of the Bureau the membership was restructured beginning of 2011. New Chair of the Bureau is D. Angermann, Secretary is T. Gruber. Additional members are J. Bouman, R. Heinkelmann, U. Hugentobler, L. Sanchez, P. Steigenberger, affiliated are J. Ihde, J. Kusche. First task was the preparation of the section related to data analysis and combination of the GGOS Action Plan. A main goal is the development of a new geodetic reference system as consistent set of best estimates of geodetic parameters.

Working Group on Data and Information Systems

Chairs: B. Richter (Germany) and C. Noll (USA)

WG Members

– *Bernd Richter chair / IERS /GGOS portal manager* – *Carey Noll chair / ILRS* – *Guiseppe Bianco /GGOS CO* – *Ruth Neilan IGS* – *Laurent Soudarin IDS* – *Pascal Willis IDS* – *Dirk Behrend IVS*	***Geometry***
– *Franz Barthelmes ICGEM* – *Jean-Pierre Barriot ICET* – *Sylvain Bonvalot BGI*	***Gravity***
– *Lesley Rickards PSMSL*	***Sea Level***
– *Felicitas Arias BIPM*	***Time Service***

GGOS Portal

The GGOS portal is thought to provide a unique access point for all data, products and information relevant in the framework of GGOS to serve Earth sciences and applications. Basically, it will provide a platform for services to deliver data, to get and use these data for processing products and to get the products.
GGOS data are classified in three different levels:

- L0 level are all raw data,
- L1 level are all RINEX files (meta data, receiver, station), and
- L2 level and higher are the data and products that are provided by the IAG services) available on the GGOS portal through meta data files on the portal's data base (time series).

Process from L0 to L2 level data: the loose service solution (e.g. IGS, ILRS, IDS, IVS, ...) undergo a transformation into the current ITRF(combination centre) from the raw data into a constrained combined solution (time series), which will be the official solution of these data.
The data and metadata of each space technique should be identified through the GGOS portal.
The GGOS Portal basically serves two different kinds of user: data providing user (IAG services and authorised non-IAG institutions) and data consuming user. Generally any registered user can upload data into the portal. Non-IAG institution's data and products will be included into the GGOS Portal only after having successfully passed a review process by the working group DIS and accepted finally by the GGOS EC. Further, each IAG and non IAG service has to specify their data by corresponding metadata.

Web site

The GGOS web site and the GGOS Portal web site will be two independent web sites:

- The GGOS web site will provide information about GGOS, the products and background knowledge to interested user.
- The GGOS Portal will be used as a platform to exchange data and products presented topically ordered (natural hazards, science applications, geodetic applications, satellite missions, techniques and services).

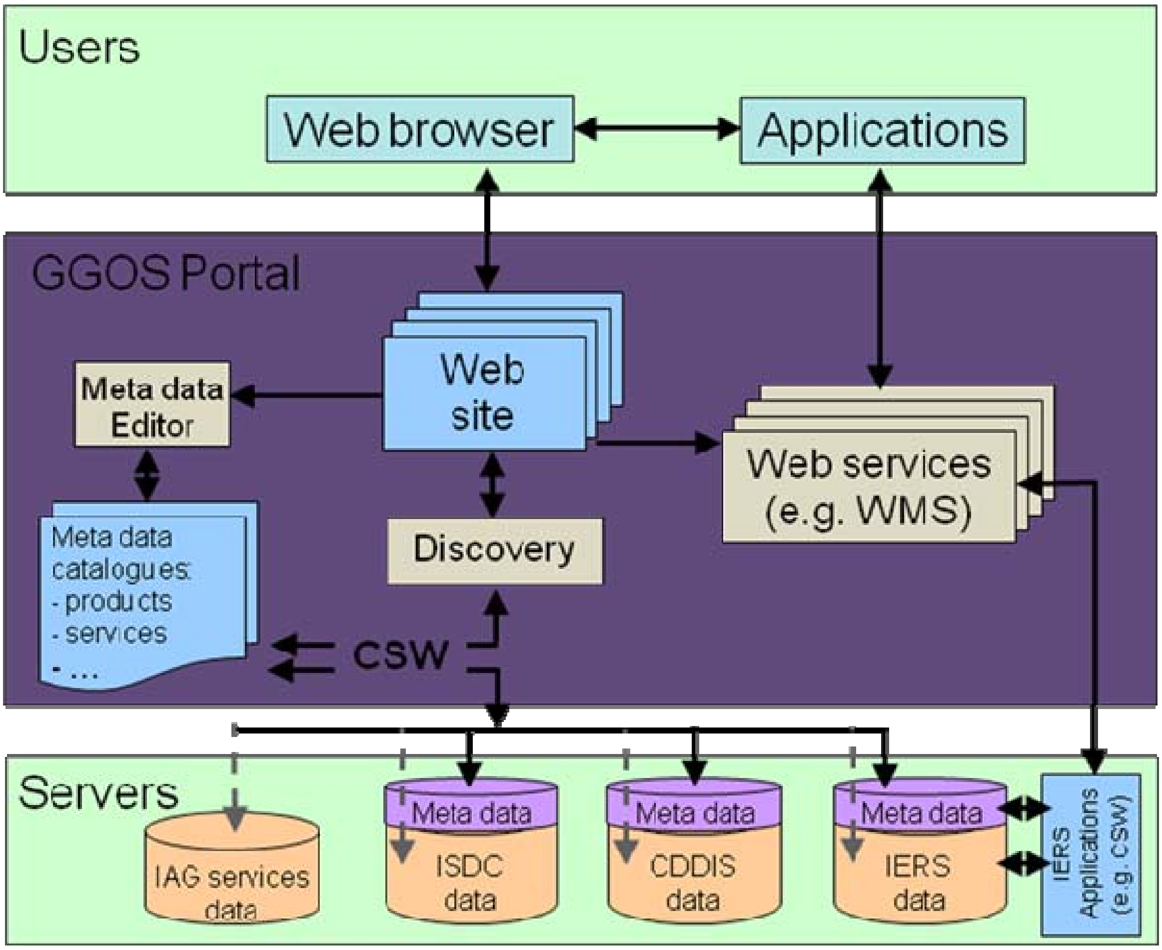

Figure 6: Service oriented architecture of the GGOS Portal

The GGOS Portal is based on service oriented architecture (see Figure 6). A prototype is ready and has been reviewed by the WG DIS and the GGOS EC. The preliminary test version of the GGOS Portals web presentation can be found under http://observing-system-portal.bkg.bund.de. The GGOS web site and the GGOS portal web site cross linked for reference information and data respectively.

In general, the category "Topics" provides general information to the topics specified. To provide the information the WG DIS and the GGOS EC has asked several individuals to detailed information to fill the various fields of interest.

The category "Discovery" will provide the possibility search for data and products based on available meta data.

GGOS Portal Meta Data

Three possibilities for the meta data description were discussed in the EG DIS:

- xml file template provided by the portal manager,
- a meta data block within the SINEX file, which includes not to distribute the SINEX files to the user,
- meta data editor.

For the GGOS Portal the GeoNetwork is embedded into the GGOS Portal web page as meta data editor. The GeoNetwork (see http://geonetwork-opensource.org/) is based on the principles of Free and Open Source Software (FOSS) and International and Open Standards for services and protocols (a.o. from ISO/TC211 and OGC). The use in numerous Spatial Data Infrastructure initiatives across the world guaranteed the long-term support. The GeoNetwork tripod consists of a meta data editor, a search tool and map service interfaces.

The available ISO meta data catalogue has been discussed within the WG DIS and tailored to the necessary geodetic applications. The used fields to describe the individual data are specified in the document presented at the GGOS / IERS UAW workshop in Monterey, Ca.

http://www.iers.org/nn_10902/IERS/EN/Organization/Workshops/Workshop2007Monterey Programme.html?__nnn=true#doc74712bodyText4 see Sess. 6

"UAW_PosPap_Session_6_GGOS_Portal_and Metadata_Flow_Annexes_1.pdf". Communication by email discussions and working group meeting on May 2, 2010.

Working Group on Satellite and Space Missions

Chairs: I. Panet (USA) and R. Pail (Germany)

December 2008 – November 2010

The GGOS Satellite Mission Working Group (SMWG) is established in December 2008, under the lead of C.K. Shum, and 20 members agreed to serve on this Working Group. An initial Terms of Reference has been drafted.

In August 2009, international collaborations were discussed with James Jong-Uk Park and his colleagues at the Korea Astronomy and Space Science Institute. In August 17–25, C.K. Shum met and discussed with Chinese scientists from Institute of Geodesy and Geophysics, State Seismology Bureau, Shanghai Astronomical Observatory, Institute of Mechanics/Mathematics, in Urumqi and Beijing, China, on GRACE research and China's laser interferometry instrument research and development collaborations. Also their participation in GEO/IAG Future Gravity Field Mission Workshop, to be held in Graz, September 2009, was discussed.

In September 2009, the Working Group jointly submitted an invited abstract to the IAG Symposia, Geodesy for Planet Earth, IAG, Buenos Aires, August 31– September 4, 2009, http://www.iag2009.com.ar/, Sub-Session 7.1: Past Progress and Future Plans, Session 7, The Global Geodetic Observing System: Science and Applications (Convenors: Richard Gross, Hans-Peter Plag, Luiz Paulo Fortes,). The title of the invited paper was: Status and Prospects of the GGOS Satellite Mission Working Group, by Shum et al.

Several Working Group members participated in a joint GGOS/IGCP565 – IAG – GEO Workshop "Towards a Roadmap for Future Satellite Gravity Missions", which was held from September 30 to October 2, 2009, in Graz, Austria. The workshop aimed at bringing together stakeholders in satellite gravity missions in order to establish a roadmap for future satellite gravity missions that outlines the sensor developments, mission concept developments, and mission implementation, and that is consistent with anticipations of the major space agencies, CEOS, and GEO, and with the needs of key user groups (such as IGWCO, the GEO Water Tasks, GOOS and GCOS, Earth scientists, and GGOS itself). The outcome of this workshop is summarized in documents available at http://www.iag-ggos.org/workshops/Graz. It identifies the need for a continuous observation of the time variable gravity field in order to implement an operational observing system for mass redistribution, global change, and natural hazards.

In the course of the workshop, several informal discussions take place with scientists on international collaborations to advocate GRACE Stop-Gap (defined as "mission to extending the current GRACE observational data span using the current GRACE technology and with the possibility to host an experimental laser interferometry sensor, to be launched no later than 2015"), and GRACE follow-on (the laser interferometry satellite-to-satellite tracking) missions. There were extensive discussions of different country/space agencies launching a coordinated GRACE constellation with multiple pairs of GRACE Stop-Gap and/or follow-on satellites to mitigate background signal aliasing errors.

In April 2010, a support letter was sent to Johnny Johannessen, NERSC, Isabelle Panet, Institut Géographique National, Thomas Gruber, and Roland Pail, for their "Earth System Mass Transport Mission (e.motion)" proposal to ESA's Earth Explorer Opportunity Mission under the EE-8-Call. Unfortunately the proposal was not selected to proceed into the next phase. The e.motion team composed by a multi-disciplinary science team and an industrial team working in the area of satellite gravimetry, including members of the Satellite Mission Working Group, will continue to work together with the goal to define a next generation gravity field mission.

December 2010 – ongoing

In December 2010, Isabelle Panet and Roland Pail agree to be nominated as the new Co-Leads for the GGOS Satellite Missions Working Group.

In a Working Group meeting on April 2, 2011, the objectives and tasks of the SMWG for the upcoming period was extensively discussed, an Action Plan was drafted, and the charter has been reviewed. The list of members of the Working group is revised, and it is decided to invite also representatives of space agencies to become members in order to strengthen these interfaces.

Working Group on Outreach

Chair: G. Bianco (Italy)

The GGOS Working Group on Outreach and Education (WGOE) has been approved during the 11th meeting of the GGOS Steering Committee held on December 2010 in San Francisco, and modified during the GGOS Strategy Retreat held in February 2011 in Zurich. It is chaired by the GGOS Coordinating Office.

The WGOE activity in this initial period has been concentrated on a new edition of a brochure which shall describe GGOS' scope and duties according to the GGOS 2020 book as well as to the Terms of Reference and other strategic indications.

Working Group on ITRS Standardization

Chair: C. Boucher (France)

The Working group was established by the GGOS SC14 (San Francisco, December 2008) to investigate the interest in and feasibility of an ISO standardization document related to ITRS.

The WG Work Plan identified three major issues:

- to identify and get all useful information about existing standardization activities under the ISO umbrella which are somewhat linked to ITRS. One can also investigate, to some extent, standardization beyond ISO, either international bodies or even national agencies
- to define various options to get an ISO document referring to ITRS
- to report to GGOS

Survey of existing standards

Three types of standardization documents has been identified:

- documents of the ISO TC 211 "Geographical information-Geomatics" ISO TC 211
  - Geographical information. Spatial referencing by coordinates (ISO 19111)
- documents of the ISO TC 20 "Aircraft and Space Vehicles" ISO TC 20/SC 14
  - Space systems. Reference coordinate systems
  - Space systems. Orbit determination and estimation. Process for describing techniques
- documents related to the European INSPIRE directive

Options for a standard on ITRS

Various strategies were considered to bring the issue to ISO. The French standardization agency (AFNOR) performed a feasibility study. France was finally ready to start the process.

Content of the standard

The content of the standardization document related to ITRS was also considered. The proposed content includes general information on terminology, a definition of ITRS and an overview of the multiple realizations, including the primary one (ITRF), the regional densifications such as EUREF and the links with GNSS providers.

The WG submitted its final report to the 18^{th} GGOS SC meeting in Vienna (2010)

Working Group on Contribution to Earth System Modelling

Chair: M. Thomas (Germany)

Purpose

In December 2010 the new Working Group on "Contributions to Earth System Modelling" has been established. The main purpose of the WG is to promote the development of a physically consistent numerical Earth system model that is simultaneously be applicable to all geodetic parameters, i.e., Earth rotation, gravity field and deformation, in order to allow homogeneous processing, interpretation, and prediction of these observables. Thus the WG is expected to finally contribute to a deeper understanding of dynamical and complex interacting processes in the Earth system integrally reflected in geodetic monitoring data.

Motivation

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 adequate 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.

Goals

The long-term goal is the development of a modular numerical Earth system model for the homogeneous and physically consistent processing, interpretation and prediction of geodetic parameters. This implicates the following objectives:

- development of a physically consistent modular Earth system model considering the interaction and relationship between surface deformation, Earth rotation and gravity field variations as well as interactions and physical fluxes between relevant sub-systems;
- promotion of homogeneous processing of geodetic monitoring data (de-aliasing, reduction) by process modelling to improve analyses of geodetic parameter sets;
- contributions to the interpretation of geodetic parameters derived from different observation techniques by developing model based strategies to separate underlying physical processes;
- application of forward modelling and inversion methods in order to predict geodetic quantities and to invert geodetic observations for the underlying causative processes;
- development and implementation of coupling algorithms to ensure consistent interactions and physical fluxes among sub-systems;

– contributions to the integration of geodetic observations based on different techniques in order to provide a tool for validation and consistency tests of various geodetic products.

First steps

In the initial phase of the WG the activities are focussing on near-surface fluid dynamics which dominate short-term variations of geodetic parameters (Figure 7). For the near-surface modular system model approach a list of appropriate models for the representation of individual sub-systems is being generated and consistent standards, parameters, analysis strategies and formats for all components of the model approach are being defined. After a constitutive meeting of the WG, that is planned in 2011 and will be open to non-members also, relevant interactions among subsystems and appropriate parameterizations, in particular to represent the dynamic links between near-surface fluids and the "solid" Earth, shall be identified. The next step will be the development of strategies for the separation of temporal variations of Earth rotation, gravity and deformation into individual causative physical processes.

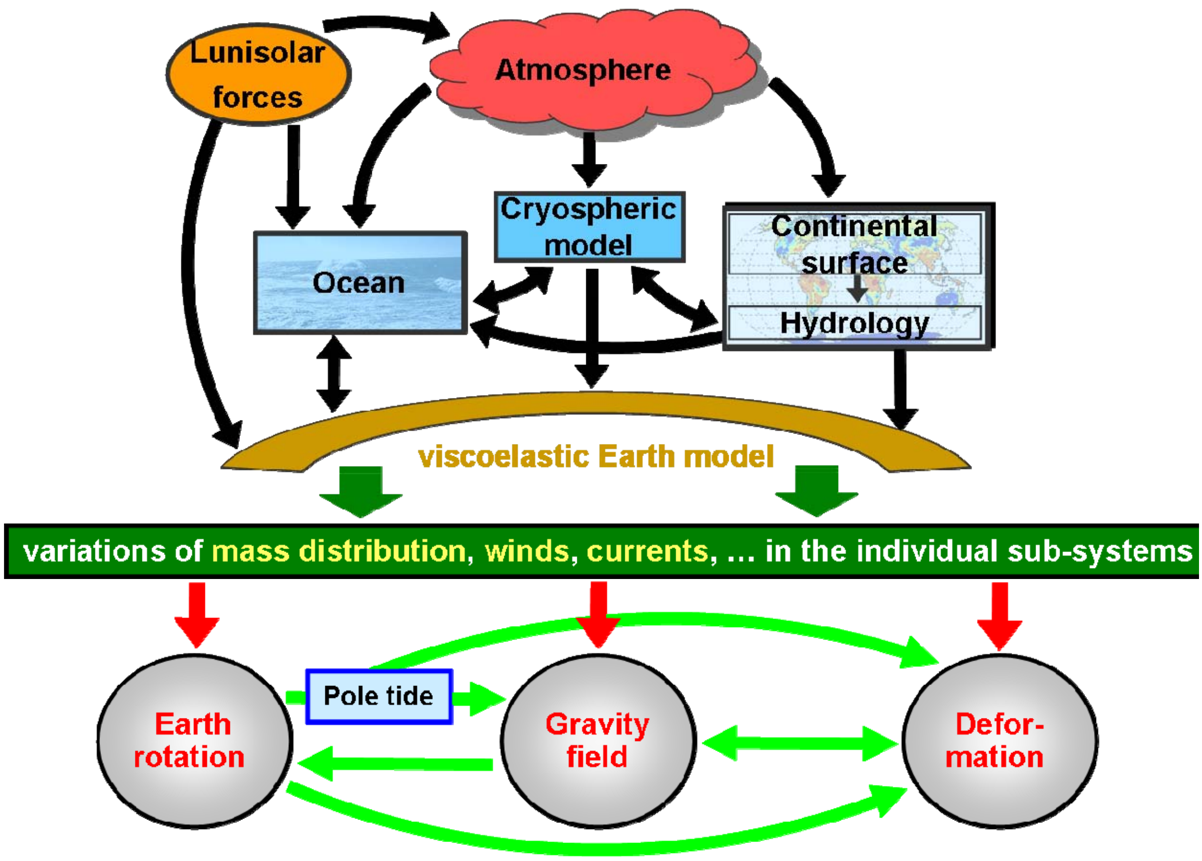

Figure 7: The modular 4d Earth system model approach for near-surface dynamics.

GGOS Coordinating Office

Chair: Giuseppe Bianco (Italy)

The GGOS Coordinating Office (CO) has been established in February, 2010, and is managed by the Italian Space Agency's Space Geodesy Centre located in Matera, Italy.

The main activities carried out by the GGOS CO have been:

- Enforcing the GGOS secretariat
- Managing the GGOS Executive Committee periodic teleconferences;
- Managing the GGOS correspondence

Another important activity done by the GGOS CO has been the new edition of the GGOS web page (www.ggos.org) which has been put on line on March, 2011 (see Figure 8). The web site will be mostly devoted to organization and documentation aspects.

Figure 8: GGOS web site home page

GGOS Portal

Chair: Bernd Richter (Germany)

The GGOS portal will provide a unique access point for all data, products and information relevant in the framework of GGOS to serve Earth science and applications. Basically, it will provide a platform for services to deliver data, to get and use these data for processing products and to get these products.

GGOS data are classified in three different levels:

- L0 level are all raw data,
- L1 level are all RINEX files (meta data, receiver, station), and
- L2 level and higher are the data and products that are provided by the IAG services) available on the GGOS portal through metadata files on the portal's data base (time series).

The GGOS Portal basically serves two different kinds of user: the data-providing user (IAG services and authorised non-IAG institutions) and the data-consuming user. Generally any registered user can upload data into the portal. Non-IAG institution's data and products will be included into the GGOS Portal only after having successfully passed a review process by the working group DIS and accepted finally by the GGOS EC. Further, each IAG and non-IAG service is required to specify their data by corresponding metadata.

The GGOS Portal will be used as a platform to exchange data and products presented topically ordered (natural hazards, science applications, geodetic applications, satellite missions, techniques and services).

The GGOS Portal is based on a service-oriented architecture. A prototype is ready and has been reviewed by the DIS WG and the GGOS EC (see Figure 9). The preliminary test version of the GGOS Portal web presentation can be found under http://observing-system-portal.bkg.bund.de. The GGOS web site and the GGOS portal web site cross linked for reference information and data respectively.

In general, the category "Topics" provides general information on a selected scientific topic . To provide the information the WG DIS and the GGOS EC has asked several individuals to provide detailed information to fill the various fields of interest.

The category "Discovery" will provide a search capability for data and products based on available metadata.

GGOS Portal Metadata

Three possibilities for the metadata description were discussed in the DIS WG:

- xml file template provided by the portal manager,
- a metadata block within the SINEX file, which includes not to distribute the SINEX files to the user,
- metadata editor.

The GeoNetwork is embedded into the GGOS Portal web page as metadata editor (see Figure 10). The GeoNetwork (see http://geonetwork-opensource.org/) is based on the principles of Free and Open Source Software (FOSS) and International and Open Standards for services and protocols (a.o. from ISO/TC211 and OGC). The use in numerous Spatial Data Infrastructure initiatives across the world guaranteed the long-term support. A range of standards is implemented like metadata standards (ISO19115/ISO19119/ISO19110 following ISO19139, FGDC and Dublin Core), Catalog interfaces (OGC-CSW2.0.2 ISO profile client and server, OAI-PMH client and server, GeoRSS server, GEO OpenSearch server, WebDAV harvesting, GeoNetwork to GeoNetwork harvesting support) and Map Services interfaces (OGC-WMS, WFS, WCS, KML and others) through the embedded GeoServer map server.

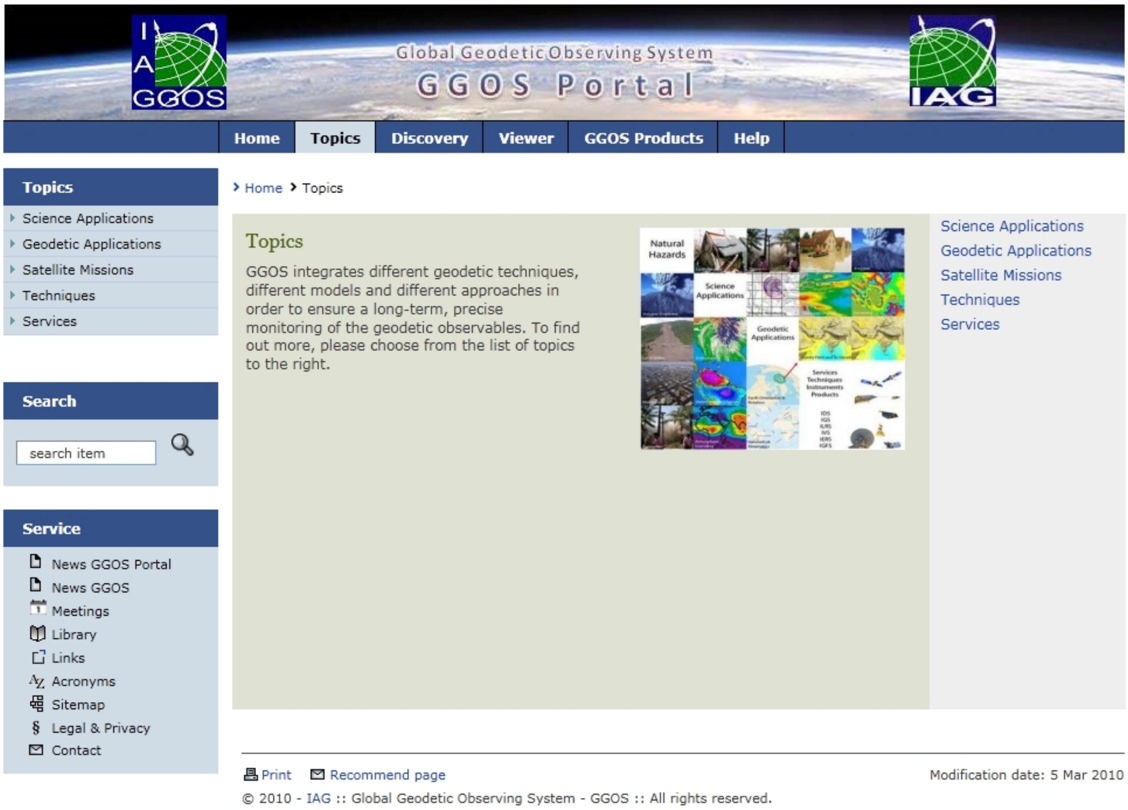

Figure 9: GGOS Portal (screen shot main page Topics)

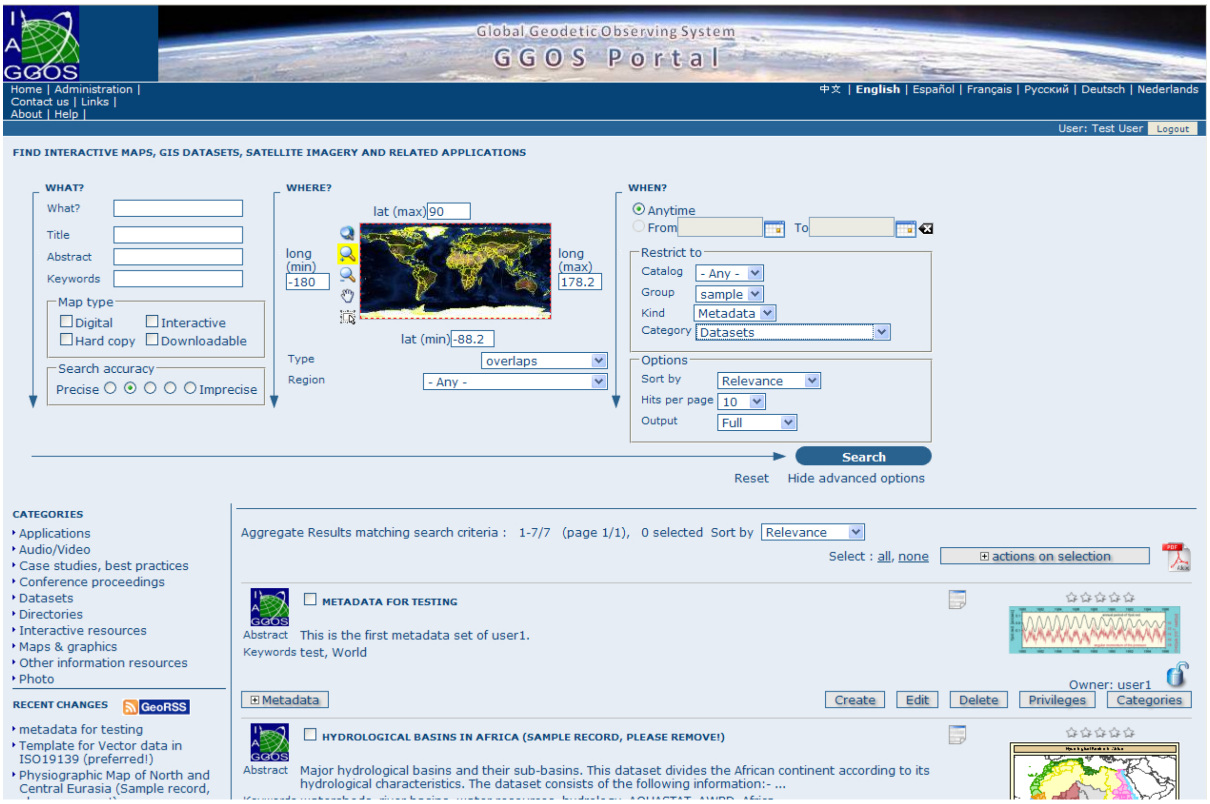

Figure 10: GeoNetwork page "Advanced search" presently under test not yet implemented

The available ISO metadata catalogue has been discussed within the DIS WG and tailored to the necessary geodetic applications. The used fields to describe the individual data are specified in the document presented at the GGOS / IERS UAW workshop in Monterey, Ca.

http://www.iers.org/nn_10902/IERS/EN/Organization/Workshops/Workshop2007MontereyProgramme.html?__nnn=true#doc74712bodyText4 see Sess. 6

"UAW_PosPap_Session_6_GGOS_Portal_and Metadata_Flow_Annexes_1.pdf".

GGOS Science Panel

Chair: Richard Gross (USA)

Members

Jonathan Bamber (UK)
Anny Cazenave (France)
Athanasios Dermanis (Greece)
Andrea Donnellan (USA)
Roger Haagmans (The Netherlands)
Paul Poli (UK)
Matt Rodell (USA)
Reiner Rummel (Germany)
Seth Stein (USA)
John Wahr (USA)
Victor Zlotnicki (USA)

The GGOS Science Panel is a multi-disciplinary group of experts representing the geodetic and relevant geophysical communities that provides scientific advice to GGOS in order to help focus and prioritize its scientific goals. The Chair of the Science Panel is a member of the GGOS Steering Committee and all members of the Science Panel are invited to participate in meetings of the GGOS Steering Committee. The Chair of the Science Panel is also a guest of the GGOS Executive Committee and is invited to participate in its meetings and teleconferences. This close working relationship between the Science Panel and the governance entities of GGOS ensures that the scientific expertise and advice required by GGOS is readily available.

Activities

Besides participating in GGOS Steering and Executive Committee Meetings, the Science Panel has been actively promoting the goals of GGOS by helping to organize relevant sessions at major scientific conferences. GGOS-related sessions have been organized each year during 2006–2011 at the General Assemblies of the European Geosciences Union and each year during 2007–2010 at the Fall Meetings of the American Geophysical Union (AGU). In addition, a GGOS session was organized at the 2009 Scientific Assembly of the IAG. And plans have been made to organize sessions relevant to GGOS at the XXV General Assembly of the IUGG that will be held during 28 June – 7 July 2011 in Melbourne Australia and at the 2011 Fall Meeting of the AGU that will be held during 5–9 December 2011 in San Francisco, Calif.

In addition to helping organize sessions at scientific conferences, the GGOS Science Panel also convenes topical workshops in order to foster discussion about the geodetic observations and infrastructure required by different scientific disciplines. Two such workshops were convened during 2007–2011:

Understanding Glacial Isostatic Adjustment: A Joint DynaQlim/GGOS Workshop

The Global Geodetic Observing System of the International Association of Geodesy and the International Lithosphere Program Regional Co-ordination Committee DynaQlim jointly organized a workshop on "Understanding Glacial Isostatic Adjustment" that attracted 36 international participants to Espoo, Finland during June 23-26, 2009. The objectives of this workshop were to: (1) review the current state of the science in modelling glacial isostatic adjustment, (2) review the use of geodetic measurements to both constrain and to test GIA models, (3) identify obstacles to improving GIA models, and (4) identify the improvements to the global geodetic observing system that are required to advance our understanding of glacial isostatic adjustment. Workshop participants made a number of recommendations regarding geodetic observations and infrastructure, including those summarized below.

Isolating the GIA signal in geodetic observations is an important prerequisite to advancing our understanding of the GIA process. Workshop participants identified gravity observations from GRACE as being key in this regard because of its ability to use the differing fingerprints of GIA and present-day ice mass change to aid in their separation. The continued acquisition of time variable gravity observations from space was strongly recommended by the workshop participants.

The BIFROST network in Fennoscandia has demonstrated the importance of regional networks of GNSS receivers, surface gravity instruments, and seismometers (not necessarily collocated) for understanding the GIA process. Such networks should be established in other areas of uplift. Measurements from such high-latitude networks can also be used to improve the terrestrial reference frame (TRF), which is currently stable to only about 1 mm/yr. Since the GIA-induced motion of the geocentre (the offset of the centre-of-mass of the Earth from the centre of the network of observing stations) is estimated to be between 0.1 mm/yr and 1 mm/yr, the stability of the TRF needs to be improved by at least an order of magnitude so that estimates of this small signal are not corrupted by errors in the reference frame within which the measurements are being taken.

A summary of the workshop was published in *Eos, Transactions of the American Geophysical Union* [Gross, R., and M. Poutanen, Geodetic observations of glacial isostatic adjustment, *Eos Trans. AGU*, *90*(41), 365, 2009] and the proceedings of the workshop will be published as a special issue of the *Journal of Physics and Chemistry of the Earth*.

Observing and Understanding Earth Rotation: A Joint GGOS/IAU Science Workshop

The Global Geodetic Observing System of the International Association of Geodesy and Commission 19 (Rotation of the Earth) of the International Astronomical Union jointly organized a workshop on "Observing and Understanding Earth Rotation" that attracted 90 participants from 12 countries to Shanghai, China during October 25-28, 2010. The objectives of this workshop were to: (1) assess our current ability to observe the Earth's time varying rotation, (2) assess our current understanding of the causes of the observed variations, (3) assess the consistency of Earth rotation observations with global gravity and shape observations, (4) explore methods of combining Earth rotation, gravity, and shape observations to gain greater understanding of the mass load acting on the surface of the solid Earth, and (5) identify improvements in the global geodetic observing system needed to further our understanding of the Earth's variable rotation.

Measurements of the Earth's time varying rotation have been traditionally provided by optical astrometry and the space-geodetic techniques of satellite and lunar laser ranging (SLR and LLR), very long baseline interferometry (VLBI), global navigation satellite systems (GNSS) like the global positioning system (GPS), and Doppler orbitography and radio positioning integrated by satellite (DORIS). However, the launch of the GRACE twin gravity satellites in March 2002 and the densification of the global GNSS ground receiver network afford new opportunities for studying the Earth's rotation. GRACE is directly observing the effect of mass redistribution on the Earth's rotation, and the global network of GNSS ground receivers can be used to infer changes in the load acting on the Earth's surface and its effect on the Earth's rotation from observations of changes in the Earth's shape.

In the future, greater understanding of the processes causing not only the Earth's rotation but also its gravity and shape to change will be obtained by integrating Earth rotation, gravity, and shape measurements into a global geodetic observing system. This integration is one of the essential goals of GGOS and this workshop took us one step closer to that goal.

A summary of the workshop was published in *Eos, Transactions of the American Geophysical Union* [Gross, R., H. Schuh, and C.-L. Huang, Spin, wobble, and nutation, *Eos Trans. AGU*, *92*(4), 31, 2011] and the proceedings of the workshop will be published as a special issue of the *Journal of Geodynamics*. This special issue will consist not only of papers presented at the workshop but will also include other contributions on this topic that are submitted in response to an open call for papers.

GGOS Themes

Chairs: Michael Sideris (Canada), Tim Dixon (USA) and C.K. Shum (USA)

Overview

The idea to establish GGOS themes goes back to the Workshop on Future Satellite Gravity Missions in Graz in September 2009, where Reiner Rummel presented his thoughts about Thematic (Geodetic) Observing Systems. Because of the complexity of the Earth system it makes sense, instead of working on the entire complex Earth system at once, to first consider Thematic (Geodetic) Observing Systems (and Models) in order to be able:

- to cope with the complexity of the Earth system
- to work on an integrated but limited / manageable part of the Earth system
- to get an independent control
- to generate suitable integrated GGOS products

Examples of such thematic geodetic observing systems are the themes „Ice Mass Balance", „Continental Water Balance" or „Sea Level Change" (see Figure 11).

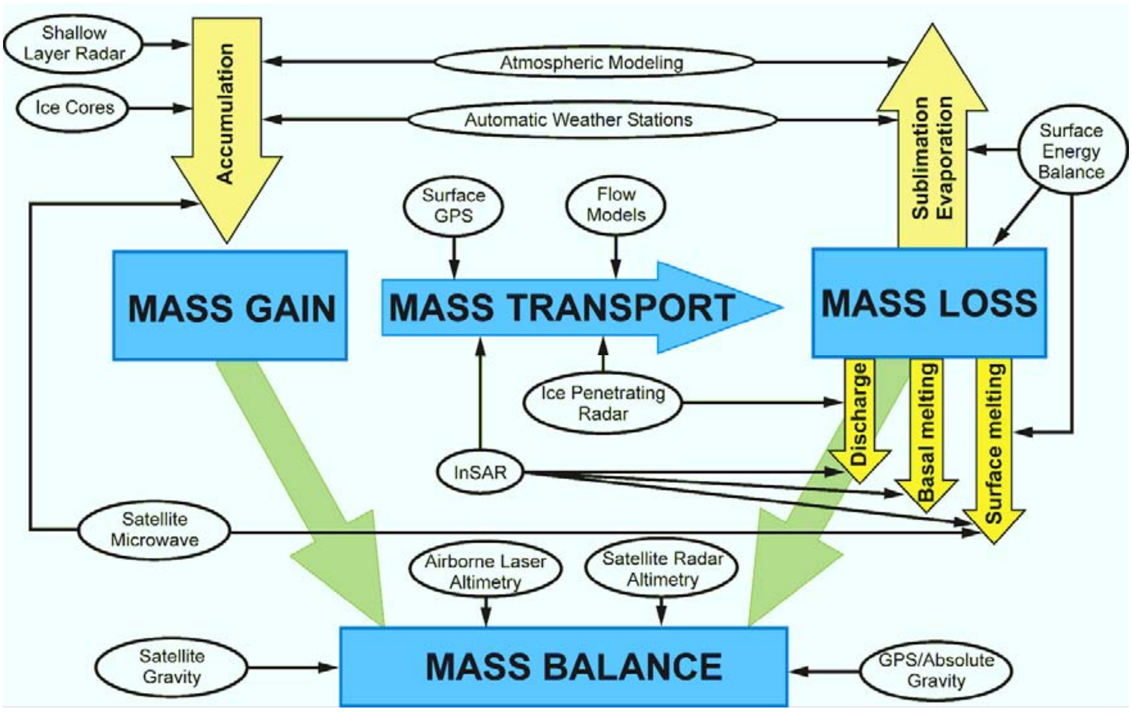

Figure 11: Example of a Thematic Geodetic Observing System on "Ice Mass Balance" (Thomas, EOS, 2001)

In a second and later step the Thematic (Geodetic) Observing Systems would then be connected and linked to the Global (Geodetic) Observing System:

- as partial systems of global Earth system studies
- for Earth rotation studies on global mass balance, where mass and motion have to be combined
- for consistency and quality checks between the Thematic (Geodetic) Observing Systems

In preparation for the GGOS Retreat in February 2010 in Miami, three thematic (geodetic) observing systems or integrated products were selected (as a start):

- Theme 1: Global Unified Height System (Chairs: M. Sideris, J. Ihde)
- Theme 2: Geohazards (global Earth surface deformations and strain rates for geohazards assessment and disaster prevention) (Chairs: T. Dixon, R. Gross)
- Theme 3: Understanding and Forecasting Sea-Level Rise and Variability (Chairs: C.K. Shum., Phil Woodworth)

The progress made since the GGOS Retreat 2010 in Miami is described in the following sections of this report.

GGOS Theme 1: Unified Global Height System

Chairs: Michael Sideris, Johannes Ihde

The Inter-Commission Project 1.2: Vertical Reference Frames (ICP1.2) is a common project of IAG Commission 1 and 2 (http://whs.dgfi.badw.de). From beginning of 2010 the activities of ICP1.2 were integrated in GGOS as Theme 1.

The definition and realization of a World Height System (WHS) is a fundamental requirement of GGOS (Global Geodetic Observing System). In the same way as the ITRS/ITRF provides a high precision geometrical reference frame, the WHS shall provide the corresponding high precision physical reference frame for studying the system Earth.

The results of the work of the ICP1.2 in the first term 2003 – 2007 are documented in Conventions for the Definition and Realization of a Conventional Vertical Reference System (CVRS), Ihde et al. 2007. The main objective for the second term 2007 – 2011 is the initiation of a pilot project for a WHS realization (WHS-PP).

In July 2010 the description of the WHS Pilot Project with a call for information about planned contributions was send out. The deadline for final contributions Survey of WHS-PP results is May 2011 and the final report will be given at IAG General Assembly 2011.

The four WHS-PP Work Items are:

1. *Analysis centres for determining and monitoring the relationship between a conventional W0 and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface*
2. *Regional processing centres and global combination centres for GNSS/levelling stations with coordinate time series in the current ITRF linked to TIGA stations and geo-potential numbers referred to the RHS at defined epochs*
3. *Investigations on the accuracy of computing point values Wp of the gravity potential by means of high resolution gravity field models and regional densifications of gravity data*
4. *Operative determination of physical WHS heights in regions with a weak geodetic infrastructure including and development of an information system (registry) providing relevant data*

At the end of the second term of ICP1.2 and after the work of the various WIs is completed, the ICP1.2 will prepare a final report and recommendations on how to best realize the WHS (including all relevant issues such as the computation and adoption of a "best" W_0 value, an optimal global geoid surface, etc.) This report will be presented at the IAG General Assembly in Melbourne.

In the future, the work of ICP should continue in the form of a GGOS Integrated Product (i.e., Theme 1) for the establishment and maintenance of a WHS. The International Gravity Field Service (IGFS) should take the leading role there and report directly to GGOS. GGOS has to clarify inconsistencies in the numerical parameters for integrated geodetic applications. Conventions for the definition and realization of the parameters of the MSSL have also to be agreed.

GGOS Theme 2: Geohazards

Chairs: Tim Dixon, Richard Gross

Geodetic measurements have a fundamental role to play in the understanding and mitigation of many natural hazards. Most hazard assessment requires comparing measurements before and after some event in order to detect a change. Examples include volcano monitoring, coastal subsidence associated with flood hazards, subsidence associated with tunnel construction or excess groundwater/oil extraction, and earthquake co-seismic offsets and post-seismic activity. While GNSS measurements have been very successfully used to study these and other geohazards, Synthetic Aperture Radar (SAR) is being increasingly used because of its superior spatial resolution. But whether using GNSS or SAR measurements, the successful detection of a change on the ground from space requires accurate reference frames, satellite orbits, atmospheric models, etc. The objective of GGOS Theme 2 on Geohazards is to improve the effectiveness of the geodetic community in geohazard identification, assessment, prioritization, prediction, warning, and research.

Much progress has been made in the past decade on improving change detection on the ground from space but more progress is needed. In particular, continued refinement of the accuracy and stability of the ITRF, improved ultra-rapid GNSS orbits including lower refresh rates, better clock estimates for precise point positioning, better atmospheric models, lower latency ultra-precise SAR orbits, and better regional coverage of InSAR images are all needed. GGOS can play a very effective role in advocating for the improvement in geodetic infrastructure and data analysis needed for geohazards applications, not only by itself but also by working with other groups such as the GEO Supersites Initiative.

The Geohazard Supersites is a GEO initiative to better understand the geophysical processes causing geohazards <http://supersites.earthobservations.org>. It consists of a global partnership of scientists and satellite and *in situ* data providers (multi-sensor InSAR, seismic, and GNSS) having the goal of supporting national authorities and policy makers in risk assessment and mitigation strategies. A closer working relationship between GGOS and the GEO Supersites Initiative would aid Theme 2 in meeting its objective.

GGOS Theme 3: Understanding and Forecasting Sea-Level Rise and Variability

Chairs: C.K. Shum, Phil Woodworth

This activity was initiated primarily as a demonstration Theme to show the value of geodesy, and GGOS in particular, to a high-profile area of science and applications. Sea level is anyway an important geodetic quantity (traditionally being the basis of the geodetic datums of many countries), but it is also of great scientific and public interest, especially with regard to potential sea-level rise, local land motion, and flooding of coastal environments and infrastructures.

The Theme is managed by a group of scientists comprising Philip Woodworth, C.K. Shum, Tilo Schöne, Mark Tamisiea and Per Knudsen. At its outset, it set itself three broad topics of activity:

1. Identification of the requirements for a proper understanding of global and regional/local sea-level rise and variability, and the associated land motion, 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).
2. Identification of the 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.
3. 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.

These topics are described in detail in the Theme Action Plan (latest version dated 6 April 2011). Although some thoughts are expressed in the Action Plan on how to take forward the first two topics, in practice progress has been made only in organizing the third topic.

This topic is based on a proposal by H-P Plag two years ago. It is concerned with the forecasting of sea-level change over various timescales, focussing on the sea-level rise to be expected in the medium term (e.g. less than 30 years) at major cities and population centres for input to coastal defence planning. Such projects would be of considerably greater utility to planners than the 2100 projections provided by IPCC Assessments, for example, a timescale of 30 years being long enough for many civil engineering schemes to be undertaken.

Our feeling is that such demonstration activities could benefit from previous experience with projects such as the Thames Estuary 2100 study for London and similar studies in the Netherlands, Denmark, US Pacific and Atlantic coasts etc. Potential areas for further study might include Manila, Bangkok, Shanghai, Djakarta, Lagos and other large Asian and African cities for which submergence (natural or anthropogenic) and/or storm surge risk of flooding are major considerations, or countries such as Bangladesh or Egypt which include large deltas where high rates of sea level rise are a natural phenomenon to be lived with. (A relevant reference here is to the 'Cities at Risk' international activities, start.org/programs/cities-at-risk.)

Our plan is to issue a Call for Proposed Projects under this action by the middle of 2011, which will require (geodetically) integrated approaches to studies of sea level change on 30 year (forecast) timescales. The projects will be publicised through GGOS using a standard format and will be open to both, existing or past projects as well as to new ones, the latter benefitting potentially from support from GGOS in their search for funding. The value of including existing or past projects is that they can be used immediately to demonstrate the value of the action.

GGOS in the Group on Earth Observation (GEO)

Representative to the Plenary: Markus Rothacher (delegation head), Ruth Neilan, Susanna Zerbini (Science and Technology Committee), Bernd Richter (Architecture and Data Committee)

Overview

GGOS, representing the IAG within GEO, has been actively involved in GEO since the IAG became a participating organization of GEO in 2005. The main contributions made by the GGOS representatives are

– GGOS tasks within the GEO Work Plan 2007-2011
– Participation in GEO Committees and Working Groups
– Participation in the GEO Plenary Meetings and Ministerial Summits

This work is especially important, because it makes GGOS much more visible to the outside world and leads to contacts to all major international organizations in the field of Global Erath Observation.

Main tasks within GEO Work Plan 2007-2011

Based on an initiative of H.P. Plag GGOS is presently contributing with two major tasks to the GEO Work Plan 2007-2011 and is involved in a third:

DA-09-02: Data Integration and Analysis. **Subtask DA-09-02c**: Global Geodetic Reference Frames. Task leader from IAG/GGOS is Zuheir Altamimi. Before March 2010 it was H.P. Plag.

AR-09-03: Advocating for Sustained Observing Systems. **Subtask AR-09-03e**: Global Geodetic Observing System (GGOS). Task leader Mike. Pearlman.

ST-09-02: Promoting Awareness and Benefits of GEO in the Science and Technology Community. Susanna Zerbini is the representative of GGOS here.

These tasks will also be continued in the GEO Work Plan 2011-2015. More details may be found below.

GEO Committees and Working Groups

The participation of GGOS in a number of GEO Committees and Working Groups from 2007-2011 is summarized in Table 5. Major efforts were done in the GEO Science and Technology Committee , the GEO Architecture and Data Committee and the GEO User Interface Committee. More details are given below. GGOS was also represented in the GEO Working Group on Tsunami during its rather short existence.

Table 5: Representatives of GGOS in GEO Committees and Working Groups

Period	GEO Committee / WG	Representatives
2007-2010	GEO Science and Technology Committee	S. Zerbini, M. Pearlman, M. Rothacher
2007-2010	GEO Architecture and Data Committee	B. Richter, C. Noll, R. Neilan, H.P. Plag
2007-2010	GEO User Interface Committee	H.-P. Plag, C.K. Shum, C. Boucher
2007-2010	GEO Capacity Building and Outreach Committee	C. Rizos, H. Drewes, L. Combrinck
2007-2010	GEO WG on Tsunami Activities	H.-P. Plag, T. Schöne
2010-…	GEO Science and Technology Committee	S. Zerbini, R. Gross
2010-…	GEO Architecture and Data Committee	B. Richter, C. Noll
2010-…	GEO User Interface Committee	J. Park, C. Rizos
2010-…	GEO Capacity Building and Outreach Committee	M. Pearlman, R. Neilan, L. Combrinck

GEO Plenaries and Ministerial Summits

During the period from 2007 to 2011 the GGOS representatives participated in all the GEO Plenary and Ministerial Summits. Table 6 lists these GEO events and the activities of GGOS during these events. The main emphasis was on getting contacts and connections to UN organizations and other international bodies and to promote GGOS within GEO. A GGOS booth was realized and a considerable amount of outreach material (leaflets, posters, brochures, 1-page stories, …) and used at many of the GEO Plenaries.

Table 6: GEO Plenary Meetings and Ministerial Summits from 2007-2011

GEO Event	GGOS Activities	GGOS Participants
GEO Plenary IV and Ministerial Summit, Cape Town, South Africa, Nov. 2007	GGOS booth set up with the help of GFZ and R. Wonnacott. Many contacts to international organizations to promote GGOS	M. Rothacher, R. Neilan, H.P. Plag
GEO Plenary V, Bucharest, Romania, Nov. 2008	GGOS booth set up with the help of GFZ and R. Wonnacott. Many important contacts to UN organizations	M. Rothacher, H.P. Plag
GEO Plenary VI, Washington DC, USA, Nov. 2009	GGOS booth, GGOS outreach material, flyers, videos; contacts to international organizations	M. Rothacher, H.P. Plag, R. Neilan, M. Pearlman, S. Zerbini
GEO Plenary VII and Ministerial Summit, Beijing, China, Nov. 2010	Official statement of GGOS in Min.Summit, GGOS booth, contacts with many international organizations	M. Rothacher, R. Neilan, C. Rizos, S. Zerbini

GEO Science and Technology Committee

Main Representative: Susanna Zerbini

The GEO Science and Technology Committee (STC) was established in 2006 and since then met 16 times in different locations all around the world. Susanna Zerbini, representing IAG/GGOS, participated to most of these meetings and provided an active contribution to the development of the STC activities. Detailed information on the meeting outcomes is available at http://www.earthobservations.org/com_stc_me.shtml.

The STC engages the scientific and technological communities in the development, implementation and use of a sustained Global Earth Observation System of Systems (GEOSS) in order to ensure that GEO has access to sound scientific and technological advice. Objectives of the STC are:

- Enable GEO to make decisions on best available and sound scientific and technological advice, through the solicitation of input from a broad, trans-disciplinary scientific and technological community
- Ensure scientific and technological integrity and soundness of GEO Annual Work Plans.
- Monitor and review output and deliverables of GEO Annual Work Plans.
- In collaboration with GEO Members and participating organizations, and through transparent processes, identify individual experts and groups to participate in GEO working groups.
- Facilitate linkages and partnership with major relevant international research programs as well as organizations willing to contribute to GEO activities.

During the reporting period, the STC was engaged in several different activities.

The Role of Science and Technology in GEOSS

A document was prepared which describes the "Role of Science and Technology in GEOSS". It was published in 2008 and it can be downloaded from http://ec.europa.eu/research/ environment/pdf/geoss.pdf. This document describes the role of science and technology in advancing the GEOSS through the GEO 2007-2009 Work Plan. The STC is working to strengthen this role by encouraging the wider scientific and technology community to participate as contributors to and benefactors of a sustained GEOSS.

STC is responsible for and/or overlooking several GEO tasks. IAG/GGOS contributes to one of them: ST-09-02.

TASK-ST-09-02 Title: Promoting Awareness and Benefits of GEO in the Science and Technology Community.

The task definition is: Promoting awareness and benefits of GEOSS in the scientific and technological communities in order to engage the research community in GEO and GEOSS with the goal to achieve breakthroughs in the understanding of the Earth's changing environment and global integrated Earth system. The scientific community should collaborate within GEO to address interactions between the components of the global integrated Earth system, and connect natural and socioeconomic sciences.

Activities include: (i) form links with major scientific research enterprises in each societal benefit area; (ii) actively encourage relevant scientists and technical experts to contribute to GEOSS in a truly participatory way; (iii) reach out to the world's diverse scientific and technological communities and make GEOSS more visible and attractive to them; (iv) contact universities and laboratories to involve them in GEOSS activities; and (v) organize a GEO presence at major symposia and other meetings, for example through plenary presentations or side events.

IAG/GGOS is actively engaged in several of the above mentioned activities, in particular, as regards activities from (ii) to (v).

Following the GEO-V Plenary (November 2008), the STC took action to develop a STC roadmap. This roadmap was finalized in early 2009 and subsequently approved by the STC. It can be downloaded from http://www.earthobservations.org/documents/committees/stc/stc_roadmap_20091202.pdf.

The status of the roadmap is being checked during the STC meetings

Roadmap

This roadmap identifies and motivates the path that the STC of the GEO has decided to pursue to achieve its objectives. It primarily addresses the Committees of GEO, its Task Teams, working groups and Communities of Practise. It also addresses the Science and Technology (S&T) communities within the scope of the Societal Benefit Areas of the GEOSS and the S&T communities needed to build, deploy, access and sustain the GEOSS.

Gap Analysis Strategy

The GEO Executive Committee (ExCom), during its 19th meeting, recognized that the GEO community needed an overall strategy for analysis of observational and structural gaps. This lead to an Action (19.11) which involves the STC, the Monitoring and Evaluation Working Group and other interested members of the GEO Community to draft an initial outline of a process that can eventually lead to a coherent overall mechanism being put in place for required GEO/GEOSS gap analyses.

GEO Architecture and Data Committee

Main Representative: Bernd Richter

The Architecture and Data Committee (ADC) supports GEO in all architecture and data management aspects of the design, coordination, and implementation of the Global Earth Observation System of Systems (GEOSS) for comprehensive, coordinated, and sustained Earth observations.

During the time span the GEOSS Common Infrastructure had been implemented. Starting with three Web-Portals and three clearinghouses benchmark tests and reviews lead to one Web-Portal hosted by ESA and one clearinghouse set up by USGS. Also necessary recommendations for standards and interoperability in GEOSS have been developed as well as the data sharing principles.

GGOS contributed to the GEO work plan by two tasks supporting an integrated GEOSS under the guidance of the Architecture and Data Committee.

AR-09-03: Advocating for Sustained Observing Systems / Subtask: e) Global Geodetic Observing System (GGOS)

This sub-task is led by IAG (mpearlman@cfa.harvard.edu)

Promote the further development of sustained infrastructure needed to satisfy the long-term (10-20 years) requirements for the reference frames and the monitoring of global change signals. GGOS provides observations of variations in Earth shape, gravity field and rotation, which are fundamental for monitoring of climate and global change. GGOS observations contribute to at least seven of the SBAs. Moreover, with the global geodetic reference frames (International Terrestrial Reference Frame (ITRF) and International Celestial Reference Frame), GGOS provide the foundation for most Earth observations. Among other components, geodetic monitoring of global change crucially depends on globally sustained geodetic ground networks.

DA-09-02: Data Integration and Analysis / Subtask: c) Global Geodetic Reference Frames

This sub-task is led by IAG (zuheir.altamimi@ensg.ign.fr)

Ensure the availability of accurate, homogeneous, long-term, stable, global geodetic reference frames as a mandatory framework and the metrological basis for Earth observation. Identify steps towards such consistent high-accuracy global geodetic reference frames for Earth observation and the observing systems contributing to GEOSS. Promote the use of common or interoperable reference frames within GEOSS.

GEO User Interface Committee

A very substantial amount of work in the GEO User Interface Committee (UIC) (as well as in other GEO committees) was done by Hans-Peter Plag. He was the main representative of GGOS in this committee until March 2010.

GEO Capacity Building Committee

Since March 2010 GGOS is also involved in the GEO Capacity Building Committee. The main representatives are Mike Pearlman and Ruth Neilan.

Bureau International des Poids et Mesures (BIPM) – Time Department[1] –

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 monthly 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 3×10^{-16} for averaging times of one month.

Fourteen primary frequency standards contributed during the period to improve the accuracy of TAI, including ten caesium fountains developed and maintained in metrology institutes in France, Germany, Italy, Japan the United Kingdom and the USA. The scale unit of TAI has been estimated to match the SI second to about 5×10^{-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. Since October 2009 a combination of code and phase measurements of geodetic-type receivers is used in the computation of TAI. Since the end of 2009 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. 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

Improvements to the algorithm for calculation of TAI and UTC contributed with the development of a new model for the clock frequency prediction. Initially thought for the hydrogen maser frequency prediction, we concluded that also the caesium clocks needed of a revision of the frequency prediction model. The new algorithm has been developed, based on a parabolic model for the clock prediction. With this new model, the drift observed in the atomic free scale (EAL) with respect to TAI disappears.

[1] The Time, Frequency and Gravimetry Section of the BIPM became the Time Department on 1 January 2011.

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, still unable to compare these standards at the level of their performances. Studies on the use of optical fibres show excellent results. The time community is engaged in a collective effort for solving this issue, since one of the interests is the possibility of redefining 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). A new version of the IERS Conventions (2010) has been published in the IERS Technical Note N°36, and is available on the internet (http://www.iers.org/nn_11216/IERS/EN/Publications/TechnicalNotes/tn36.html). 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 IAU and IVS activities.

The campaign of comparison of absolute gravimeters ICAG 2009 took place at the BIPM in October 2009, with the participation of 23 instruments. First measurements of the gravity on the site where the BIPM watt balance will be operated were made.

Following the decision of the CIPM in October 2009, the BIPM stop 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 ICAGs.

The total number of publications of the Time Department staff during the period is 75.

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 2007, 2008, 2009* and *for 2010* have been published. Starting by the report for 2009, this publication is only in electronic version, complemented by computer-readable files, and 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.

The effect of the linear prediction algorithm has been studied for different types of clocks in TAI. Until present the algorithm predicts the clock frequency with a linear model for the two types of industrial standards in TAI, caesium clocks and hydrogen masers. This model of prediction proved to be well adapted to the caesium clock behaviour not affected by ageing, and is not at all suitable for the hydrogen masers, whose frequency presents a short-term drift. A new mathematical expression for the prediction of the hydrogen maser frequency is proposed taking into account this drift. Also a mathematical expression has been developed to account for the effects (long-term) of the age of the caesium clocks. Tests have been performed applying a quadratic prediction to the clocks. The results indicate that non-modelling of the frequency drift of hydrogen masers could be responsible for 20% of the drift of EAL with respect to TAI observed in the past five years. Completed with the new modelling of the caesium clock frequency the drift of EAL disappears.

Stability of TAI

Some 87 % of the clocks used in the calculation of time scales 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 15 % 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 3×10^{-16} for averaging times of one month. Slowly varying, long-term drifts limit the stability to around 2×10^{-15} for averaging times of six months.

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 fourteen primary frequency standards, including ten 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, a maximum, 0.7×10^{-15} is applied as deemed necessary to put the frequency of TAI as close as possible as that of the primary frequency standards. 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 $+2.6 \times 10^{-15}$ to $+6.9 \times 10^{-15}$, with a standard uncertainty of less than 1×10^{-15}.

To improve the performances of TAI, in term of accuracy, a study of the influence of different atomic clocks (caesium clocks, hydrogen masers, etc.) on the time scale algorithm has been conducted (see section "Algorithms").

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(BIPM10), valid until December 2010, has an estimated accuracy of order 3×10^{-16}. Starting with TT(BIPM09), an extrapolation for the current year of the latest realization TT(BIPMYY) is provided and is updated each month after the TAI computation.

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 Committees for Length and for Time and Frequency, seeking to encourage knowledge sharing between laboratories, the creation of better documentation, comparisons, and the use of high accuracy PFS (Cs fountains) for TAI.

Other microwave and optical atomic transitions are being proposed as secondary representations of the second by the CCL/CCTF Frequency Standards Working Group. The list containing frequency values and uncertainties for transitions in Rb, Hg^+, Yb^+, Sr^+ and Sr, recommended by the Consultative Committee for Time and Frequency (CCTF) has been updated in 2009. 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.

Clock comparison for TAI

TAI relies at present on 69 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; with dual-frequency, multi-channel GPS geodetic type receivers (P3); with code and phase measurements (GPS PPP); and with two-way satellite time and frequency transfer through geostationary telecommunications satellites (TWSTFT). Most of the old GPS single-channel single-frequency receivers had been replaced by either multi-channel single- or dual-frequency receivers. Ten TWSTFT links are officially used for the computation of TAI, representing 15% of the time links

Results of link comparisons by the different techniques and methods are made available on the BIPM website (http://www.bipm.org/jsp/en/TimeFtp.jsp). Testing continues on other time and frequency comparison methods and techniques.

All GNSS links are corrected for satellite positions using IGS (International GNSS Service) and ESA post-processed, precise satellite ephemeredes, and those links made with single-frequency receivers are corrected for ionospheric delays using IGS maps.

The TWSTFT technique is currently operational in twelve European, two North American and seven Asia-Pacific time laboratories. Ten TWSTFT links are routinely used in the computation of TAI.

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 GPS receiver from our time laboratory.

Work on absolute calibration of GNSS receivers has been started by a PhD student trough a collaboration co-financed with the French space agency CNES, and also involving the French laboratory for time metrology LNE-SYRTE at the Paris Observatory. This work is close to conclusion, with excellent results.

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 BIPM shares with the US Naval Observatory the responsibility for providing the IERS Conventions Centre. The web and ftp site for the *IERS Conventions* established at the BIPM (http://tai.bipm.org/iers/) has been maintained. The version *Conventions* (2010) have been posted on the website and the printed version is expected soon.

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. Within the period of this report, the new conventional reference frame was submitted to the IAU and approved by a resolution in August 2009.

Activities in Frequency

Frequency comb

As the result of the reorganization of activities in the Section, the comb activities are limited to the comb maintenance for BIPM internal applications.

Calibration and measurement service

The section 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, for the calculable capacitor project and the gravimeter instrumentation at the BIPM. The combs are passively kept in running conditions and used when needs appear.

Iodine cells

Although the continuation of the iodine cell service was accepted in the frame of the 2009-2012 work program, the BIPM budget voted by the General Conference for Weights and Measures (CGPM) in 2007 led the CIPM to reconsider the BIPM work program and to take the decision to stop this activity by the end of July 2009.

Gravimetry

The activities on gravimetry were interrupted following a decision of the CIPM in 2009. We report here on those until the end of the service.

Gravimeter FG5-108

The laser head of the compact Nd:YVO_4/KTP/I_2 laser at 532 nm has been modified and the optical fibre system for the light delivery to the interferometer of FG5-108 has been tested. The gravimeter is out of use at the moment of concluding this report.

Truncation tests

The truncation tests, i.e. the study of the dependence of the results of *g* measurement on the choice of the initial and final interference fringes of the series of recorded fringes used in the data processing, were performed for the data obtained with the gravimeter FG5-108 during the comparison ICAG-2005.

Correction related to the distortion due to diffraction effects

The modern design of an absolute gravimeter is based on laser interferometers for the determination of the time-dependent position of the falling test mass. Ideally, the light field for such an interferometer is considered to be a monochromatic plane wave of infinite lateral extension. However, the fact that the laser sources most often used have a resonant cavity composed of spherical mirrors imposes broader conditions on the Helmholtz equation giving beam-like solutions with different spatial extensions. For each of these, minute corrections in the phase progression compared to the plane wave approximation are present. A study has been made in which expressions for these phase-corrections were derived for the case of a two-beam interferometer. The contribution from these diffraction-induced shifts to the *g* value determined in absolute gravimetry has been calculated.

Correction related to the finite speed of light

The existing methods for the evaluation of the correction to the results of *g* measurements related to the effects of the light propagation in the interferometer with the free-falling reflector are under analysis for the preparation of the recommendations by the Consultative Committee for the Mass and Related Quantities (CCM) Working Group on Gravimetry on the evaluation of such a correction for the absolute ballistic gravimeters.

The 8th International Comparison of Absolute Gravimeters, ICAG-2009

The evaluation of the results of the ICAG-2005 provided valuable input to the design and preparation of the 8th ICAG-2009.

Two meetings of the Steering Committee of ICAG-2009 were organized in November 2008 at the BIPM and on 11-12 May 2009 in Prague (Research Institute of Geodesy, Topography and Cartography). Twenty-three participated in the comparison. Of these, twelve gravimeters will took part in the Key Comparison CCM.G-K1 which is the part of ICAG-2009. The measurements of the remaining subset of gravimeters were organized as a Pilot Study but still being part of ICAG-2009.

The strategy of the absolute and relative measurements, the data processing and evaluation of the Comparison Reference Values with their uncertainties are defined in the Technical Protocols. Two different protocols are being developed for CCM.G-K1 part of the ICAG-2009 and for the whole ICAG-2009.

The final report of ICAG 2009 is under preparation. Results of the Key Comparison CCM.G-K1 will be published in the BIPM KCDB.

Preliminary study on the BIPM watt balance project in view of gravimetry

The watt balance requires an uncertainty of 10^{-8} in the absolute gravity value. Preliminary studies have been carried out on the equipment and the influence of local and global environment for accurate gravity measurements.

Staff of the Section

Dr Elisa Felicitas Arias, Principal Research Physicist, Director
Mr Raymond Felder, Physicist (Frequency), retired 09/2009
Ms Aurélie Harmegnies, Assistant (Time), since 11/2008
Dr Zhiheng Jiang, Principal Physicist (Time, Gravimetry)
Mrs Hawaï Konaté, Principal Technician (Time)
Mr Jacques Labot, Principal Technician (Frequency)[2], retired 07/2009
Dr Wlodzimierz Lewandowski, Principal Physicist (Time)
Dr Gianna Panfilo, Physicist (Time), since 08/2007
Dr Gérard Petit, Principal Physicist (Time)
Dr Lennart Robertsson, Principal Physicist (Frequency, Gravimetry)
Mr Laurent Tisserand, Principal Technician (Time) *
Dr Leonid Vitushkin, Principal Research Physicist (Gravimetry), retired 10/2009

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BIPM publications

76. BIPM Annual Report on Time Activities for 2010, 2011, **5**

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78. BIPM Annual Report on Time Activities for 2008, 2009, **3**, 97 pp.

79. BIPM Annual Report on Time Activities for 2007, 2008, **2,** 97 pp.

80. BIPM Annual Report on Time Activities for 2006, 2007, **1,** 100 pp.

81. *BIPM Circular T* (monthly)

International Altimetry Service (IAS)

http://ias.dgfi.badw.de

Chairman of the Steering Committee: Wolfgang Bosch (Germany)

Overview

With the precise surveying of the ocean surface, nearly coinciding with the geoid, satellite altimetry provides fundamental contributions to the geodetic science for the determination of the figure of the Earth and its gravity field. Thus, satellite altimetry definitely has to become a core component of the Global Geodetic Observing System (GGOS). Moreover, there are many other applications which underpin the significant potential of the altimetry technology for oceanography, marine geophysics, hydrology, meteorology, glaciology, and geodesy. Thus, satellite altimetry is a fundamental space technique for Earth system research.

Following endorsements by GLOSS, IAPSO and IAG the **International Altimetry Service (IAS)** was established as initiative of the International Association of Geodesy at its General Assembly, 2007 in Perugia, Italy.

At this time, numerous services for processing and distributing altimeter mission data and value-added products already existed. The IAS initiative did not intend to replace any of the existing service components. But there was a general consensus on the need for an IAS suggesting that an altimetry service can only be realized as an international, mission and agency independent, integrated effort: a distributed approach with close collaboration between data providers, archive and product centres, and research laboratories - similar as for example realized by the International GNSS service (IGS). The general IAS politics is therefore, to act non-competitive, but to identify and pool together national and international resources in altimetry, proposing missing or complementary components for the establishment of an International Altimeter Service and suggesting pilot projects, coordinated on voluntary basis and gradually improving existing services for the benefit of the altimetry community at large.

Activities

The IAS Terms of References were defined and published in Geodesist's Handbook (Drewes, 2008). According to IAG's Bylaws a Steering Committee was constituted. Members of the IAS Steering Committee are

- Yoshi Fukuda (president of IAG Commission 2)
- Cheinway Hwang (chairing IAG Subcommission 2.5 on Satellite Altimetry)
- Ole Anderson (representative for IGFS)
- Richard Gross (for Geophysical Fluids, Vice-President of IAG Commission 3)
- Phil Woodworth (for PSMSL and GLOSS Experts)
- Alexander Braun (ice applications)
- Wolfgang Bosch (Chair, chair of former IAS Planning Group)

2008/03/01 Re-Submission of a proposal for "Coordinating operations and science to establish an International Altimeter Service as a core element of the Global Earth Observing System (COSIAS)" in response to COST Open Call (OC-2007-2-1460)

The COSIAS proposal (Bosch 2007), initially submitted in March 2007 and re-submitted in autumn 2007, was supported by fourteen altimeter experts from nine European countries and eleven international consultants. It can be considered as a broad consensus with the most comprehensive description of necessary activities to coordinate operations and science of satellite altimetry for a Global Earth Observing System. Unfortunately the proposal was rejected in the very last stage of the evaluation process – obviously due to political reasons as it was criticized as a "danger and confusion to existing service elements". Nevertheless, the COSIAS proposal is certainly a rather complete compilation of requirements to be set up for the establishment and operation of an altimetry service.

2008/04/19 Report of the IAS Chair at IAG Executive Committee Meeting in Vienna

2008/06/24 1st Business Meeting of the IAS-Steering Committee at the International IAG Symposium on Gravity, Geoid & Earth Observation, GGEO2008, Chania, Crete

2008/12/18 Presentation of the IAS Chair on "IAS as a core element of GGOS", AGU Fall Meeting, San Francisco, Session G31C

Further activities were hindered by the fact that the Steering Committee did not succeed to nominate a chair for the Altimeter Service. A corresponding call remained unanswered. This is certainly caused by the fact that the International Altimeter Service is immediately seen as a competition to existing service elements. Obviously, the intention of IAS to be non-competitive was not recognized. Even one of the most popular data provider was not willing to take over the lead for the IAG service.

Web site development

The intention to set up a Web site on satellite altimetry is for several reasons rather ambitious: The existing service entities and numerous institutes with multi-disciplinary applications of satellite altimetry come along with many excellent Web sites – partly administrated by professional teams; As IAS has no resources at all, it is rather illusionary to set up the ultimate "one-stop shop" for altimeter users.

However, most of the existing altimetry web sites have a rather limited view, focussing either on a particular mission or a specific application. Geodetic applications are in general not well represented. Therefore, the most basic objectives of an IAS Web site is:

– provide users with information on where to get altimetry data and products by compiling and providing associated metadata,

– setting links to existing data providers and giving advice how to read, transform, and apply data and products.

– to improve information and documentation on all altimetry mission data and related products.

An initial compilation of available mission data and their associated data handbooks has been realized (http://ias.dgfi.badw.de). A list of the most basic products, their characterization and links for downloads has been considered. This will inform the user about existing mean sea surface models, sea level anomalies, models of dynamic ocean topography, ocean tide models, and marine gravity data.

Documentation is sometimes insufficient and information on data and product quality (procedures) are often missing. This makes it difficult for users to get sufficient information on how similar products were generated by different groups, how they compare with each other and what specific processing steps have been performed. On the basis of already existing metadata standards (ISO19xxx or the Directory Interchange Format DIF) the IAS Web site will try to develop a general frame for the compilation, representation (e.g. by XML) and provision of metadata for altimeter mission data and derived high-level products and correction models. The WG has to comply with the GGOS Working Group on Data and Information Systems (GGOS WG DIS), the standards of the Open Geospatial Consortium (OGC) and cooperate and contribute to the EU INSPIRE initiative.

Pilot Projects

IAS will foster pilot projects demonstrating how resources can be shared in order to achieve a faster upgrade of altimeter data, a homogeneous long-term time series with consistency across different missions. The pilot projects are aimed at demonstrating particular advantages of a coordinated service and are expected to develop into core elements of the IAS. Following themes have been identified and discussed as possible themes for pilot projects:

- **Orbit as reference frame**: compile processing standards; toolbox to merge new orbits into altimeter records; compare geocentre realisation and geographical error pattern; comparison with crossover statistics;
- **Support to Cal/Val Activities** (with PSMSL & TIGA): Compile results of tide gauge trends, vertical velocities at tide gauges and sea level trends.
- **Ocean tides models**: compilation of state-of-the-art models; toolbox to merge them to altimeter records; transformation to spherical harmonics;
- **Ocean mass redistribution** (with Fluids Bureau): sea level variation minus steric effects (from climatologies, ARGO floats, SMOS.ocean models); effect on Earth rotation (OAM) and gravity field;
- **Marine gravity data** (with IGFS): set links to data sets of NSDC, SIO/NOAA, NGA; harmonize user interfaces; comparison of altimetry derived gravity data with ship-born and satellite-only gravity data;
- **Faster, distributed upgrade and online access of GDR:** Merging of re-tracked sensor data, new orbits and new correction models can take advantage of high granularity of GDRs by de-composing, reprocessing and re-merging. Sharing distributed resources can be accomplished by GRID technology.

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IAG Bibliographic Service (IBS) and the Literature Database GEOdesy, PHOtogrammetry, CArtography on the Internet

http://www.bkg.bund.de/nn_159914/EN/FederalOffice/InformationServices/iag__node.html__nnn=true

Chairperson: Annekathrin Michlenz (Germany)

Overview

The IBS is based on the literature database Geodesy, Photogrammetry and Cartography GEOPHOKA, which is maintained by the Federal Agency for Cartography and Geodesy, Branch Office Leipzig.

History: The activities concerning this literature database started in the years 1984/85 for tasks of surveying and mapping of the former GDR. At that time, also the Centre for International Documentation of Geodesy of the Technical University Dresden, the Central Institute of Physics of the Earth, Potsdam, and two research institutes of geodesy and cartography of former Czechoslovakia participated in the development and use of this database. From 1984 to 1991 the database was further developed with program systems of the Automated Information and Documentation System AIDOS under the operating systems OS/ES and VS 2 on large-capacity computers of an external contractor. In autumn 1991 the data stock existing so far was transferred to the IfAG with new software (Leistungsstarkes Archivierungs- und Recherchesystem = LARS). At mid-year 1997 once more a software change was necessary because of the limited search capabilities of the old system and the large amount of literature entries. Since that time GEOPHOKA is running under MIRES (Modular Information Retrieval System) and is freely accessible via the Internet.

Activities

Size: In the beginning of 2011 the database comprises about 63.000 literature entries, the annual increase is about 1.300 entries.

Contents: Thematically, the whole special field is reflected in its complexity. Theoretical bases as well as measuring and evaluation techniques are included. Sources for the database are mainly technical journals and all kinds of publications from home and abroad as well as books and the so-called „gray“ (unpublished) literature.

Features: For each literature source formal, bibliographic and contents data are stored.

One finds a description of the information service including the input screen and some search instructions via the homepage of the BKG (under the link „Information Services“). Normally, the database is supplemented each working day by results of the evaluation of special literature. These entries are also available for searching immediately after input.

Example for search in GEOPHOKA:

GEOPHOKA

MIRES® - Query

Help

Author:

Title:

Journal:

Year:

Language:

Descriptors:

Abstract:

Date of input:

Maximal number of documents: 20

Using the search screen it is possible to search for the named 8 features separately or in combination. The syntax is described in the instructions for search. It has to be taken into account that with the exception of the features descriptors, year of publication and entry date words can be entered both in German and in English in natural language. For searching in the abstract it is advisable to use English search terms since most abstracts are taken from the original in English.

Within the next few weeks the internet access will be updated.

Since September 1997 annually about 6 files with approximately 100 to 200 literature sources are compiled from the database for the IBS. Thematically these sources contain information from the fields Theory of Errors and Compensation Computation; Theoretical and Physical Geodesy; Geodetic Control Networks; Astronomy and Space Research and Geophysics.
These compilations are published at irregular intervals as literature list in the „Journal of Geodesy" as IAG Bibliographic Service.

International Centre for Earth Tides (ICET)

http://www.upf.pf/ICET/

Director: Jean-Pierre Barriot (Tahiti, French Polynesia)

Main Activities

1 The new ICET database, presented at the ETS2008 meeting in Vienna, is now on line at http://maregraph-renater.upf.pf, or www.bim-icet.org, or www.upf.pf/ICET/. The database currently hosts all the validated one-minute GGP data until March 2010 and is able to store any kind of data related to Earth Tides (e.g. tiltmeter or spring gravimeter data). See Annex 2 and Annex 3.

2 GGP one-minute filtered and manually validated data are routinely processed at ICET and uploaded to the ICET and GFZ database. We plan to switch to an automated validation as soon as possible, in order to cope with manpower restrictions (see Annex 2 and point 3).

3 A new validation software able to automatically validate GGP data has been developed (Annex 5). The purpose of this software is to identify and discard jumps and spikes in the raw data on an automated or nearly automated basis. Based on Wiener-Kolmogorov filtering techniques, it responds to the critics raised during the ETS2008 meeting in Iena, by re-adding the "noise" to the GGP filtered data. We are currently testing this software on several GGP raw files and a workshop about it is planned in August 2011 at National Chiao Tung University (Taiwan, GGP Hsinchu station).

4 A Python script able to write strictly normalized headers for GGP files has been completed. This is another key to alleviate the burden of validating and storing GGP data. It is available for download at www.bim-icet.org (see Annex 2).

5 A a new XML format for storing GGP data has been developed. It is a modern format, free of the limitation of the current GGP “fixed columns” format (see Annex 4). This format also permits to build a native XML database (Sedna) instead of standard relational databases (SQL queries).

6 Bulletin International des Marées: 25 scientific papers have been published on BIMs 144, 145 and 146 (one issue per year with ISSN numbers). 23 papers are related to the ETS2008 meeting in Jena. All the BIMs issues are online at: www.bim-icet.org. See Annex 6.

7 The new gPhone gravimeter of the ICET center in operation in Tahiti-Pamatai since March 2008. We routinely monitor all Earthquakes > 6.0 along the Pacific Rim (see Annex 2).

8 ICET is also participating in the deployment in Fench Polynesia of a network of Tide Gauge / GPS stations (POGENET, POLynesian GEodetic NETwork), as a contribution to the IAG Global Geodetic Observing System (GGOS).

Annex: Publications / Reports

Oral and Posters Communications directly related to ICET

Barriot, J.-P., Gabillon, A., Verschelle, Y., Capolsini, P., Ducarme B.: The foreseen SCHEMA of the new ICET database at the Geodesy Observatory of Tahiti. ETS5-P2 (Poster Session) Space Geodetic Techniques /GGOS, New Challenges in Earth Dynamics, Jena, Germany, Sept. 1-5, 2008.

J.-P. Barriot, The International Center for Earth Tides in Tahiti, Geodesy for Planet Earth Meeting (oral), International Association of Geodesy, Buenos Aires, August 31- September 04, 2009.

J.-P. Barriot, L. Sichoix, Y. Verschelle, A. Gabillon, ICET activities at the Geodesy Observatory of Tahiti, Oral Presentation, Second Asia Workshop on Superconducting Gravimetry, Taipei, June 20-22, 2010.

J.-P. Barriot, Y. Verschelle, A. Gabillon, M. Hassanzadeh-Bahabadi, N. Tseng, An XML schema for GGP data archivingPoster, Second Asia Workshop on Superconducting Gravimetry, Taipei, June 20-22, 2010.

J.-P. Barriot, Identification and removing of outliers and jumps in supraconducting gravimeter time series, Oral Presentation, Second Asia Workshop on Superconducting Gravimetry, Taipei, June 20-22, 2010.

J.-P. Barriot et al., ICET Activities at the Geodesy Observatory of Tahiti, JG05 session: Integrated Earth Observing Systems, IUGG Melbourne 2011.

J.-P. Barriot et al., An XML Schema for GGP Data Archiving, JG05 session: Integrated Earth Observing Systems, IUGG Melbourne 2011.

Oral and Posters Communications indirectly related to ICET

J.-P. Barriot, P. Ortéga, A. Fadil, L. Sichoix, D. Reymond, Y. Dupont, P. Mainguy and D. Graffeille, The Polynesian Geodetic Network (POGENET): 2009 milestone (Poster), 2èmes assises de la recherche française dans le Pacifique et 11ème Inter-Congrès des Sciences du Pacifique, March 2nd - 6th 2009, ISBN 978-2-11-098964-2.

L. Sichoix and J.P. Barriot: Regional Tide gauge network report of French Polynesia (South central Pacific Ocean), 11th Global Sea Level Observing System - Group of Experts Meeting, May 2009, UNESCO Paris.

J.-P. Barriot, The Geodesy Observatory of Tahiti as a GGOS Observatory. Geodesy for Planet Earth Meeting (oral), Int. Association of Geodesy, Buenos Aires, August 31st -September 04th , 2009.

J.-P. Barriot, L. Sichoix, Y. Vota, L. Mercier and Youri Verschelles, The Geodesy Observatory of Tahiti , Oral Presentation, Observing and Understanding Earth Rotation, A GGOS/IAU Science Workshop, Oct 25-28, 2010, Shanghai.

Student reports related to ICET (University of French Polynesia)

L. Emilion, Identification et suppression des irrégularités sur des mesures de gravité, stage de fin d'étude IPSA, 19 sept. 2008.

Y. Verschelle, Conception et développement d'une base de données marégraphiques et de son interface Web, stage de fin d'étude licence Technicom UPF, juin 2008.

International Centre for Global Earth Models (ICGEM)

http://icgem.gfz-potsdam.de/ICGEM/

Director: Franz Barthelmes (Germany)

Overview

The International Centre for Global Earth Models is mainly a web based service and comprehends:

- collecting and long-term archiving of existing global gravity field models
- making them available on the web in a standardised format (self-explanatory)
- interactive visualisation of the models (geoid undulations and gravity anomalies)
- solutions from dedicated time periods (e.g. monthly GRACE models) are included
- 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)
- managing the ICGEM web-based discussion forum (answering questions)
- evaluation of the models
- visualisation of surface spherical harmonics as tutorial

Services

The Models

Currently, 119 models are listed with their references and 105 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. Monthly solutions from GRACE are included. Differences of two models, arbitrary degree windows, zooming in and out, are possible. The visualisation of single spherical harmonics is possible for tutorial purposes.

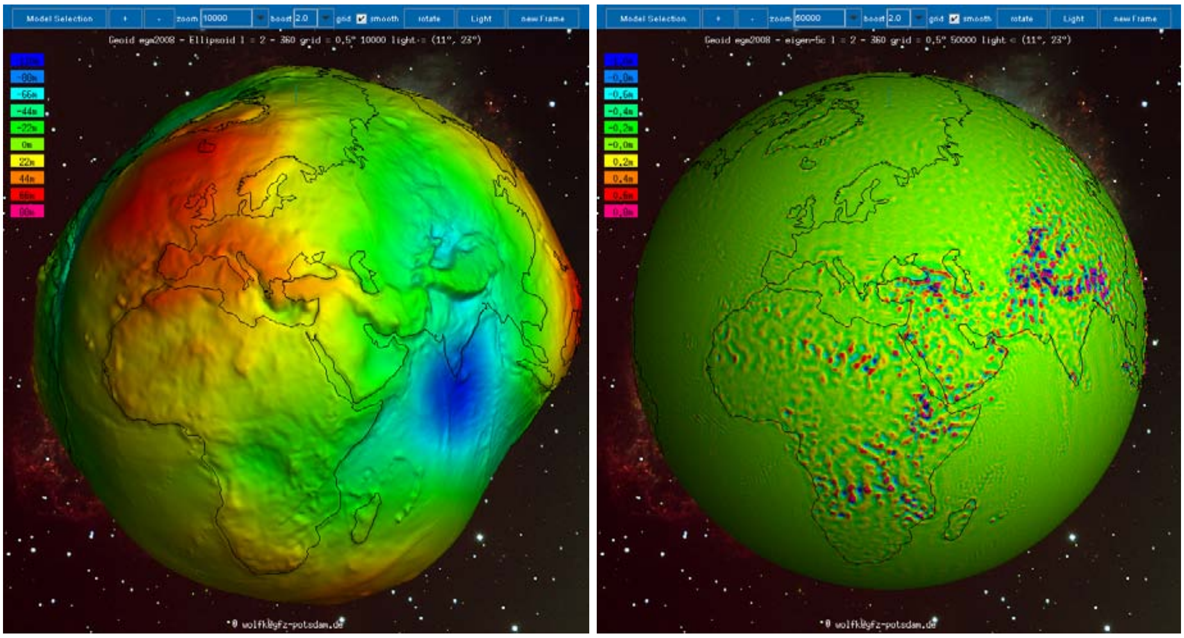

Fig. 1: Visualisation (geoid) of a global gravity field model and of differences of two models

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)
– second derivative in spherical radius direction (at arbitrary height over the ellipsoid)
– equivalent water height (water column)

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 (post-script) 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 2 shows the input mask of the calculation service and figures 3 to 5 show examples of plots (of grids) generated by the calculation service.

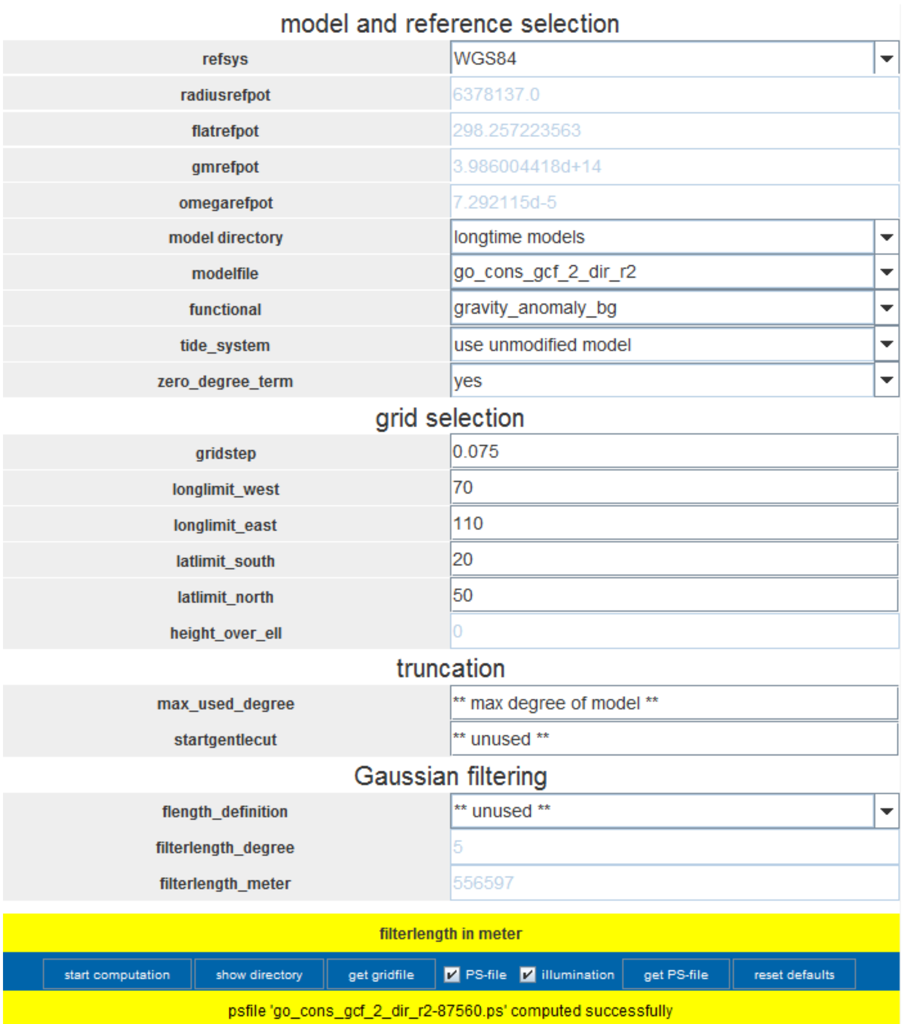

Fig. 2: Input mask of the calculation service

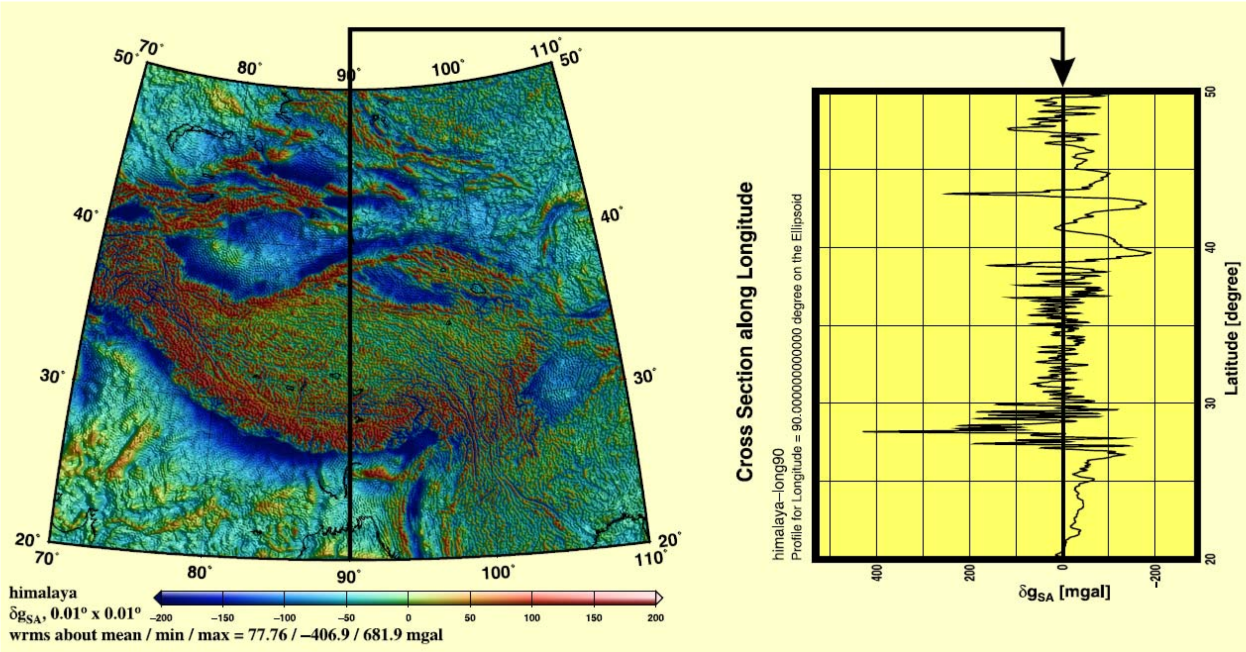

Fig. 3: Example of grid and plot generation by the calculation service: gravity disturbances of the Himalayan region and cross section along a defined longitude from the model EGM2008

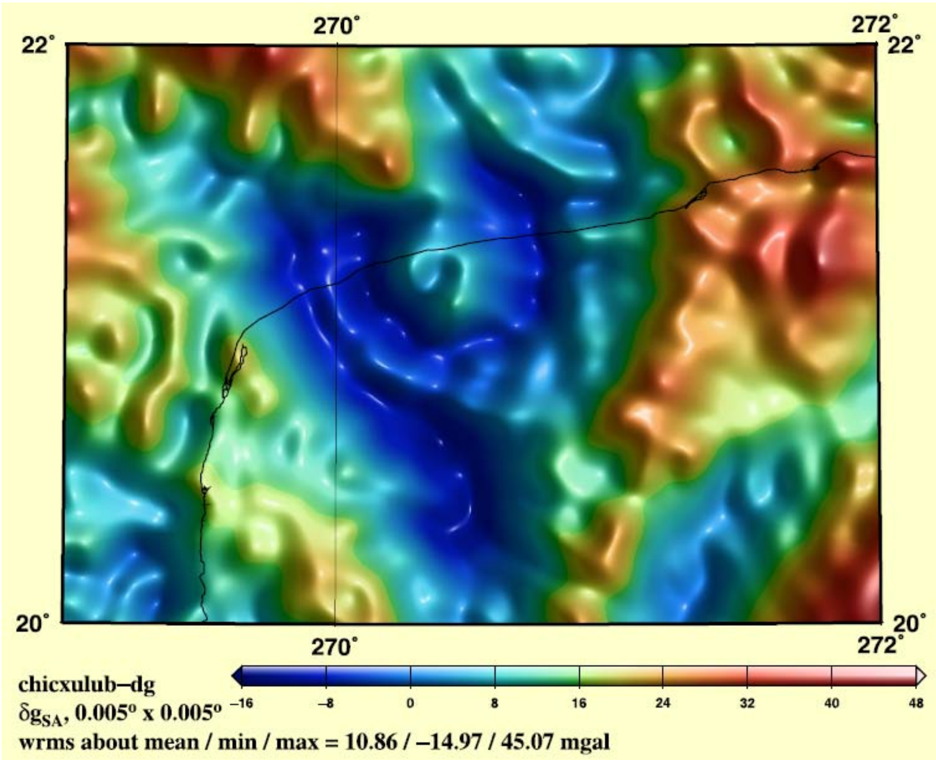

Fig. 4: Example of grid and plot generation by the calculation service: gravity disturbances of the Chicxulub crater region from the model EGM2008

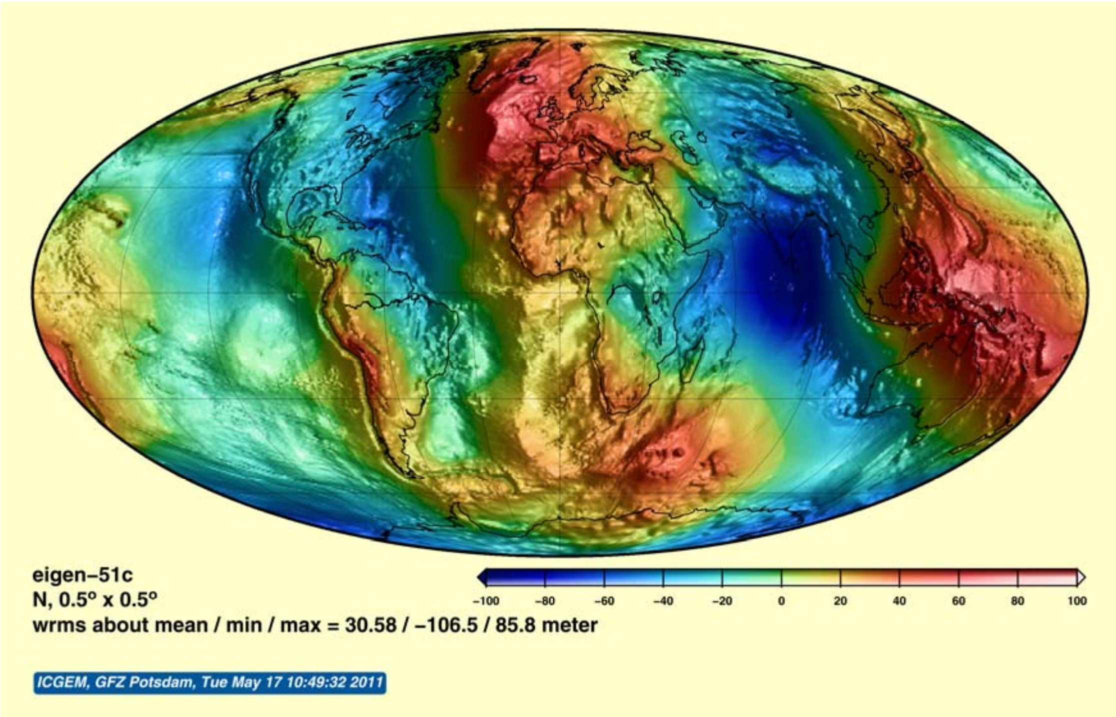

Fig. 5: Example of grid and plot generation by the calculation service: global geoid from the model EIGEN-51C

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 6 and 7).

Model	Nmax	USA 6169 points	Canada 1930 points	Europe 1235 points	Australia 201 points
GOCO02S	250	0.435 m	0.352 m	0.434 m	0.372 m
AIUB-GRACE03S	160	0.650 m	0.514 m	0.713 m	0.486 m
GO_CONS_GCF_2_DIR_R2	240	0.443 m	0.374 m	0.449 m	0.391 m
GO_CONS_GCF_2_TIM_R2	250	0.436 m	0.355 m	0.434 m	0.376 m
GO_CONS_GCF_2_DIR_R1	240	0.407 m	0.319 m	0.402 m	0.319 m
GO_CONS_GCF_2_TIM_R1	224	0.455 m	0.378 m	0.474 m	0.371 m
GO_CONS_GCF_2_SPW_R1	210	0.471 m	0.399 m	0.498 m	0.384 m
GOCO01S	224	0.451 m	0.374 m	0.473 m	0.370 m
EIGEN-51C	359	0.335 m	0.245 m	0.289 m	0.234 m
EIGEN-5C	360	0.341 m	0.251 m	0.303 m	0.244 m
AIUB-CHAMP03S	100	0.755 m	0.743 m	1.148 m	1.148 m
EIGEN-CHAMP05S	150	0.784 m	0.763 m	1.216 m	0.661 m
ITG-GRACE2010S	180	0.548 m	0.459 m	0.595 m	0.523 m
AIUB-GRACE02S	150	0.630 m	0.571 m	0.701 m	0.495 m
GGM03C	360	0.346 m	0.279 m	0.334 m	0.259 m
GGM03S-UPTO150	150	0.641 m	0.521 m	0.710 m	0.494 m
AIUB-GRACE01S	120	0.724 m	0.628 m	0.930 m	0.563 m
EGM2008	2190	0.248 m	0.126 m	0.208 m	0.217 m
EIGEN-5S	150	0.630 m	0.547 m	0.737 m	0.475 m

Fig. 6: 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]

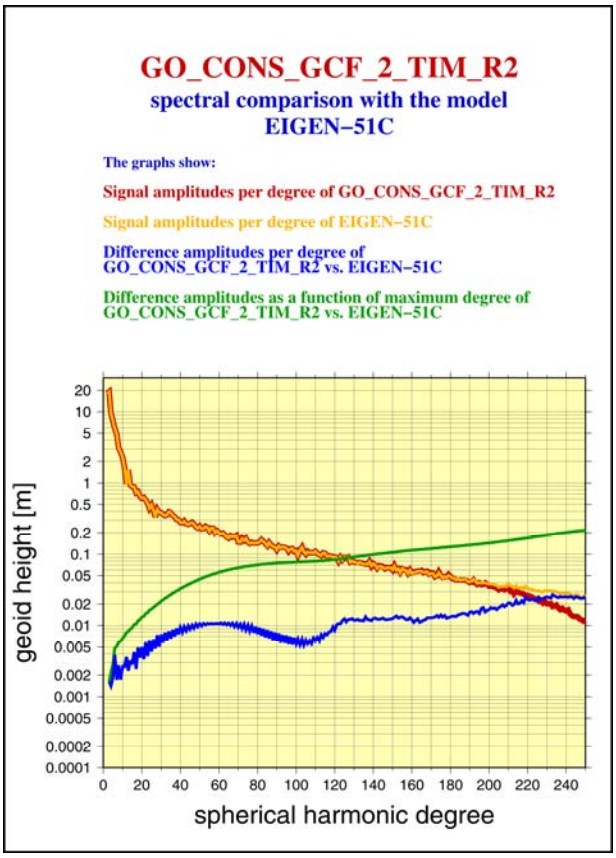

Fig. 7: Comparison of the models in the spectral domain (e.g.: GO_CONS_GCF_2_TIM_R2) with one of the most recent combination models (e.g. EIGEN-51C)

Main changes since 2006

For the calculation service the new software shm2func has been developed and installed in April 2007. Now it is possible to use the information of a digital terrain model. The topography model is used for two different purposes: (a) to calculate the exact coordinates on the Earth's surface for the height anomalies on the Earth's surface, the gravity disturbances and the modern gravity anomalies, and (b) to calculate the geoid undulations from pseudo height anomalies on the ellipsoid considering the topographical effect. For (a) bi-linear interpolation of the original ETOPO2-grid is used to calculate the positions as accurately as possible. For (b) the spherical harmonic expansion of the DTM2006 model is used which comes with EGM2008. The software was ready to calculate the Legendre functions up to degree and order higher than 2190, hence with the availability of EGM2008 (April 2008) the full service was offered for this model.

The report STR09/02 has been published where the theory and formulas of the calculation service are described.

The visualisation is now possible not only for geoid undulations but also for gravity anomalies. A new tool for the animated visualisation of monthly models has been installed.
The GPS/Levelling data (Button "Evaluation of the Models") are now compared with geoid heights instead of height anomalies.

The release-04 monthly solutions and the GRGS-10-day solutions are now also available after non-isotropic smoothing (decorrelation). For this purpose the mean model EIGEN-5C has been subtracted and to the difference the 3 different filters DDK1, DDK2, and DDK3 after Kusche et al (2009) have been applied. After filtering the mean model has been added back to ensure that they can be used in our calculation service to calculate the defined functionals.
All changes since October 2006 are recorded on the web site under the button "latest changes".

Main changes since 2009

In the calculation service the calculation of the simple Bouguer gravity anomaly has been realised.

The new models based on data of the GOCE mission have been included into ICGEM as soon as they were available.

Some ICGEM-related documents are now available for downloading, e.g. a figure which demonstrates the improvement of the global models during the past decades (see fig. 8).
Although it is not the main purpose of ICGEM, we also offer the calculation and visualisation service for some gravity field models of the celestial bodies Moon, Mars and Venus (see fig. 9).

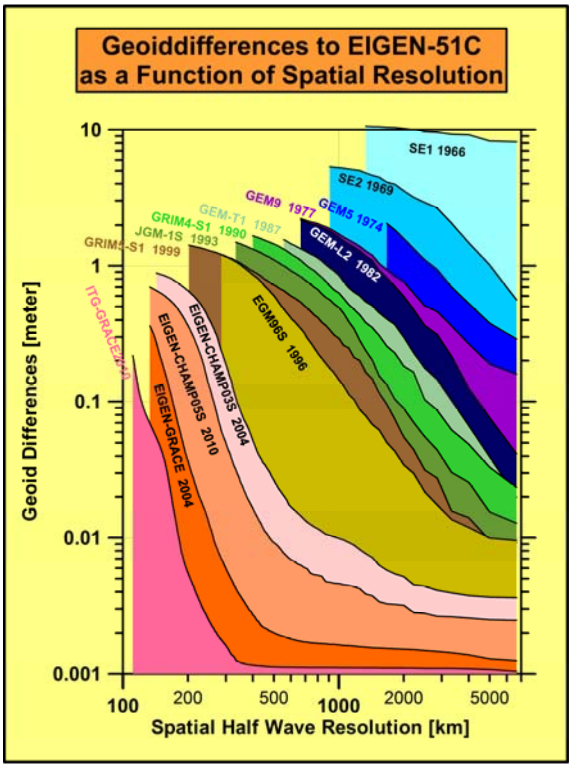

Fig. 8: Visualisation of the improvement of satellite-only models over the past decades: Geoiddifferences to the model EIGEN-51C as a function of spatial resolution.

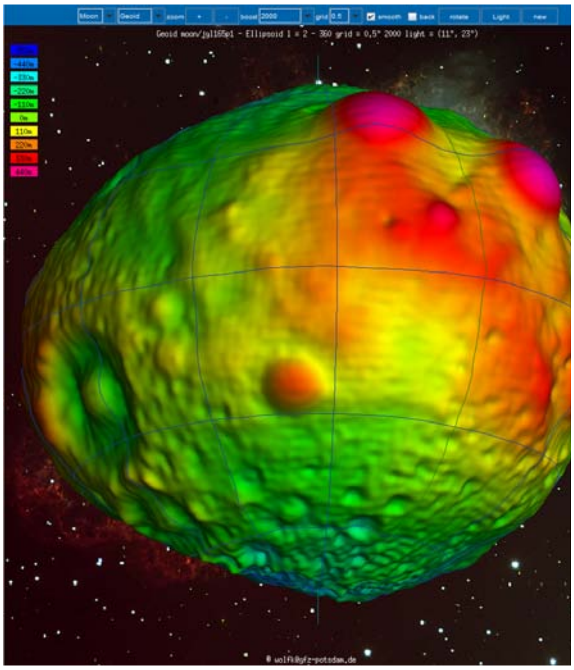

Fig. 9: Visualisation of the "Geoid" of the Moon

Publications

Kusche, J.; Schmidt, R.; Petrovic, S.; Rietbroek, R. (2009): Decorrelated GRACE time-variable gravity solutions by GFZ, and their validation using a hydrological model, Journal of Geodesy, DOI 10.1007/s00190-009-0308-3

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 (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, Deutsches GeoForschungsZentrum GFZ.

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)

Overview

The International Digital Elevation Model Service (IDEMS) is one of the more recently formed of the IAG services, and it continues to grow and establish a community of academic and industrial contributors. This has been a period of intense development in Digital Elevation Models, with the final release of the SRTM GDEM in 2007 since augmented by the ACE2 release, and the ASTER GDEM. These freely available global DEM datasets, coupled with enhanced computing capability, are steadily transforming this discipline as researchers move from small-scale regional studies to continental and even global scale analyses.

There is a steadily increasing requirement for related surface hydrology information, both for synergy with GRACE data and in support of climate change investigations. Results from this reporting period are briefly summarised below.

Activities

1. GDEM data

The ACE2 GDEM was released on 1 July 2009; this model was produced with a core contribution from the unique SRTM dataset plus over 70 million altimeter derived heights and additional ground truth. Key contributions to the datasets from the geodetic community enabled fused models to be also produced in response to a range of geodetic requirements, including bathymetry and Mean Sea Surface data from DNSC08, providing combined datasets for users at a range of spatial resolutions. An example is given in Figure 1. Links to GDEM datasets may be accessed from the IDEMS webpages.

The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) GDEM was first released towards the end of 2009. One key issue is the appearance of 'stripes' in the ASTER DEM heights; publications are being added to the website as they become available.
Recurring topics of queries and discussion over this period have related to the comparison of GPS measurements with Digital Elevation Models, and inter-comparison of different regional DEM and GDEM models at varying spatial resolutions.

Because many DEM users are non-geodesists, the requirement to ensure compatibility in reference frames and geoid models when inter-comparing or fusing disparate datasets is often not recognised. This is a recurring area of difficulty, and misunderstandings cause naïve researchers to submit conference/journal papers that contain technical errors; after initial discussion, researchers are then directed on to the International Geoid Service for further information.

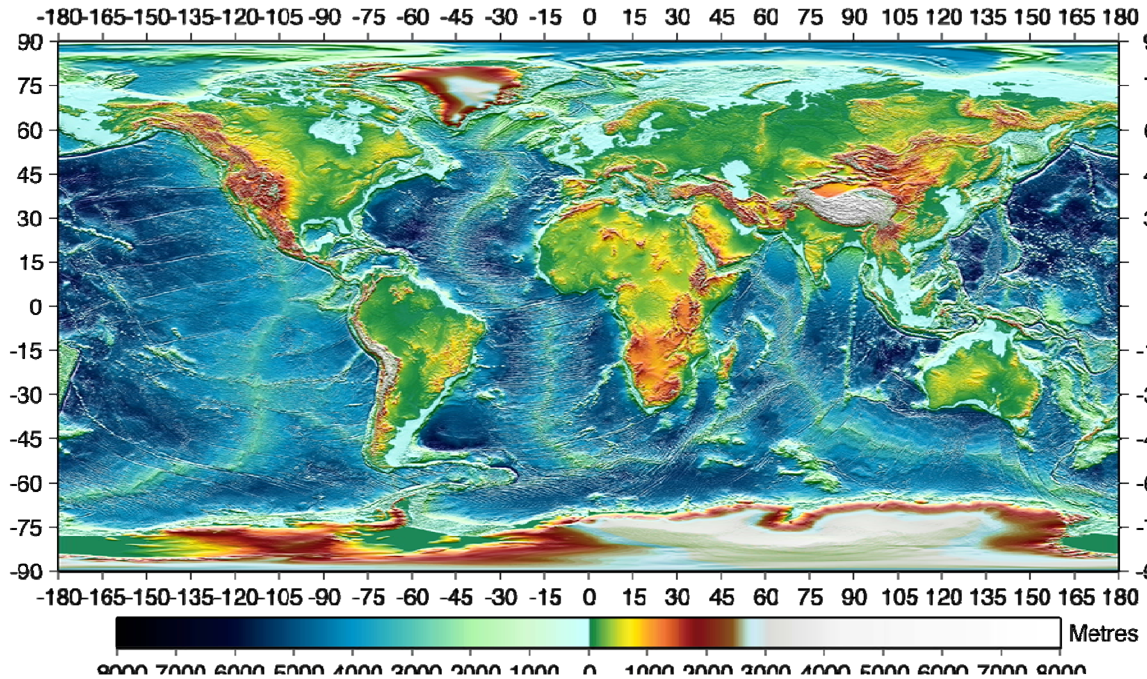

Figure 1.1: Fused ACE2 dataset with DNSC08 bathymetry

To monitor the accessibility and usefulness of the IDEMS webpages, enhanced search engine monitoring software has been put in place; typical user distribution from 97 countries is shown below.

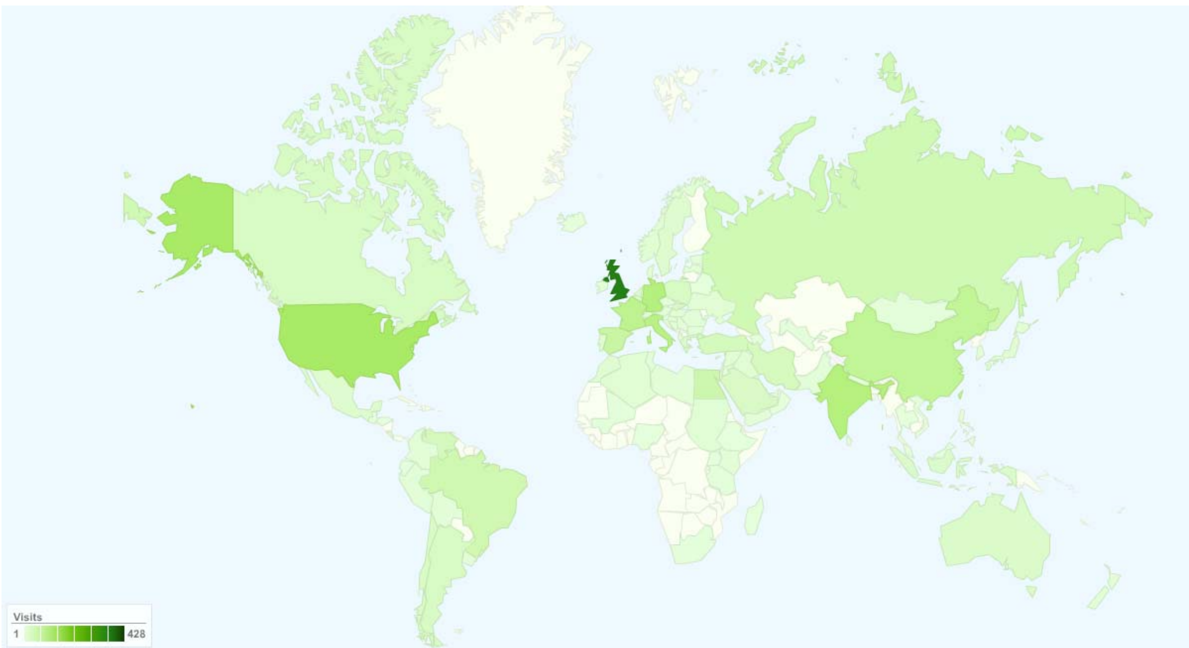

Figure 1.2: Typical IDEMS Service website usage

2. Inland Surface Water

A growing number of queries both to the IDEMS webpages and directly to DEM researchers over this period relate to liquid flow over topography and disparity in DEM information content and precision for hydrological purposes. This is particularly relevant when deriving flow networks from available GDEM datasets. There is a sustained interest in representation of inland water within DEMs. Over this period, a requirement is increasingly reported to add max/min water level data in a separate hydrology layer, and interest in river and lake height changes continues to grow. These data are primarily utilised to support large scale climate studies, and the requirement is therefore global/continent scale in nature, in contrast to the 'traditional' detailed information for individual water-bodies, already well served by the hydrological community. A second key use is in synergy with GRACE data on a range of spatial and temporal scales.

This forms part of a rapidly expanding user community for surface hydrology data on basin and continental scales, encompassing remote sensing information, ground based measurements and hydrological models. The IDEMS webpages and activities are being progressively augmented to include sites offering satellite derived height and spatial extent measurements, river modeling initiatives including access to in-situ data, and large-scale outreach programmes such as the WMO (WHYCOS) and ESA (TIGER) initiatives.

Future activities

IDEMS meetings will continue on an ad-hoc basis at relevant conferences and workshops: in addition it is planned to exploit existing freely available software to study the viability of virtual workshops to assist information dissemination on specific topics. The current programme of progressively enhancing links to source DEM data and code held in institutes/universities will continue (with a continuing emphasis on open source code!), to add new publications as these are notified to us and to continue to define and service requirements for regional and global surface inland water datasets.

International DORIS Service (IDS)

http://ids-doris.org/

Chairman of the Governing Board: Pascal Willis (France)

Overview

Over the past four years, the International DORIS Service (IDS) has evolved significantly. There are now seven Analysis Centres from six different countries using five different software packages, all providing regular products to the IDS. These centres cooperate through an Analysis Working Group (AWG), which held six technical meetings during this four-year period. These meetings led to a significant improvement in the precision of the results, and for the first time, seven solutions were available to the IDS for combination and submission for the ITRF2008 combination. To obtain these solutions, several test campaigns were organized to compare results between groups for precise orbit determination as well as for precise ground geodetic positioning. The goal of this document is to present the various activities related to the International DORIS Service within the last four years.

Activities

1. DORIS system

1.1 DORIS satellites

As described in Table 1.1, two new satellites were launched in the last four years: Jason-2 and Cryosat-2, both using the new 7-channel DG-XX DORIS receiver on-board the satellite. The DORIS constellation then steadily increased, including currently six satellites at altitudes of 800 and 1300 km, with almost polar or TOPEX-like inclination (66 deg).

Table 1.1: DORIS data available at IDS data centres. As of March 2011

Satellite	Start	End	Space Agency	Type
SPOT-2	31-MAR-1990 04-NOV-1992	04-JUL-1990 15-JUL-2009	CNES	Remote sensing
TOPEX/Poseidon	25-SEP-1992	01-NOV-2004	NASA/CNES	Altimetry
SPOT-3	01-FEB-1994	09-NOV-1996	CNES	Remote sensing
SPOT-4	01-MAY-1998	PRESENT	CNES	Remote sensing
Jason-1	15-JAN-2002	PRESENT	NASA/CNES	Altimetry
SPOT-5	11-JUN-2002	PRESENT	CNES	Remote sensing
Envisat	13-JUN-2002	PRESENT	ESA	Altimetry, Environment
Jason-2	12-JUL-2008	PRESENT	NASA/CNES	Altimetry
Cryosat-2	30-MAY-2010	PRESENT	ESA	Altimetry, ice caps

In the next few years, more DORIS satellites are foreseen: SARAL/AltiKa (India), HY-2A (China), Jason-3 (USA). The Chinese HY-2A satellite for altimetry could be followed by other satellites of the same type (HY-2B, HY-2C, HY-2D). Furthermore, other missions are in consideration. Of particular interest is GRASP (Geodetic Reference Antenna in Space, USA), providing on board the same spacecraft several well calibrated geodetic systems such as GNSS, DORIS, SLR, and VLBI. The following figure displays the evolution of the DORIS constellation, since the first launch, and also including already foreseen satellites.

Figure 1.1 summarizes the evolution of the DORIS constellation since the launch of the SPOT-2 satellite in 1990. It must be noted that in the past last years, four or more DORIS satellites were available to IDS users, which is a key requirement for the precision of the geodetic products.

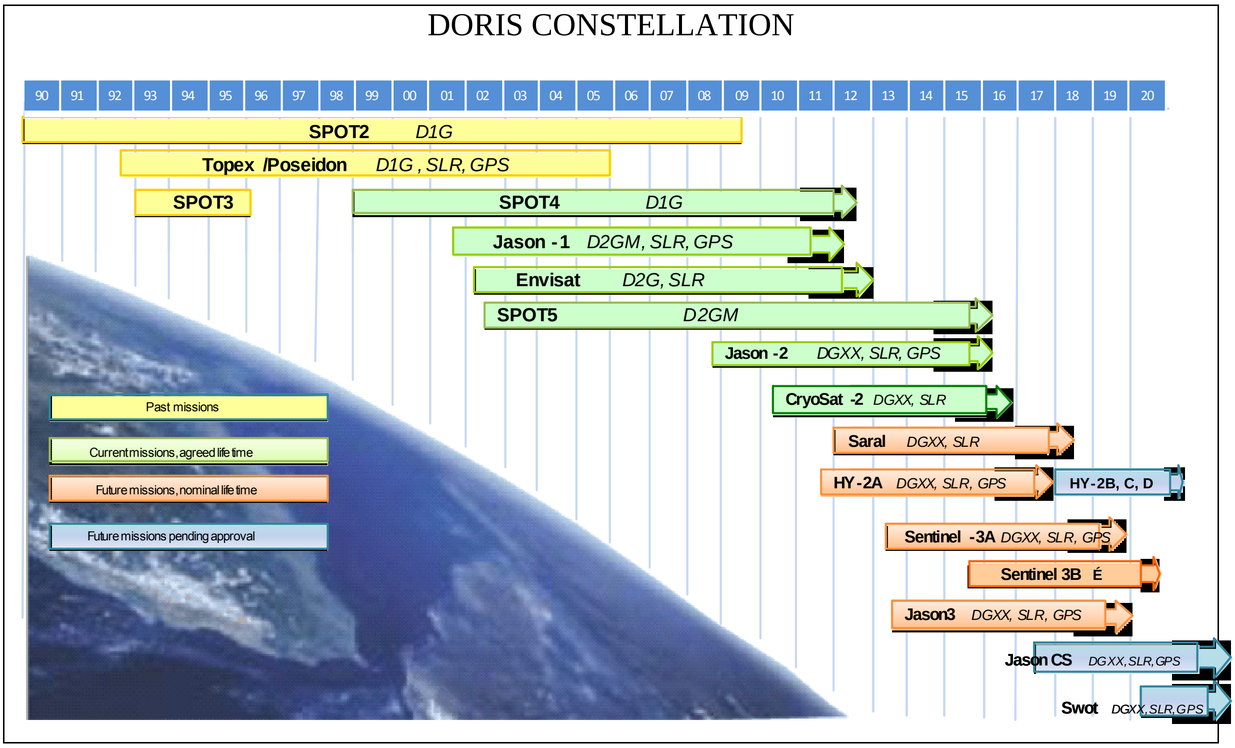

Figure 1.1: DORIS satellite constellation. As of March 2011.

1.1 DORIS network

The DORIS tracking network remains very stable (Figure 1.2). More than 50% of the DORIS antennas are in co-location with other space geodetic techniques (GNSS (38), SLR (9), VLBI (6)) and several are also in co-location with other instruments such as tide gauges and absolute gravimeters. Transmissions at Monument Peak station have been stopped since February 2010. DORIS actively participates in the GGOS (Global Geodetic Observing System) network of the International Association of Geodesy (IAG).

The rejuvenation of the DORIS network, started in 1999 is now complete. All sites are now equipped with the latest generation Alcatel antenna (3.0 model) and a large number of antennas are now installed using improved criteria for geodetic stability.

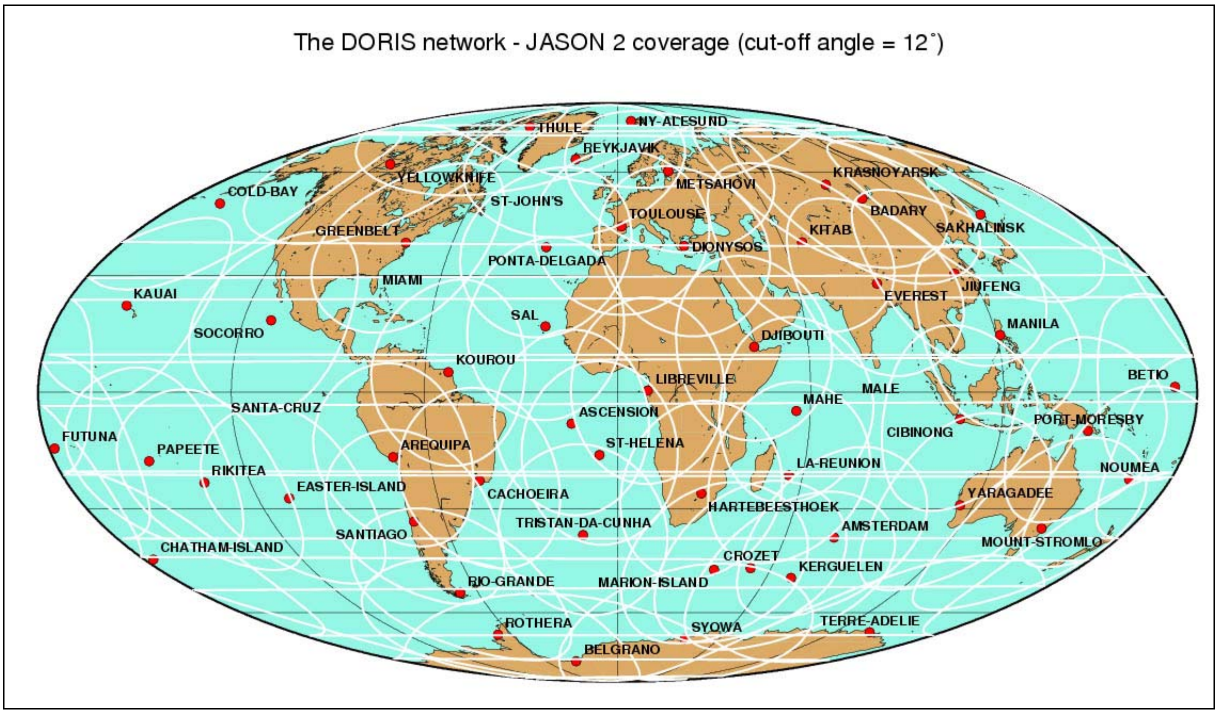

Figure 1.2: DORIS tracking network. As of March 2011. White circles correspond to visibility of the Jason-2 (1300 Km altitude) above 12° elevation at the tracking stations.

2. IDS organization

Like the other IAG Services, an IDS Governing Board, helped by a Central Bureau, organizes the activities done by the Analysis Centres, the Data Centres, and the Combination Centre.

2.1 IDS Governing Board

At the end of 2008, an election was conducted to appoint a new IDS Governing Board. Table 2.1 present the composition of the IDS Governing Board before this election.

Table 2.1: Composition of the IDS Governing Board (2003 to 2008)

Name	Institution	Country	Mandate
Hervé Fagard	IGN	France	Network representative
Martine Feissel-Vernier	OP	France	Analysis Coordinator (*)
Frank Lemoine	NASA/GSFC	USA	Analysis coordinator
Carey Noll	NASA/GSFC	USA	Data flow coordinator
Ron Noomen	Delft University	The Nether-lands	IERS Representative
John Ries	U. Texas/CSR	USA	Member at large
Laurent Soudarin	CLS	France	Director IDS Central Bureau
Gilles Tavernier (chair)	CNES	France	Member at large
Pascal Willis	IGN+IPGP	France	Analysis centre representative

(*) in 2005 Martine Feissel resigned as Analysis Coordinator and was replaced by Frank Lemoine.

After the election, several new members of the Governing Board were appointed (Table 2.2), leading to a better geographic distribution of the members.

Table 2.2: Composition of the IDS Governing Board (2009 to 2011, current)

Name	Institution	Country	Mandate
Hervé Fagard (*)	IGN	France	Network representative
Pascale Ferrage	CNES	France	Member at large
Frank Lemoine	NASA/GSFC	USA	Analysis coordinator
Chopo Ma	NASA/GSFC	USA	IERS representative
Carey Noll	NASA/GSFC	USA	Data flow coordinator
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

(*) in 2010, Hervé Fagard resigned as network representative and was replaced by Bruno Garayt (IGN). Current activities related to DORIS tracking network is now performed by Jerome Saunier.

2.2 IDS Central Bureau

During the last four years, the Central Bureau reorganized the IDS Web site, using better tools and changing the URL address to http://ids-doris.org. The IDS Web site archives information of interest to IDS users and participants including:

– DORIS results such as plots of station coordinates time series at http://ids-doris.org/network/ids-station-series.html.

– DORIS station site logs providing information and pictures of the DORIS antennas at http://ids-doris.org/network/sitelogs.html.

– daily statistics of DORIS residuals for Precise Orbit Determination at http://ids-doris.org/system/poe.html.

– historical records of specific events affecting DORIS satellites (maneuvers, change of on-board receiver, on-board software update,…) or stations (discontinuities, data gaps, temporary failures,...)

– A bibliography of DORIS-related papers in the published literature, and an archive of presentations at Analysis Working Group meetings and IDS workshops (see sections 4.2 and 4.3 of this report).

In addition a kml file has been created to allow a virtual tour of the DORIS network using GoogleEarth, providing key information on its exact location and of surrounding geodetic equipment. It can be found at http://ids-doris.org/network/googleearth.html

The Central Bureau also manages the different IDS mailing lists: DORISMails for general information on DORIS and DORISReports for technical reports mostly from the IDS Analysis Centres. More information on the DORIS email facility is available at http://ids-doris.org/report/mails.html.

2.3 IDS Data centres

Since the beginning of the IDS, two data centres have provided open access to IDS data and products: the CDDIS, located in the U.S. and funded by NASA/GSFC (ftp://cddis.gsfc.nasa.gov) and IGN in France using two mirroring sites (ftp://doris.ign.fr and ftp://doris.ensg.ign.fr). In the last four years, a major activity was conducted between the two groups to ensure a more operational mirroring of the information contained in these data centres.

2.4 IDS Analysis centres

In the last four years, the organization of the IDS drastically changed to include more international participants. There are currently seven active Analysis Centres, using five different software packages, as displayed in Table 2.3.

Table 2.3: IDS Analysis centres. As of March 2011.

Acronym	Analysis Centre	Country	Software Package
ESA	European Space Operation Centre	Germany	NAPEOS
GAU	Geoscience Australia	Australia	GEODYN
GOP	Geodetic Observatory Pecny	Czech Rep.	Bernese
GSC	Goddard Space Flight Centre	USA	GEODYN
IGN	Institut Geographique National	France	GIPSY/OASIS
INA	INASAN	Russia	GIPSY/OASIS
LCA	Centre National d'Etudes Spatiales + Collecte Localisation Satellite	France	GINS/DYNAMO

This group worked together within the Analysis Working Group, under the initiative of the IDs Analysis Coordinator (Frank Lemoine, NASA/GSFC) discussed their analysis strategy and provided tests solutions to IDS, as well as operational solutions in view of the ITRF2008 realization.

2.5 IDS Combination

For ITRF2005, the IDS did not construct a technique-level combination. The DORIS-combination was done by the IRF Product Centre. For ITRF2008, the IDS developed a technique level combination based on the seven individual AC submissions (ESA, GAU, GOP, GSC, IGN, INA AN LAC). The steps in the combination development are described in Valette et al. (2010), however we note the level of coordination among the AC's to intercompare their analysis strategies, and that in large part the processing strategies of the individual ACs adhered to the IERS standards. This careful attention to modelling standards was one of the reasons for the improvement in the quality of the DORIS geodetic products in ITRF2008 compared to ITRF2005. Three iterations of the combination were completed by CLS (Jean-Jacques Valette) to provide the best IDS combination to the IERS for inclusion with the submissions of the other technique services in the development of ITRF2008. In the course of the IDS development, the ACs worked to improve their analysis strategies and submitted updated solutions to eliminate troposphere-derived biases in the solution scale, to reduce drag-related degradations in station positioning, and to reduce remaining periodic signals in the individual AC geocenter and scale solutions. Both the evaluation and combination process were successfully achieved with the IGN/LAREG CATREF package. As the final result, IDS-3 combination included solutions for 130 DORIS stations on 67 different sites of which 35 have occupations over 16 years (1993.0-2009.0). More information about the IDS contribution to ITRF2008 is available at IDS web site (http://ids-doris.org/analysis-combination.html) or in Valette et al (2010).

In line with the successful DORIS contribution to ITRF2008, IDS decided to extend the IDS3/ITRF2008 combination process to forge an operational service. At this time, this operational service is still in development, and AC's are requested to periodically submit SINEX solutions. In addition to the realization of weekly combined solutions, the combination center is also in charge of the evaluation of ACs series release as well as analysis of AC submissions to support specific analysis campaigns. These analysis campaigns, included an evaluation of the impact of Jason-2 in the combination solutions, a satellite-by-satellite analysis (Envisat, Jason-2, SPOT-2, SPOT-4, SPOT-5) of the TRF-related parameters (scale and geocenter), and validation of improved or new SINEX time series from individual ACs.. Analysis of these single satellite solutions is completed at the IDS Central Bureau, under the responsibility of the Analysis Coordinator, and has helped all Analysis Centres ti better understand limitations in their previous modelling, and to improve the consistency and accuracy of the IDS products.

3. IDS products

Table 3.1 presents the current IDS products available through the two IDS data centres. All Analysis Centres provided at a least a long-term weekly solution of SINEX files.

Table 3.1: IDS products available at IDS data centres. As of March 2011.

Product	Format	ESA	GAU	GOP	GSC	IGN	INA	LCA		IDS
Weekly station coordinates	SINEX	X	X	X	X	X	X	X		X
Weekly station coordinates	STCD					X	X	X		
Cumulative solution (position/velocity)	SINEX					X		X		
Geocenter motion	text					X	X	X		
EOPs	IGS					X	X	X		
orbits	sp3	X	X	X	X	X	X	X		

4. IDS meetings and publications

4.1 IDS meetings

IDS organizes two types of meetings:
- IDS Workshops (every two years), opened to a large public and related to scientific aspects or applications of the DORIS systems
- Analysis Working Group Meetings (AWG) (when needed), more focussed on technical issues, and usually attended by representatives of Analysis Centres.

The following Table summarizes all the IDS meetings held during the last four years.

Table 4.1: IDS meeting (July 2007 – June 2011).

Meeting	Location	Country	Dates
DORIS AWG Meeting	Paris	France	13-14 March 2008
DORIS AWG Meeting	Paris	France	5-6 June 2008
IDS Workshop	Nice	France	12-14 November 2008
DORIS AWG Meeting	Paris	France	23-24 March 2009
DORIS AWG Meeting	Darmstadt	Germany	26-27 May 2010
IDS Workshop	Lisbon	Portugal	21-22 October 2010
DORIS AWG Meeting	Lisbon	Portugal	22 October 2010
DORIS AWG Meeting	Paris	France	23-24 May 2011

4.2 IDS publications

During the last four years, IDS published several annual reports (by chronological order) :

Tavernier, G., Ferrage, P., Fagard, H., Lemoine, F., Noll, C., Noomen, R., Ries, J.C., Soudarin, L., Valette, J.J., Willis, P., Stepanek, P., Otten, M., Kuzin, S., Moore, P., Govind, R., The International DORIS Service, January 2006- December 2008 report, 93 pages, 2009. http://ids-doris.org/documents/report/IDS_Report_2006_2008.pdf

Ferrage, P., Garayt, B., Govind, R., Kuzin, S., Lemoine, F., Ma, C., Noll, C., Otten, M., Ries, J.C., Saunier, J., Soudarin, L., Stepanek, P., Valette, J.J., Willis, P., The International DORIS Service, January 2009 – December 2009 report, 83 pages, 2010.

Willis, P., International DORIS Service (IDS), Report of the International Association of Geodesy 2007-2009, Travaux de l'Association Internationale de Geodesie, 2009. http://ids-doris.org/documents/report/IDS_Report_2007_2009_for_IAG.pdf

Ferrage, P., Garayt, B., Govind, R., Kuzin, S., Lemoine, F., Ma, C., Moreaux, G., Noll, C., Otten, M., Ries, J.C., Saunier, J., Soudarin, L., Stepanek, P., Willis, P., The International DORIS Service, January 2010 – December 2010 report, 94 pages, 2010. (in preparation)

4.3 peer-reviewed publications related to DORIS

Following a first DORIS Special Issue published in Journal of Geodesy, a call for participation was issued by the Guest Editor (Pascal Willis) for a new DORIS Special Issue in Advances in Space Research (ASR). A large number of manuscripts were received and 23 articles were published in 2 issues of ASR: 45(12) in June 2010 and 46(12) in December 2010.

IDS also maintained on its Web site a complete list of DORIS-related peer-reviewed articles published in international Journals (http://ids-doris.org/report/publications/peer-reviewed-journals.html). In the last four years, the following articles were published (by year):

2007

Altamimi, Z.; Collilieux, X.; Legrand, J.; Garayt, B.; Boucher, C., 2007. ITRF2005, A new release of the International Terrestrial Reference Frame based on time series of station positions and earth orientation parameters, Journal of Geophysical Research, 112(B9), B09401, DOI: 10.1029/2007JB004949.

Amalvict, M.; Willis, P.; Shibuya, K. 2007. Status of DORIS stations in Antarctica for precise geodesy, in Dynamic Planet, Monitoring and understanding a dynamic planet with geodetic and oceanographic tools, P. Tregoning, C. Rizos (Eds.), *IAG Symposium*, 130:94-102, DOI: 10.1007/978-3-540-49350-1_17.

Beckley, BD; Lemoine, FG; Luthcke, SB; Ray, RD; Zelensky, NP 2007. A reassessemnt of global and regional mean sea level trends from TOPEX and Jason-1 altmetry based on revised reference frame orbits, Geophysical Research Letters, 34(14), L14608, DOI: 10.1029/2007GL030002.

Coulot, D.; Berio, P.; Biancale, R.; Loyer, S.; Soudarin, L.; Gontier, A.-M., 2007. Toward a direct combination of space-geodetic techniques at the measurement level: Methodology and main issues, Journal of Geophysical Research, 112(B5), B05410, DOI: 10.1029/2006JB004336.

Doornbos, E; Willis, P 2007. Analysis of DORIS range-rate residuals for TOPEX/Poseidon, Jason, Envisat and SPOT, Acta Astronautica, 60(8-9), 611-621, DOI: 10.1016/j.actaastro.2006.07.012.

Feissel-Vernier, M.; de Viron, O.; Le Bail, K. 2007. Stability of VLBI, SLR, DORIS and GPS positioning, Earth Planets and Space 59(6), 475-497. **Free access**

Li, F.; Parrot, M. 2007. Study of the TEC data obtained from the DORIS stations in relation to seismic activity, Annals of Geophysics, 50(1), 39-50.

Poretti, G; Mandler, R; Lipizer, M. 2007. The GPS station at the Pyramid geodetic Laboratory. Bollettino di Geofisica Teorica ed Applicata 48(1), 25-32.

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International Earth Rotation and Reference Systems Service (IERS)

http://www.iers.org

Chair of the Directing Board: Chopo Ma (USA)
Director of the Central Bureau: Bernd Richter (Germany)

Overview

The International Earth Rotation and Reference Systems Service continued its operation as in previous years. It provided Earth orientation data, terrestrial and celestial references frames, as well as geophysical fluids data to the scientific and other communities.

Earth orientation data have been issued on a daily, weekly, and monthly basis, and new global geophysical fluids data were added. Work on new realizations of the International Terrestrial Reference System (ITRF2008) and the International Celestial Reference System (ICRF2) was finished. The IERS Conventions (i.e. standards etc.) have been updated regularly, a new revised edition was published at the end of 2010.

The IERS continued to issue Technical Notes, Annual Reports, Bulletins, and Newsletters. It held Workshops on Conventions (September 2007) and on EOP Combination and Prediction (October 2009) and organized two GGOS Unified Analysis Workshops and a follow-up meeting (December 2007, April 2008, December 2009).

The IERS Data and Information System (DIS) at the web site 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 also links to other servers, among these to about 20 web sites run by other IERS components.

Activities

Publications

The following IERS publications and newsletters appeared between mid-2007 and 2011:

- IERS Technical Note No. 35: The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry
- IERS Technical Note No. 36: IERS Conventions (2010)
- IERS Annual Reports 2005, 2006, and 2007
- IERS Bulletin A, B, C, and D (weekly to half-yearly)
- IERS Messages Nos. 115 to 190

Workshops

The IERS organized the following Workshops:

- *Workshop on Conventions (Sèvres, France, September 20–21, 2007).* The main conclusions of the workshop include the classification of models, the criteria for choosing models for conventional station displacements, the treatment of non-tidal loading effects, existing and proposed new models for S1/S2 atmospheric loading, the troposphere, a conventional model for the effect of ocean tides on geopotential, a model for diurnal and semidiurnal EOP variations, and recommendations for handling technique-dependent effects.
- *GGOS Unified Analysis Workshops (Monterey, CA, USA, December 5–7, 2007).* It was intended to be a forum to exchange information and results and thus increase the common understanding of all the technique representatives for each of the individual techniques as they contribute to GGOS. The participants decided the following action items and recommendations: extension of the SINEX format for other parameter types and representations; tests on atmospheric loading: application on the observation or solution level?; generation of daily SINEX files (IVS Intensives and IGS Rapids); parameterisation and modelling for the next ITRF; benchmark tests for models common to several techniques; documentation of AC modelling standards and parameterisation; definition of meta data standards (e.g. SINEX meta data block).
- *GGOS Unified Analysis Workshop, Follow-Up Meeting (Vienna, Austria, April 15, 2008).* The status of the action items from the previous workshop, SINEX issues, a proposal for reference pressure, and a common analysis description form were discussed.
- *Workshop on EOP Combination and Prediction (Warsaw, Poland, October 19–21, 2009).* Its main goal was to provide the current state-of-the-art for EOP predictions in terms of data sets and algorithms as well as to discuss recommended actions for improving EOP predictions, including improving the IERS rapid combined series. The Workshop was attended by about 50 participants and about 40 papers and 5 posters were presented. The 20 concluding recommendations concerned e.g. EOP tidal models, the IERS precession/nutation model, a priori tropospheric gradient models, the latency of IVS intensive and IGS rapid EOP products, systematic errors in EOP, EOP + TRF consistency, modern Earth rotation theory, fluid excitation functions time series and their forecasts as well as required EOP prediction length and accuracy. The proceedings of this Workshop were published in a special issue of Artificial Satellites Vol. 45, No. 2, 2010.
- *Second GGOS Unified Analysis Workshop (Grand Hyatt, San Francisco, CA, USA, December 11–12, 2009).* This 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 organized in the following four sessions: 1. Products by the Services, GGOS Portal and Metadata (including portal and meta data). 2. Modelling Deficiencies and Modelling Based on External Data (Atmosphere, Ocean, ...). 3. Combination Strategies, Common Parameters and Combined Products. 4. Network Simulations and Analyses. Among the action items and recommendations were the following: Introduce benchmarking of diverse models in the software packages, that are common to all techniques; distribute new version 2.10 of the SINEX format; create an IERS Working Group for the maintenance and updating of the SINEX format; establish a data base of daily SINEX files from reprocessing activities; accomplish a Troposphere Combination Campaign; work towards a sub-daily resolution and a representation of EOPs; establish an IERS Working Group on Parameterization and Modeling for IERS201x (ITRF/EOP/ICRF); work on documentation of modeling and

parameterization standards; investigate reference pressure for atmospheric loading, atmospheric loading on the observation level, sub-daily ERP tidal model, combination of SLR range biases, EOP parameterization, solar radiation pressure models.

Abstracts and presentations of these workshops 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. 45 in San Francisco, December 11, 2007;
- No. 46 in Vienna, April 13, 2008;
- No. 47 in Washington D.C., October 27–28, 2008;
- No. 48 in Vienna, April 19, 2009;
- No. 49 in Warsaw, October 22–23, 2009;
- No. 50 in Vienna, May 1, 2010;
- No. 51 in Paris, October 10, 2010;
- No. 52 in Vienna, April 3, 2011.

Among the most important decisions made by the DB in 2007–2011 were the following:

- Terminate the present CRCs at the end of 2008.
- Revitalise the present GGFC Special Bureaus by new calls.
- Add a new Special Bureau for Propagation Delays.
- IERS will work for membership in the newly structured ICSU World Data System.

The *Central Bureau* coordinated the work of the Directing Board and the IERS in general, organized meetings and issued publications. 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 meta data. The system provides general information on the structure and the components of the IERS and gives access to all products. A plot tool was developed and installed which allows visualizing some of the Earth orientation data provided by the IERS. The data include pole coordinates, UT1–UTC, LOD, and celestial pole offsets. For most IERS products, meta data according to ISO 19115 were produced as well as a proposal for SINEX file meta data. The move to a new Content Management System was finished and the web site was re-launched in February 2010.

The work of the *Analysis Coordinator* focused on coordinating the Combination Pilot Project, to prepare the GGOS Unified Analysis Workshops, and to propose a new version of the SINEX data format.

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. In 2009 the working group updated its Charter, changed the list of its members and presented a new schedule for work. The major task of the *Working Group on Combination* was the coordination of the IERS Combination Pilot Project. The working group was terminated by December 31, 2008. A new *Working Group on Combination at the Observation Level* was established at a kick-off meeting in October 2009. Its major task is to study methods and advantages of combining techniques at the observation level, searching for an optimal strategy to solve for geodetic parameters. Demonstration will be based on weekly combined SINEX files (containing unconstrained normal equations of station coordinates, EOPs, nutation parameters and eventually quasar coordinates) from all space geodetic techniques together. The new products resulting from these combination procedures will be compared to the current IERS products routinely produced. The working group maintains an online "Forum Multi-technique Combinations". The *Working Group on Prediction* existed from December 2005 to October 2009. It was designed to build upon the foundation laid by the Prediction Comparison Campaign (PCC) and also investigate the new data sets from the Combination Pilot Project. The objectives of the PCC were the comparison of the various methods, models, techniques and strategies, which can be applied for EOP prediction with equal rules. In total 12 scientists participated with 20 prediction techniques in four categories: ultra short-term (10 days), short-term (30 days), medium term (500 days) and long term (20 years). The purpose of the *IERS/IVS Working Group on the Second Realization of the ICRF* was to generate the second realization of the ICRF from VLBI observations of extragalactic radio sources, consistent with the current realization of the ITRF and EOP data products.

International Geoid Service (IGeS)

http://www.iges.polimi.it

President: Fernando Sansò (Italy)
Director: Riccardo Barzaghi (Italy)

Overview

Over the period 2007-2011, IGeS activities have been mainly focussed on:

- a test on quasi-geoid computation methods, the Auvergne test;
- the participation to the validation of the EGM2008 global geopotential model;
- the computation of a global geopotential model based on GOCE data;
- the organization of schools on geoid computation;
- the support given in computing high definition geoid in South India and Bangladesh.

The Auvergne test on quasi-geoid estimation has been set up in co-operation with IGN and EGGP. IGN supplied the gravity, DTM and GPS/levelling data while EGGP contributed in assessing the test procedures. A first comparison between the computations performed by six different groups have been presented during the last Hotine-Marussi Symposium held in Rome (July 5th-9th, 2009). The results of this test proved the substantial equivalence of the applied computation methods.

The validation of the EGM2008 global geopotential model has been performed in the framework of the activities of the Joint Working Group (JWG) between the International Gravity Field Service (IGFS) and the Commission 2 of the International Association of Geodesy (IAG), entitled "Evaluation of Global Earth Gravity Models". IGeS participated to the test on EGM2008 comparing it with data covering two areas: the Central Mediterranean area and the South of India. The scientific papers on EGM2008 validation have been collected in a special issue of the *Newton's Bulletin* (the Bulletin n° 4) which can be downloaded at the IGeS web page (www.iges.polimi.it). This special issue of *Newton's Bulletin* consists of 25 peer-reviewed evaluation papers of EGM2008 (and partially of PGM2007A), which are grouped into four different sections according to the geographical region of the evaluation tests: Global, the Americas, Europe and Africa, and Asia, Australia and Antarctica. Their results provide a thorough external assessment of EGM2008, using a variety of geodetic data and testing methodologies.

Furthermore, IGeS has been deeply involved in estimating a global geopotential model based on GOCE data and the space-wise approach. As new data have been provided by ESA, refinements in the global geopotential model estimating procedure have been devised and applied to these data.

Also, as it is usually done since 1999, schools on geoid computation have been organized by IGeS. One school have been held in Como (Italy), in September 15th-19th, 2008. On September 7th-11th , 2009 a second geoid school was organized at the Universidad National de la Plata, Fac. de Ciencias Astronómicas y Geofísicas, La Plata (Argentina) which was then followed by a third school held in St. Petersburg (Russia), from June 28th to July 2nd, 2010.

Finally, IGeS gave support to researchers in computing local geoids. This has been done in the last two years period in two different areas of the world, namely South India and Bangladesh.

The National Geophysical Research Institute of Hyderabad (India) contacted IGeS in order to get support in computing a gravimetric geoid in South India. This has been done mainly for geophysical investigation in this area, even though the quality of the estimated geoid allows its use also in height conversions (e.g. from ellipsoidal to orthometric heights).

A co-operation was also established with the Survey of Bangladesh. A researcher of the Survey of Bangladesh was hosted at IGeS in Milano, in February, 2009. During this period, a refinement of the EGM2008 over Bangladesh was computed, based on GPS/levelling points which were collected by the Survey of Bangladesh. This refinement proved to be effective and led to a significant improvement of the global EGM2008 model.

Activities

1. The Auvergne test on geoid computation

This test aims at comparing different gravimetric geoid estimation methods. Data were provided by H. Duquenne (IGN) and were distributed by IGeS. IGeS and EGGP co-operated in defining the testing procedures and the general framework of this test.

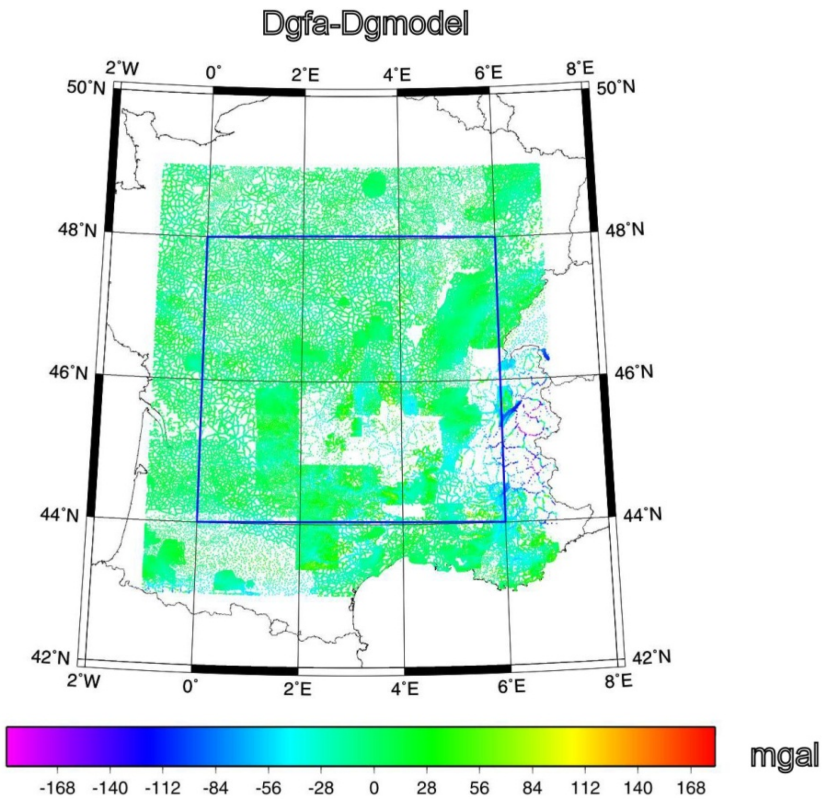

Figure 1. – The test area and the gravity database (residual gravity after geopotential model reduction)

The test field is the Auvergne area, located in the centre of France, covering a 4° x 6° wide area (see the blue square in the Figure 1). The IGN gravity dataset consists of 244009 values, covering most of the French territory. The used DTM is based on SRTM, with a 3''x 3'' grid spacing and the global geopotential model taken into account is EIGEN_GL04C up to degree and order 360 (this was the most recent model available when the project started). In the test field, 75 GPS/leveling points are also available to be used as control points.

The six participating research groups have performed the computation using, basically, remove-solve-restore procedure. The main differences refer to the residual height anomaly computation. In the following table, the six research group participating to the test and the different methods applied in this computation step are summarized.

Table 1. – The six research groups participating to the test and the used computation methods

Swedish Mapping, Cadastre and Registry Auth / Zanjan University (**Swed_Map**)	KTH (Sjöberg) method: least squares (stochastic) kernel modification; additive corrections for: topography, downward continuation, the atmosphere and the ellipsoidal shape of the Earth.
Politecnico di Milano (**PoliMi**)	Fast collocation approach.
Institut f.Erdmessung (**IFE**)	Data screening, RTM terrain reductions, spectral combination with 1D FFT.
Niels Bohr Institute (**NBI**)	Least-Squares Collocation as implemented in GEOCOL.
Department of Geodesy and Surveying, Aristotle University of Thessaloniki (**DGS_Thess**)	1D spherical FFT methods.
Laboratoire de Recherche en Géodésie, Institut Géographique National (**IGN**)	Stokes' integration.

The results obtained using the estimation methods listed above are collected in Table 2. They are the statistics of the residuals on the 75 GPS/levelling points after datum shift estimation.

Table 2. – The results of the Auvergne test

	Swed_Map	**PoliMi**	**IFE**	**NBI**	**DGS_Thess**	**IGN**
Check points	75	75	75	75	75	75
Mean (m)	0.000	0.000	0.000	0.000	0.000	0.000
St. dev. (m)	0.029	0.036	0.035	0.067	0.035	0.037
Min (m)	-0.094	-0.100	-0.085	-0.196	-0.066	-0.069
Max (m)	0.053	0.078	0.079	0.161	0.092	0.093

Height anomalies were computed on a 1´ × 1´ grid, in the area 44°N < lat. < 48°N; 0°E < lon. < 6°E, and then interpolated on the 75 GPS/levelling control points.

The results achieved by the different research groups show a reasonable agreement. Differences are only of the second order, thus assessing the substantial equivalence of the different approaches and software. In the frame of a future research it seems interesting to involve other research groups with different methodologies. Also an optimization of different groups' results will be carried out, by testing other data configurations, for instance using other DTMs, or different global models (i.e. EGM2008).

2. The participation to the EGM2008 validation test

IGeS participated to the validation of the geopotential model EGM2008 by testing its precision in two different areas, i.e. the Central Mediterranean and the South of India. Here, only a synthetic description of the main results is given. The computation details can be found in Barzaghi and Carrion (*Testing EGM2008 in the Central Mediterranean area, Newton's Bulletin, n° 4, 2009*) and in Carrion et al. (*Gravity and geoid estimate in South India and their comparison with EGM2008, Newton's Bulletin, n°4 ,2009*).

2.1 The Central Mediterranean test area

The test in the Central Mediterranean area was based on comparisons with gravity and GPS/levelling data available in this area. This was done both with respect to previous existing geopotential models (EGM96, GPM98CR and EIGEN-GL04C) and the last estimate of the Italian geoid, ITALGEO2005 (*Barzaghi et al., Bollettino di Geodesia e Scienze Affini, n° 1, 2008*).

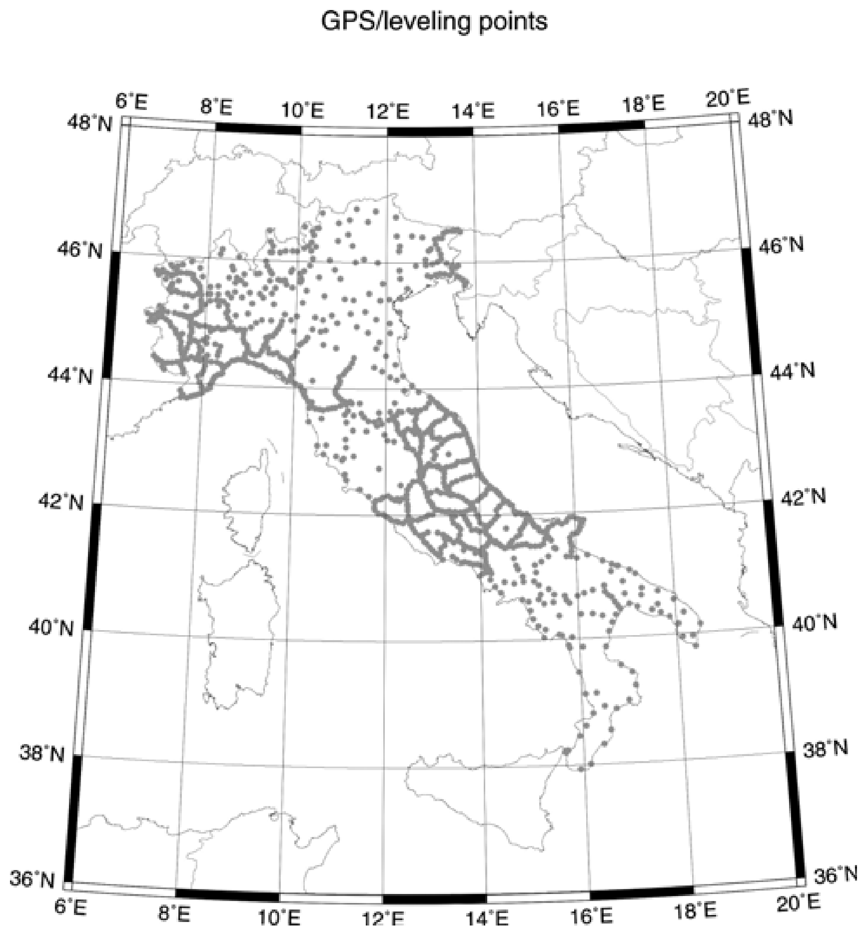

Figure 2. – The test area and the used GPS/leveling points

The test area is included in the window 35°≤ lat. ≤48°, 5°≤ lon. ≤20°. In this area, 310.660 point gravity values and 977 GPS/leveling data are available. In Figure 2, the distribution of the GPS/leveling points is shown.

A first comparison has been made using the full gravity data set and the EGM2008 and GPM98CR models. The GPM98CR model has been used because it is the one giving the best results, before EGM2008.

Statistics refer to residuals after model and terrain effect reduction.

Table 3. – The statistics of the gravity residuals after geopotential model and terrain effect reduction (mgal)

	$\Delta g_{FA} - \Delta g_{EGM2008} - \Delta g_{RTC}$	$\Delta g_{FA} - \Delta g_{GPM98CR} - \Delta g_{RTC}$
E	-0.94	-1.14
St.dev.	7.88	10.69
Min	-287.74	-274.55
Max	117.26	106.64

Also, the statistics of the reduced gravity values were computed on a reduced gravity data set consisting of 142.196 values (the maximum geopotential model degree is listed too). In this case, the EGM2008 model is compared to EIGEN-GL04C and EGM96 models.

Table 4. – The statistics of the gravity residuals after geopotential model reduction (mgal)

	$\Delta g_{FA} - \Delta g_{EGM08(2190)}$	$\Delta g_{FA} - \Delta g_{GL04C(360)}$	$\Delta g_{FA} - \Delta g_{EGM96(360)}$
E	-5.41	-7.33	-6.42
St.dev.	20.32	32.24	31.13
Min	-241.56	-255.89	-253.98
Max	119.49	194.81	188.23

The comparison with GPS/levelling data are referred to EGM2008, GPM98CR and ITAL-GEO95 (statistics refer to residuals after datum shift estimation).

Table 5. – The statistics of the GPS/leveling residuals after geoid model reduction (m)

	NEGM2008 - NGPS/lev	NGPM98CR - NGPS/lev	NItalgeo05 - NGPS/lev
E	0.00	0.00	0.00
St.dev.	0.10	0.35	0.12
Min	-0.33	-1.30	-0.50
Max	0.34	0.64	0.32

2.2 The South India test area

In this test, a comparison over the Southern India region using a quite large data base collected by National Geophysical Research Institute of India is presented.

The gravity field of this area is quite regular and its structure is mainly connected to the topography**;** in fact the major variations are in the area 10°≤ lat. ≤12°, 76°≤ lon. ≤78° where the principal relieves are concentrated. The topography varies from sea level to high mountains (about 2500 meters) and the area is surrounded by deep ocean. Land gravity is known inside the area 8°≤ lat. ≤15°, 74°≤ lon. ≤81° where 16013 gravity values were measured (see Figure 3).

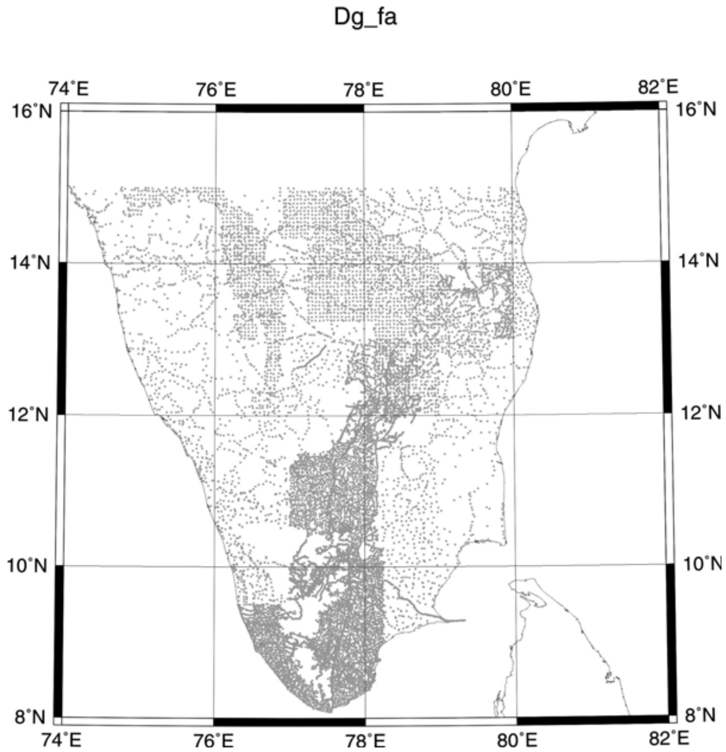

Figure 3. – The South India gravity data base

Since no GPS/levelling data were available, comparisons restrict to gravity only. In Table 6, reduced gravity statistics can be compared with those of the unreduced data

Table 6. – The statistics of the gravity residuals after geopotential model reduction

Gravity	E(mgal)	St.dev.(mgal)	Min(mgal)	Max(mgal)
Δg_{FA}	-33.93	29.13	-120.93	192.77
$\Delta g_{FA} - \Delta g_{EGM96}$	-6.45	21.85	-94.46	182.32
$\Delta g_{FA} - \Delta g_{GPM98CR}$	-7.56	22.42	-83.08	200.56
$\Delta g_{FA} - \Delta g_{GL04C}$	-6.08	21.65	-92.55	183.23
$\Delta g_{FA} - \Delta g_{EGM2008}$	-0.08	10.88	-112.54	79.40

2.3 Conclusions

The EGM2008 global geopotential model proved to be very effective in fitting gravity and GPS/leveling both in the Central Mediterranean and in the South India area. The same conclusions hold for the tests documented in the papers published in the special issue of the *Newton's Bulletin.* Hence, the tests performed by 25 research groups proved that this model is remarkably better than those previously estimated. Thus, the EGM2008 coefficients contain, even at high order, valuable information. Furthermore, its accuracy in fitting GPS/leveling data is, in most cases, equivalent to those obtained with high resolution geoid estimates based on local gravity databases (e.g. ITALGEO05). This is quite surprising since, up to now, local geoid estimates have given better results. Thus, the EGM2008 model opens new perspectives on local geoid computation that probably require the definition of new computation strategies.

3. The GOCE mission: computation method at IGeS

Since the launch of the GOCE satellite (March 17th, 2009), IGeS has been actively involved in estimating a global geopotential model based on GOCE data.

The most recent solution has been computed by applying the space-wise approach to eight months of data.

GOCE data have been divided in subsets of continuous observations with similar behaviour. The subsets were then pre-processed in such a way to mark and remove outliers and fill small data gaps. Datasets with not enough valid data were disregarded.

Five subsets have been selected to produce the solution; from about 8 months of data, only 80% of them have been finally used.

The scheme adopted in computing the solution can be detailed as in the following (see also Figure 4):

- each subset is processed following the space-wise approach producing grids of potential and second order radial derivative, plus Monte Carlo (MC) sample grids describing the error;
- merged grids of the two functionals are obtained by using a moving window and weighting data on the bases of MC error covariance matrices;
- harmonic analysis is finally applied to these grids, obtaining two sets of coefficients that are merged by collocation based on the errors propagated from the MC sample grids.

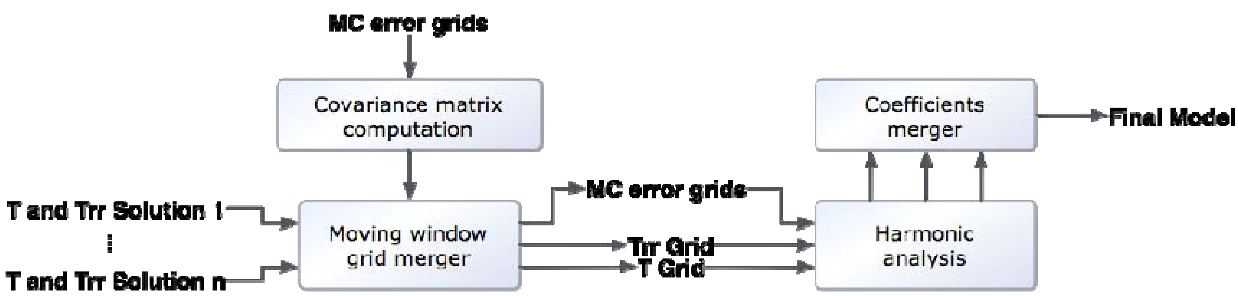

Figure 4. – The GOCE data processing scheme adopted at IGeS

The new solution has led to remarkable improvements which can be clearly seen in Figure 5 where the error degree variances of this new solution (blue line) are compared to those of a preliminary space-wise solution (black line) and to those of the time-wise solution (orange line)

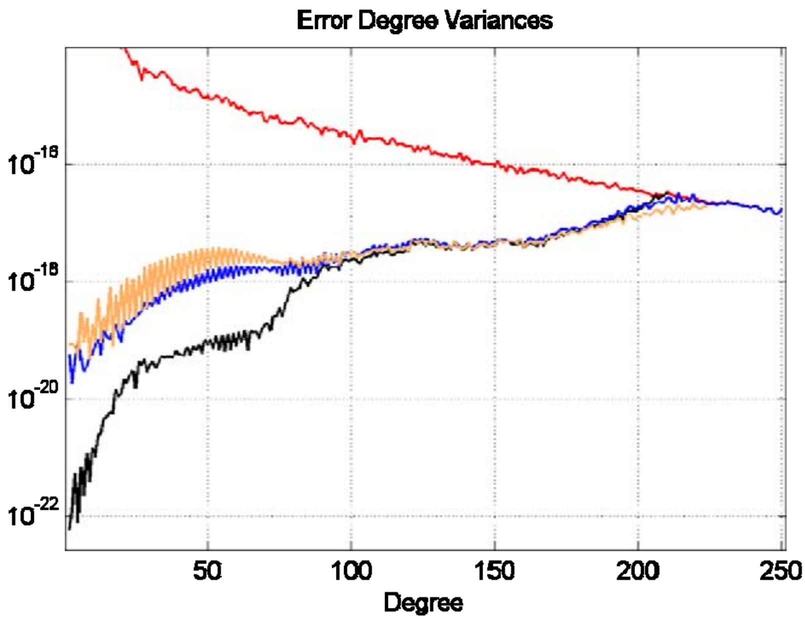

Figure 5. – Error degree variances derived from GOCE data by applying different processing strategies

Thus GOCE-only models can be estimated by using this last version of the space-wise approach; in particular a solution based on the first delivered eight months has been computed. Further improvements in the model can be achieved by properly modeling the residual signal covariance so to better control the regularization at the highest degree.

At present, the commission error up to degree 200 in the latitude interval -80 < lat. < 80 is of about 6 cm in terms of geoid undulations and 1.6 mgal in terms of gravity anomalies. The maximum degree of the model is 240.

4. The schools on geoid computation

The VIII International Geoid School on 'The Determination and Use of the Geoid' has been organized by IGeS at the Como Campus of the Politecnico di Milano, from September 15th to September 19th, 2008.

The school included both theoretical lectures and numerical exercises on local geoid computation. Lectures on theory for geoid computation, terrain effect, global geopotential models, collocation method in Geodesy and FFT for geoid estimation were respectively given by F. Sansò, R. Forsberg, N. Pavlis, C.C. Tscherning and M. Sideris. The school was attended by 23 participants coming from 12 countries. Morning theoretical lessons were given at Palazzo Natta in the historical centre of Como while afternoon computer exercise sessions were held in the computer centre at the Politecnico di Milano Campus in Como. The computer room is provided with 40 computers working with O.S. WinXP S.P.3, on which Fortran compilers and Phyton interface have been installed to use FORTRAN programs that usually run under Unix systems.

The IX school was organized at the Faculty of Astronomical and Geophysical Sciences of the University of La Plata in Argentina, from September 7th to September 11th , 2009.

23 participants from 5 countries attended the school. Lectures were on theory and practice on geoid computation following a structure similar to the one held in Como. Teachers were: F. Sansò, R. Forsberg, N. Pavlis, C. C. Tscherning and M. Sideris. On the first day, two seminars on *Geoid, Gravity and Sea-Level from Radar Altimetry* and *Monitoring Gravity Variations* were given by O. Andersen and S. Bonvalot respectively. On the third day, there was a seminar on *Fitting the Gravimetric Geoid to GPS Benchmarks* by G. Fotopoulos and during the last day a seminar on *Gravity and Geoid in Argentina*. As for the Como geoid school, morning theoretical lessons were followed by practical numerical exercises that were held in a computer room equipped with 25 computers running LINUX operating system.

The last geoid school in the 2007-2010 period, the X organized by IGeS, was carried out in St. Petersburg, from June 28th to July 2nd, 2010. 15 participants attended this school from 5 countries. As for the two previous schools, lectures were given on the theory of geoid computation (R. Barzaghi), global geopotential models (N. Pavlis), marine gravity (O. Andersen), terrain effect in geoid estimation (R. Forsberg), collocation applied to geodesy (I. Tziavos), FFT methods in geodesy (M. Sideris). L. Vitushkin gave a lecture on *Absolute gravity measurements*. Numerical exercises, as usual, were performed using software related to geoid estimation.

During each school, Lecture Notes, with some upgrading as addendum, IGeS CD with software and data for exercises, the GRAVSOFT manual and a user guide explaining FFT programs were distributed to the participants. Moreover, CDs have been supplied containing all the lectures presented during the week.

5. Supporting geodetic activities in South India and Bangladesh

Contacts have been established with the National Geophysical Research Institute of Hyderabad (India) and the Survey of Bangladesh. In both cases, a support was requested for geoid computation.

In the South India area, a gravimetric quasi-geoid has been estimated in co-operation with the National Geophysical Research Institute of Hyderabad that supplied 16013 gravity data (*D. Carrion et al., Gravity and geoid estimate in South India and their comparison with EGM2008, Newton's Bulletin, n°4 ,2009*). Data over the surrounding seas were derived from altimetry (*Andersen et al., Improved High Resolution AltimetricGravity Field Mapping (KMS2002 Global Marine Gravity Field*) - *A window on the Future of Geodesy, IAG symposium, 128, 2005)*. The final global gravity data base consists of 63968 values.

The standard "remove-restore" procedure was adopted to estimate this quasi-geoid; the residual component was computed via Fast-collocation. The estimated quasi-geoid is plotted in Figure 6.

Unfortunately, no GPS/leveling data were available and thus no tests on its accuracy were possible. However, this can be considered a reliable estimate which will be used mainly in geophysical investigation over the South India region.

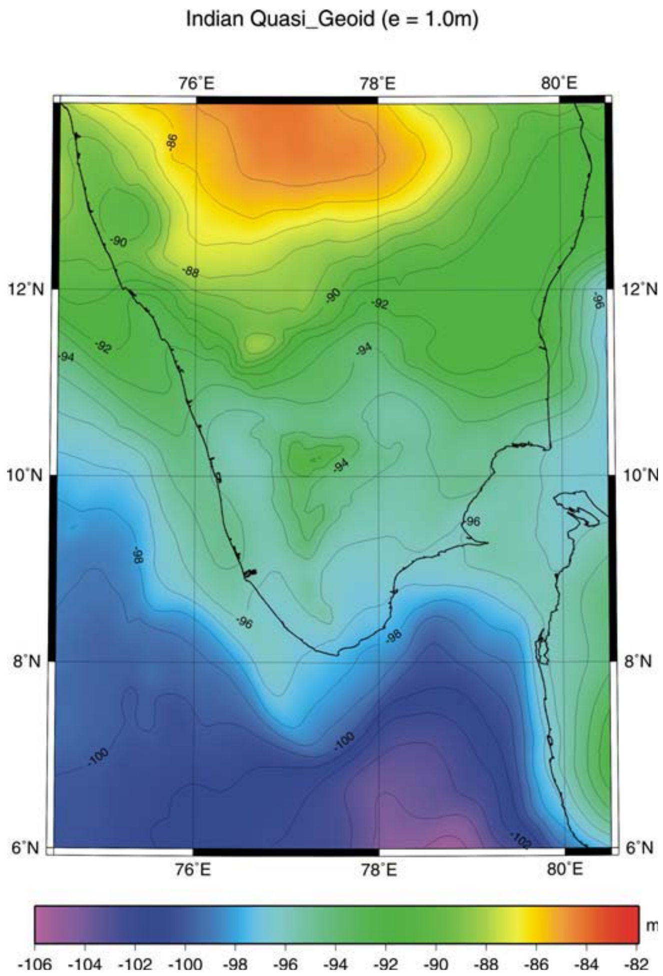

Figure 6. – The South India quasi-geoid

The co-operation with Survey of Bangladesh led to a geoid estimate based on GPS/levelling points used to refine the EGM2008 geopotential implied undulation. Survey of Bangladesh supplied 155 GPS/leveling points: 110 were used in the computation while the remaining 45 were considered as control points. The geoid residuals computed as

$$\Delta N_i = N_i(GPS/lev) - N_i(EGM\,2008)$$

were interpolated on a regular 5' grid covering Bangladesh. The final geoid estimate has been obtained by adding, on the same grid points, the geopotential model component thus obtaining:

$$\hat{N}_{grid} = N_{grid}(EGM\,2008) + \Delta\hat{N}_{grid}$$

$$\Delta\hat{N}_{grid} = Collo(\Delta N_i)$$

This geoid estimate improved the EGM2008 geoid estimate in this area. This has been proved by comparing the refined geoid estimate and EGM2008 on the 45 GPS/leveling control points. The statistics of this comparison are shown in Table 7.

Table 7. – The statistics of the residual undulation over the 45 control points

	EGM2008	**N_{grid}**
Check points	45	45
Mean (m)	0.010	0.018
Standard dev. (m)	0.152	0.089
Minimum (m)	-0.292	-0.199
Maximum (m)	0.358	0.237

As one can see, a remarkable improvement in st. dev. is obtained using N_{grid}. Contact with Survey of Bangladesh will continue in the future with the aim of improving the geoid estimate in this area, also including gravity data that are going to be measured.

International Global Navigations Satellite System Service (IGS) 2007 – 2011

Web: http://www.igs.org/

(Formerly the International GPS Service until 2005)

Chair of the Governing Board**: Urs Hugentobler, 2011- 2014,**
Technical University of Munich (Germany)
John M. Dow, 2002 - 2010,
European Space Agency / European Space Operations Center (Germany)
Director of the Central Bureau: **Ruth Neilan,**
Jet Propulsion Laboratory, California Institute of Technology (USA)

Mission: The International GNSS Service provides the highest-quality GNSS data and products in support of the terrestrial reference frame, Earth rotation, Earth observation and research, positioning, navigation and timing and other applications that benefit society.

Overview

During the years between 2007-2011, the International GNSS Service (IGS) continued to flourish and thrive. The IGS is a voluntary federation of more than 200 organizations in 100 countries that pool resources and permanent GNSS station data, predominantly from GPS and GLONASS, to generate precise data products and information. (See organization chart, Figure 1 and IGS maps, Figure 2 and 3)

The IGS is dependent on its cooperative global tracking network of over 400 stations, providing the global reference and links to many denser regional networks, such as EUREF, SIRGAS, AFREF, and so on.

Global Navigation Satellite System (GNSS) is a general term describing space-based position, navigation, and timing (PNT) satellite systems. Currently there are two fully functional GNSSs: the US Global Positioning System (GPS) and the Russian Federation's GLONASS. GPS demonstrates the potential for precise ground- and space-based PNT anywhere in the world.

IGS data are collected continuously and archived at distributed Data Centers. Analysis Centers then retrieve the data and produce the most accurate GPS/GLONASS data products available anywhere. IGS data and data products are made readily available to any user reflecting the IGS commitment to an *open data policy*. The IGS intends to incorporate future GNSSs, the European Union's Galileo and China's COMPASS, and potentially space-based GNSS augmentation systems such as Japan's Quasi-Zenith Satellite System (QZSS) and India's GPS Aided Geo Augmented Navigation system (GAGAN).

The IGS is a highly successful international scientific federation and a model of international cooperation. IGS is proud to be a recognized scientific service of the International Association of Geodesy (IAG) since 1994. IGS is one of the key elements of the IAG's new Global Geodetic Observing System (GGOS). IGS was also a member of the International Council for Science's (ICSU) interdisciplinary body, the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) since 1996 until it was dissolved in 2009. IGS will apply for membership with the new ICSU body, the World Data System (WDS).

IGS Strategic Plan 2008-2012, Mission Statement and Long Terms Goals

In 2006-2007, the IGS engaged in a strategic planning process to update the 2002-2007 plan. This resulted in a revised mission statement, long term goals and objectives and strategies to achieve the goals. The mission of the IGS is to provide:

The highest quality GNSS data, products, and services in support of the Earth observations and research, positioning, navigation and timing, the terrestrial reference frame, Earth rotation, and other applications that benefit society.

To accomplish this mission, the IGS outlines six long-term goals for the period 2008-2012. These goals are to:

– Serve as the premier source of the highest-quality GNSS-related standards (conventions), data and products, openly available to all user communities.
– Attract leading-edge expertise to pursue challenging, innovative projects in a collegial, collaborative and creative culture.
– Maintain an international federation with committed contributions from its members, and with effective leadership, management and governance.
– Incorporate and integrate new systems, technologies, applications and changing user needs into IGS products and services.
– Facilitate the integration of IGS into the Global Geodetic Observing System (GGOS) and other more broadly-based Earth observing and global navigation systems and services.
– Promote the value and benefits of IGS to society, the broader scientific community, and in particular to policy makers and funding entities.

IGS Components

IGS Governing Board 2011

The principal roles of the Governing Board are to set policy and to exercise broad oversight of all IGS functions and components.

Chair: Urs Hugentobler (Germany)

Felicitas Arias (France)

Yoaz Bar-Sever (USA)

Gerhard Beutler (Switzerland) *Founding Chair & IAG Representative*

Geoff Blewitt (USA) *IAG Representative*

Claude Boucher (France) *IERS Representative to IGS*

Carine Bruyninx (Belgium)

Mark Caissy (Canada)

John Dow (Germany) *Past Chair*

Bruno Garayt (France) *IGS Reference Frame Coordinator*

Christine Hackman (USA)

Gary Johnston (Australia)

Andrzej Krankowski (Poland)

Bob King (USA)

Charles Meertens (USA)

TBA, (USA) *IGS Network Coordinator*

Ruth Neilan (USA) *Director*, *IGS Central Bureau*

Carey Noll (USA)

James Park (Rep. of Korea)

Jim Ray (USA) *IGS Analysis Center Coordinator*

Chris Rizos (Australia)

Ignacio Romero (Germany, Spain)

Stefan Schaer (Switzerland)

Ralf Schmid (Germany)

Tilo Schoene (Germany)

Ken Senior (USA) *IGS Clock Products Coordinator*

Tim Springer (Germany)

Robert Weber (Germany)

Richard Wonnacott (South Africa)

IGS Meetings 2007-2011

IGS Meeting	Location	Date
30th GB	Perugia, Italy; IUGG XXIV	30 June 2007
31st GB	San Francisco	9 Dec 2007
32nd GB	Miami	1 June 2008
Analysis Workshop 2008	Miami	2-6 June
Closing 32nd GB	Miami	6 Jun 2008
33rd GB	San Francisco	15 Dec 2008
34th GB	Vienna	19 April 2009
IGS Executive & Business Meeting	Buenos Aires, IAG General Assembly	1 Sept 2009

35th GB	San Francisco	13 Dec 2009
36th GB	Newcastle-upon-Tyne	27 June 2010
IGS Newcastle Workshop 2010	Newcastle-upon-Tyne	28 June – 2 July 2010
Closing 36th GB	Newcastle-upon-Tyne	2 July 2010
37th GB	San Francisco	12 Dec 2010
38th GB	Vienna	3 April 2011
IGS Executive and Business Meeting	Melbourne IUGG XXV General Assembly	30 June 2011

Projects and Working Groups

The IGS continues to develop and improve traditional products such as orbits, clocks, station positions and velocities, as well as fostering projects and working groups that produce additional data products, such as precipitable water vapor (PWV), a valuable input into weather forecasting; and total electron content (TEC), useful for ionospheric space weather research. IGS projects and working groups are dependent upon the infrastructure of the IGS and include:

IGS Projects	***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 Pilot Project	Demonstrate for IGS real-time network and applications
IGS Working Groups	***Purpose***
IGS Reference Frame Working Group	Global reference frame, Earth orientation, station positions and velocities determined by GPS
Ionospheric Working Group	Ionospheric science research, global ionospheric maps
Clock Products	Global sub-nanosecond time transfer, and IGS time-scale, jointly with the Bureau International des Poids et Mesures (BIPM)
Tropospheric Working Group	Estimate water vapor in atmosphere from the GPS signal delay
Global Navigation Satellite Systems (GNSS)	Determine actions necessary for IGS to co-opt new GNSS systems, European Union Galileo system, China's COMPASS, and GPS modernization
Data Center	Coordination among IGS data centers and support for increasing number of products and real-time.

Calibration and Bias	Update various values for consistent analysis processing, e.g., differential code biases, cc2nocc, etc.
Antenna	Coordinates research in the field of GNSS receiver and satellite antenna phase center determination.
Space Vehicle Orbit Dynamics	Improved understanding and modeling of satellite dynamics towards further improvement of precise orbit determination.

The Low Earth Orbiter Working Group was dissolved in 2010.

A more detailed description of the IGS's components, structure, and how it works can be found here: http://igs.org/overview/pubs.html and in the publication: *IGS Strategic Plan 2008-2012*.

IGS products can be described and accessed here: http://acc.igs.org/

Key IGS Aspects by Year, 2007-2011

2007

- Reprocessing campaign initiated to reanalyze all IGS data for improved products and time series
- James Zumberge and Markus Rothacher complete their four-years terms as Analysis Representatives.
- New Analysis Representatives elected: Bob King and Tim Springer, for 2008-2011.
- Chris Rizos appointed to a second term for 2008-2001.
- Release of the Real-Time Call for Participation, 32 proposals received.
- Jim Ray of US NGS succeeds Gerd Gendt of GFZ Potsdam as Analysis Center Coordinator.

2008

- Analysis Workshop held in Miami hosted by the US National Geodetic Survey. Recommendations and summary can be found here: http://www.igs.org/overview/pubs.html and http://www.igs.org/overview/pubs/IGSWorkshop2008/
- IGS Infrastructure Committee established.
- IGS joins RTCM via IGS Institute.
- Steve Fisher rejoins the IGS CB.
- ACC website fully transferred from GFZ to NGS.
- Ionospheric WG Chair and product generations transitions from Manuel Hernandez-Pajares, Technical University of Catalonia) to Andrezj Krankowski, University of Warmia and Mazury, Institute of Geodesy

- Next generation IGS combination software, 'ACC2.0' call issued.
- IGS CB plans and hosts the third meeting of the International Committee on GNSS (ICG-3) in Pasadena.
- IGS Institute established.
- ICG-3 results in establishing 2 Task Forces within the International Committee on GNSS: Task Forces on Reference Frame and Timing.
- IGS GB begins a process for strategic plan implementation (SIP).

2009

- IGS Special issue in Journal of Geodesy published, edited by Chris Rizos.
- Remi Ferland, of NRCan ends his role as IGS Reference Frame Coordinator.
- Bruno Garayt or IGN, France succeeds Ferland as IGS Reference Frame coordinator.
- During IAG General Assembly on Beunow Aires, John Dow presentation for IGS shows strong links between IGS and GGOS.
- Ignacio Romero appointed as Chair of the IGS Infrastructure Committee.
- Template for annual reporting by IGS components developed by the CB.
- Terms of Norman Beck (Network), Carey Noll (Data) and Urs Hugentobler end (Analysis) end. Noll and Hugentobler re-elected, Gary Johnston, Geoscience Australia, elected as Network Representative for terms 2010-2013.
- Richard Wonnacott re-appointed to the GB on recommendation of the CB.
- Score card for strategic implementation plan (SIP) developed.

2010

- IGS Newcastle Workshop 2010, links to the presentations are here: http://www.igs.org/event/newcastle2010/
- Newcastle Workshop recommendations and summary can be found here: http://www.igs.org/overview/pubs.html
- Review of IGS Associate Members results in establishment of the Associate Members Committee to determine and establish a process for better membership.
- IGS Terms of Reference revised.
- ITRF 2008 released, highlights issues with uncalibrated radomes and site tie errors.
- IGS increasing involvement in Multi-GNSS campaign activities initiated within the GNSS WG and at the Newcastle Workshop relating to the CONGO network. Also with JAXA for QZSS tracking demonstration.
- Predicted iono products introduced.
- LEO Working Group dissolved.

International Gravimetric Bureau (Bureau Gravimétrique International, BGI)

http://bgi.cnes.fr

Director: Sylvain Bonvalot (France)

Overview

1.1 Missions / Tasks

"Collection, Validation, Archiving and Distribution of Gravity data"

The Bureau Gravimétrique International (BGI) has been created in 1951 by the International Association of Geodesy (IAG), one of the seven associations of which IUGG (International Union in Geophysics and Geodesy) is composed. The initial task of BGI was 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 contributed to provide original databases and services for a wide international community concerned by the studies of the Earth gravity field.

BGI has thus played a fundamental role in the worldwide compilation and validation of gravity data and their distribution to the international scientific community. The BGI database, which now contains over 12 millions of observations compiled and computerized from land, marine and airborne gravity measurements, has been extensively used for the definition of Earth gravity field models and for many applications in geodesy, satellite orbit computation, oceanography, geophysics, etc. In addition, BGI developed other additional services in the area of gravimetry (data validation for regional or global projects, bibliography database, online access to reference gravity stations, expertise, etc.). It also contributed to research & development activities (software developments, interpretation) and to educational activities (summer schools on gravity data acquisition and processing, provision of tutorials and educational materials in gravimetry).

1.2 An international service

BGI is a service of the International Association of Geodesy (IAG). Since 2001, it is one of the "Centers" of the International Gravity Field Service (IGFS) which coordinates within the IAG, the activities of BGI, IGeS (International Geoid Service), ICET (International Center for Earth Tides), ICGEM (International Center for Global Earth Models) and IDEMS (International DEM Service). The overall goal of IGFS is to coordinate the servicing of the geodetic and geophysical community with gravity field-related data, software and information. BGI also belonged until 2008 to the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) which operates under the auspices of the International Council of Scientific Unions (ICSU) and the United Nations Educational Scientific and Cultural Organization (UNESCO). BGI also applied in 2010 as membership of the new World Data System (WDS) born from the merging of FAGS and World Data Centers (WDC).

1.3 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-Pyrenees (OMP), where it has been directed successively by G. Balmino (1979-1998), J-P. Barriot (1998-2007 – with a few months interim by R. Biancale) and S. Bonvalot (since July 2007). Today, BGI is also recognized as a permanent service of the Observatoire Midi-Pyrénées (OMP) in Toulouse, accredited by the Institut National des Sciences de l'Univers (INSU).

The activities of BGI in France are supported today by most of the French Institutions, Universities and Laboratories involved in the acquisition or use of gravity data for a wide range of applications (research, education, exploration, reference system, metrology…). They include: Centre National d'Etudes Spatiales (CNES), 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). A new covenant[1] defining the contribution of each supporting Institutions/Agencies has been updated and approved by their respective Directors.

It is noteworthy that a new partnership has been also established in 2008 between BGI and the Bundesamt für Kartographie und Geodäsie (BKG) Germany for the realization and the maintenance of a global database of absolute gravity measurements.

Activities

The BGI activities for the last four years were scheduled according to the project[2] proposed and approved at the last IUGG General Assembly in Perugia, Italy (July 2007). Our main objectives were (i) to consolidate the terrestrial gravity databases (relative and absolute) and encourage the collection and compilation of new incoming data sets, (ii) to develop new products and services for the Earth Science community, and (iii) to ease the consultation and diffusion of gravity data and products for end-users, through a user friendly Internet Interface.

We have thus focused our activities on:

- the modernization of the web site including new web services and a full upgrade of the BGI database systems,
- the realization of two new global projects: the set up of a global Absolute gravity database (in collaboration with BKG) and the realization of the World Gravity Map project in collaboration with Commission for the Geological Map of the World (CGMW).

In the same time, BGI also continued operating with its supporting organizations, in Educational, Research and Development activities with the aim to maintain a high level of compe-

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[1] *"Convention inter-organismes relative au fonctionnement du Bureau Gravimétrique International ", Déc. 2007, 9p.*

[2] *"International Gravimetric Bureau: Project 2007-2011". Proposal submited to the IAG Commission, IUGG XXI General Assembly, Perugia, Italy, 2007, 42p.*

tence and to improve the efficiency and the quality of its services. We have maintained the activities of services relatively to the existing gravity database (integration, validation of new datasets, processing of data requests from external users, etc.) and have participated to IAG activities (IAG, IGFS, GGOS meetings). We also have contributed to software developments in gravity processing and modeling and to outreach activities (International Summer Schools with IGeS for instance). The main activities are summarized hereafter.

2.1 New Internet web site and web services

A new BGI website has been activated in 2010. It is aimed to provide updated information about BGI services and to ease the access to databases and to other relevant information (data products, bibliography, software, etc.). New functionalities have been implemented to allow automatic procedures for data request, evaluation and distribution. A full upgrade of the BGI databases has to be done in 2009-2010 to improve the data access and compatibility with these new functionalities. Users can now make their consultations and direct requests within various global gravity databases (land and marine relative gravity measurements, absolute gravity measurements, reference gravity stations, GRACE decade solutions from CNES/ GRGS …). Since the website has been activated, we noted a significant increase of the number of requests and consultations. This site is under development to improve the services.

Fig. 1: BGI main webpage (http://bgi.cnes.fr - http://bgi.omp.obs-mip.fr)

2.2 New global Absolute Gravity database

The absolute gravity database has been initiated in collaboration within BGI and BKG Germany that had previously developed a prototype of an Absolute gravity database. This application (AGRAV), based on a Google map interface, has been installed at BGI in late 2007 by H. Wziontek (BKG). New functionalities have been implemented to fit with the requirements of BGI data compilation and archiving. The database is currently accessible through two mirrored sites at BGI (http://bgi.dtp.obs-mip.fr/agrav-meta/) and BKG http://agrav.bkg.bund.de/agrav-meta/).

The information provided ranges from meta-data (localization of stations) up to a 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. See communications and publications in the section "references" for more details.

Such database is expected to contribute also to the new standard absolute gravity reference frame, who will replace advantageously in a next future the previous IGSN71 network.

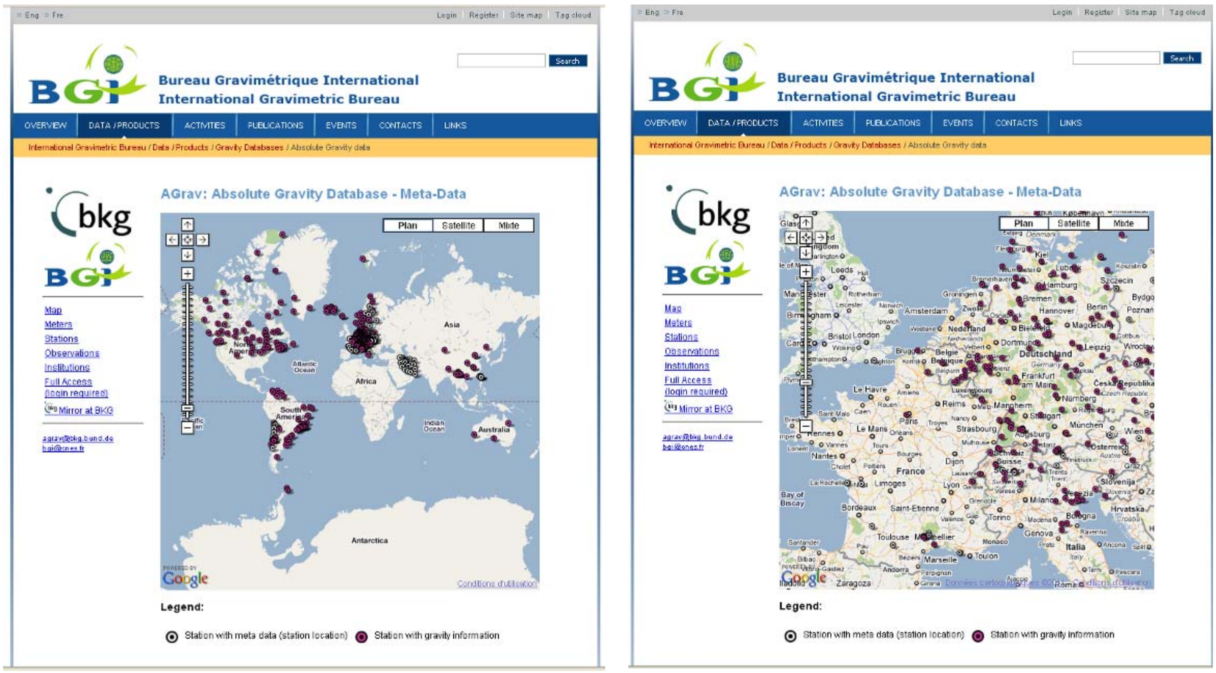

Fig 2: Internet Interface of the Absolute Gravity database (BGI-BKG) (http://bgi.dtp.obs-mip.fr/agrav-meta/ - http://agrav.bkg.bund.de/agrav-meta/)

2.3 WGM (World Gravity Anomaly Map) project and high resolution gravity modeling

The WGM project is a new gravity mapping project undertaken by BGI under the aegis of the Commission for the Geological Map of the World (CGMW), of the International Association of Geodesy (IAG) - and of its International Gravity Field Services (IGFS) with the support of the United Nations Educational Scientific and Cultural Organization (UNESCO).

This project, launched in 2008, will complement a set of global geological and geophysical digital maps published and updated by CGMW for educational and research purposes. Following the example of the World Digital Magnetic Anomaly Map (WDMAM) and of the World Stress Map (WSM), released in 2007 (http://ccgm.free.fr/index_gb.html), this new global digital map aims to provide a high resolution picture of the gravity anomalies of the world based on the up-to-date available information on the Earth gravity field. The objective of the WGM project is to contribute to a better understanding and interpretation of the gravity anomalies at regional and global scales in terms of the geological structure and composition of the Earth. Another objective of the map, and associated booklet, is to help teaching gravity concepts.

Major contributions to high resolution global gravity mapping are provided today by the Earth Geopotential Model (EGM08)[3] computed at NGA (National Geospatial-Intelligence Agency) from surface and satellite data or also by the DNSC08/DTU10 model computed at DTU Space (Technical University of Denmark)[4,5] or the one computed at SIO (Scripps Institution of Oceanography)[6] from satellite altimetry and marine measurements. Here, we focused our efforts to compute in spherical geometry global maps and grids of various quantities useful for geodesists, geophysicists and geologists: surface free air, terrain corrected Bouguer or isostatic gravity anomalies. One of our objectives was also to provide precise gravity terrain corrections at global scale (which are usually computed at regional scales), using high resolution global models of topography/bathymetry.

With that aim, we have first developed new software to compute terrain corrections by integration of spherical prisms, based on a previous computed program developed at BGI. This new software (QUASPH-TC, Balmino, Moreaux et al) has been successfully finalized and matched with other available programs. Later on, this project benefited from new theoretical developments specifically done by G. Balmino on spherical harmonics modeling to ultra-high degrees. A specific algorithm was developed to enable the computation of associated Legendre functions to any degree (and order), that was successfully tested up to degree 32400. The main application was the production of a 1' x 1' global complete Bouguer anomaly grid which was computed by spherical harmonic analysis of the Earth's topography-bathymetry ETOPO1 data (NOAA) set up to degree and order 10800, taking into account the characteristics (precise boundaries and densities) of major lakes and inner seas (with their own altitude), polar caps (with bedrock information) and of land areas below sea level. The harmonic coefficients for each entity were derived by analyzing the corresponding ETOPO1 part (and free surface data when required) at one arc minute resolution. In addition, isostatic corrections have been also computed according to the Airy Heiskanen model in spherical geometry for a constant depth of compensation (T_c) of 30km.

[3] *N. K. Pavlis, S. A. Holmes, S. C. Kenyon, J. K. Factor. An Earth Gravitational Model to Degree 2160: EGM2008. EGU General Assembly 2008, Vienna, Austria, April 13-18, 2008. http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008*

[4] *Andersen, O. B., P. Knudsen and P. Berry (2010) The DNSC08GRA global marine gravity field from double retracked satellite altimetry, Journal of Geodesy, Volume 84, Number 3, DOI: 10.1007/s00190-009-0355-9*

[5] *Andersen, O. B., The DTU10 Gravity field and Mean sea surface (2010), Second international symposium of the gravity field of the Earth (IGFS2), Fairbanks, Alaska*

[6] *Sandwell, D. T., and W. H. F. Smith (2009), Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge segmentation versus spreading rate, J. Geophys. Res., 114, B01411, doi:10.1029/2008JB006008.*

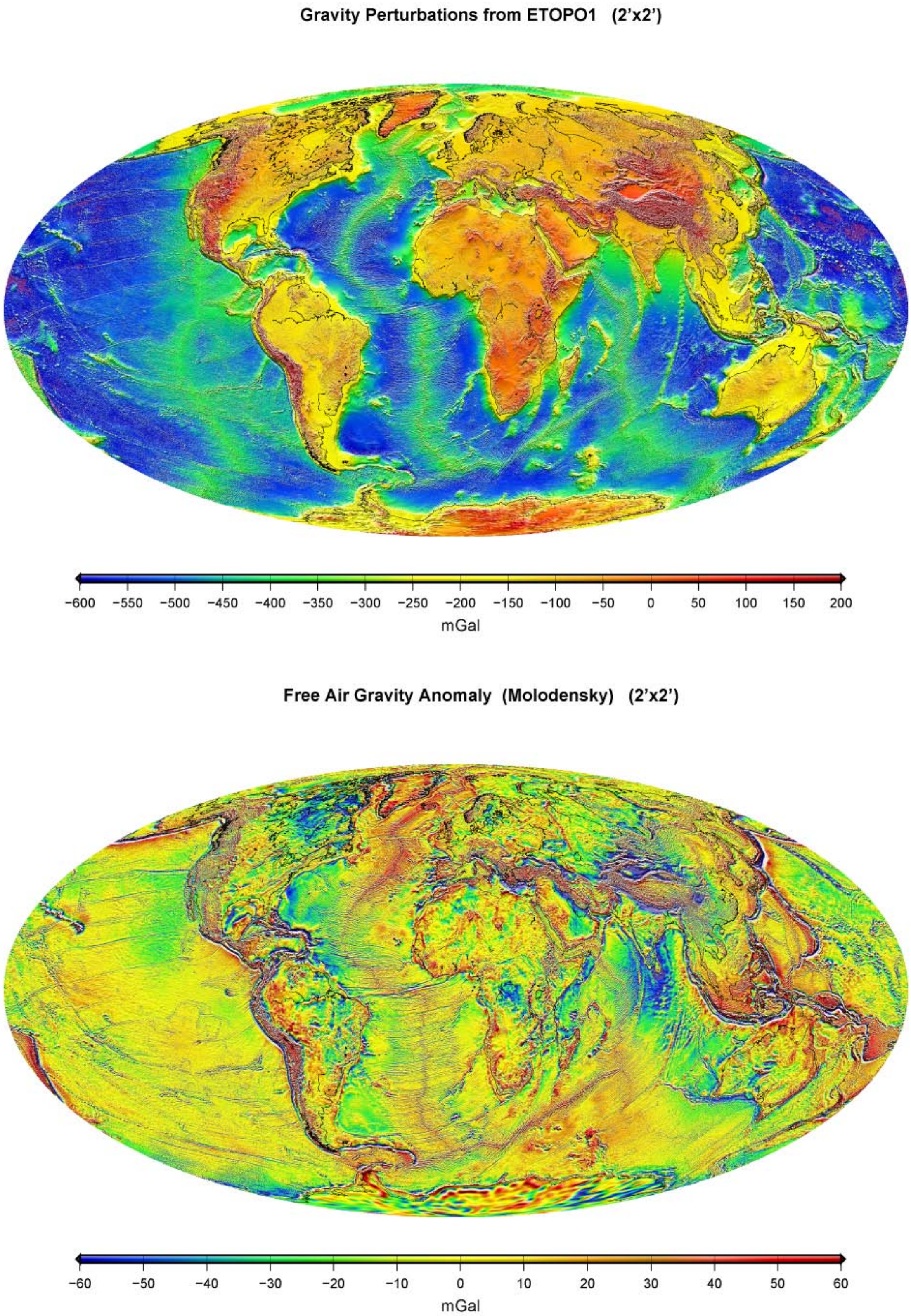

Fig. 3a: Gravity Anomaly Maps computed using high resolution spherical analysis approach (degree 10800). Upper: Gravity perturbations computed in spherical geometry at 1'x1' resolution using ETOPO1 ice surface and bedrock models from the NOAA (National Oceanic and Atmospheric Administration) and taking into account precise characteristics (boundaries and densities) of major lakes, inner seas, polar caps and of land areas below sea level. Lower: Surface gravity anomaly (free air) computed in the context of Molodensky theory and including corrections from the mass of the atmosphere. The gravity information given here is provided by the EGM2008 model.

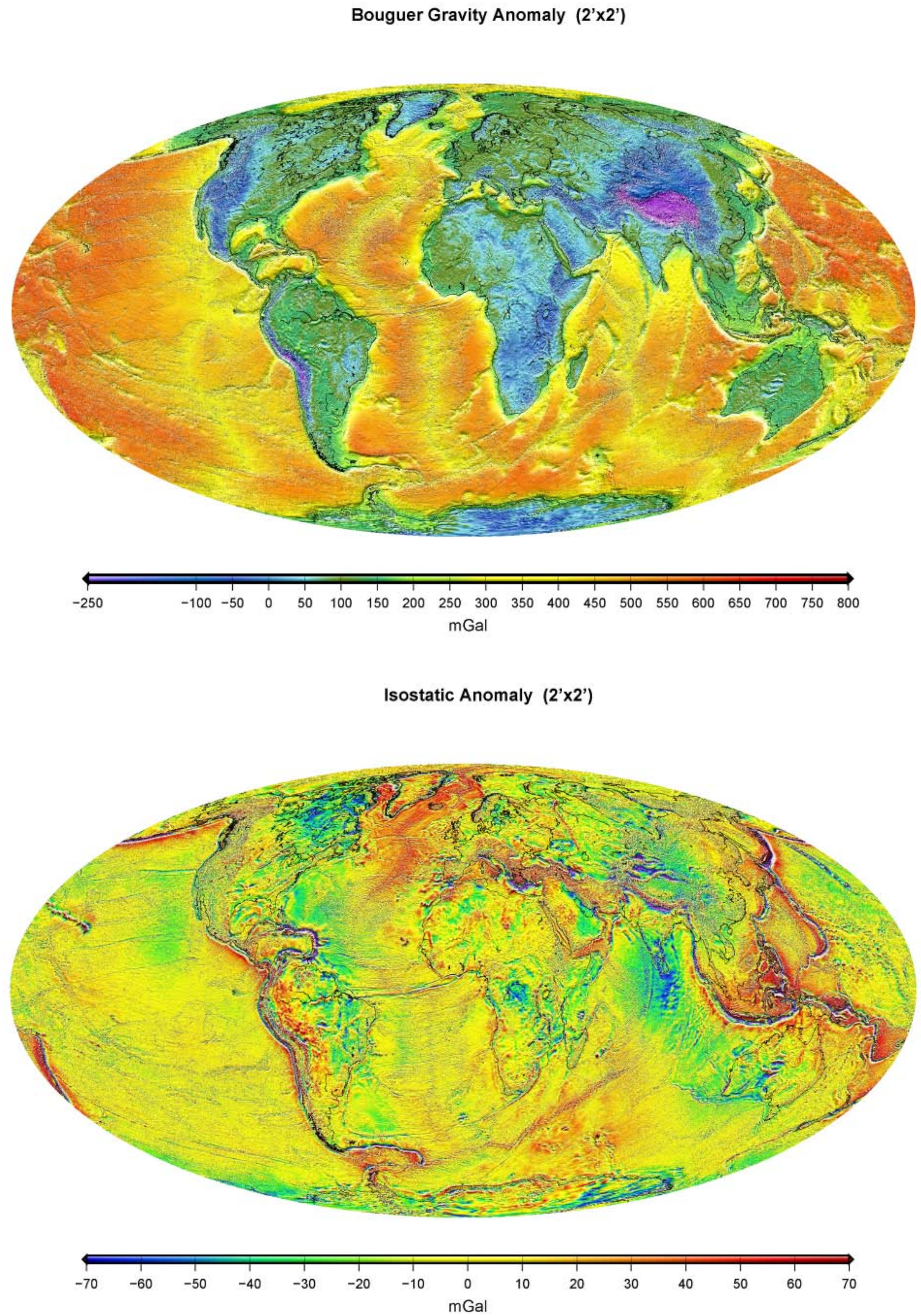

Fig. 3b: Gravity Anomaly Maps computed using high resolution spherical analysis approach (degree 10800). Upper: Complete Bouguer computed in spherical geometry at 1’x1’ resolution using ETOPO1 ice surface and bedrock models from the NOAA (National Oceanic and Atmospheric Administration) and taking into account precise characteristics (boundaries and densities) of major lakes, inner seas, polar caps and of land areas below sea level (sea fig. 3a for gravity perturbations). Lower: Isostatic anomaly computed according to the Airy Heiskanen model in spherical geometry for a constant depth of compensation (T_c) of 30km. The gravity information given here is provided by the EGM2008 model.

For version 1.0 of the WGM project, the gravity information we used is derived from the EGM2008 developed at degree 2160 (as being the best up-to-date candidate of high resolution global gravity model including surface and satellite gravity measurements). We thus have computed a set of global gravity maps and grids including: 1) Complete Bouguer anomaly; 2) Isostatic anomaly; 3) Surface free air anomaly; 4) Gravity perturbation. The surface gravity anomaly (computed in the context of Molodensky theory) also includes corrections from the mass of the atmosphere. The final grid resolution is 2'x2' keeping in mind that terrain corrections are computed at degree 10800 (1'x1') and that gravity model is available only at degree 2160 (5'x5').

The WGM project will consist in a 1/50000000 printed maps and accompanying digital grids of gravity anomalies. Its advances have been presented at: IGFS Retreat (Bertinoro, March 2008), IAG meeting (Creete, June 2008), CGMW General Assembly at the 33th International Geological Congress (Oslo, August 2008). A splinter meeting has been organized jointly by BGI and CGMW at the EGU (European Union in Geosciences) General Assembly (Wien, April 2009). The version 1.0 (that should be published in fall 2011 by CGMW) will be presented at the IUGG General Assembly (27 June – 7 July, 2011, Melbourne - Australia).

As other maps produced by CGMW, updated versions might be done in the future according to the availability of more precise gravity model based on new data from surface surveys (land, marine, airborne) or satellite missions data (GOCE for instance). Obviously, collection of new datasets or regional compilation projects at BGI would be necessary to improve the accuracy of such global gravity maps at short wavelengths. Contributions from national organizations involved in gravity data acquisition or compilation are very welcome!

2.5 Other activities

Participation of BGI to IAG working groups & International meetings

- IUGG 2011 General Assembly *(Melbourne, July 2011)*
- GOCE 2011 Users Workshop *(Munich, Germany, 03/2011)*
- IAG 2010 "Int. Gravity Field Service" *(Fairbanks, USA, Sept. 2010)*
- AGU 2010 "Meeting of Americas" *(Iguazu, Brazil, August, 2010)*
- CGMW 2010 General Assembly / UNESCO *(Paris, France, Feb. 15-16, 2010)*
- 2nd IAG meeting on "Terrestrial Gravimetry" *(St. Petersburg, Russia, June 22-25, 2010)*
- IAG Symposium "Geodesy for Planet Earth" *(Buenos Aires, Arg., 09/2009)*
- EGU (European Union in Geosciences) General Assembly *(Wien, April 2009)*
- IGFS / GGOS Retreat *(March 24-28, 2008. Bertinoro, Italy)*
- FAGS / ICSU Annual Meeting *(April 23-24, 2008. Paris, France)*
- IAG Symposium "GGEO2008" *(23-27 June, 2008. Chania, Crete, Greece)*
- 33th Int. Geol. Congress & CGMW General Assembly *(Oslo, Norway, 6-14 Aug. 2008)*
- IUGG General Assembly – *(Perugia, Italy, July 2007)*
- IAG meeting "Terrestrial Gravimetry, Static and Mobile measurements" *(August 2007. St Petersburg, Russia)*

- 3rd Joint Meeting of the Consultative Committee for Mass and Related Quantities - Gravity Group *(August 2007. St Petersburg, Russia)*

Coordinating meetings (BGI, FAGS, World Gravity Map)

- June 2010: CNES Paris - BGI annual coordinating committee
- June 2009: CNES Paris - BGI annual coordinating committee
- June 2008: CNES Paris - BGI annual coordinating committee
- Feb 2008: CGGM Paris - Working meeting on World Gravity Map project
- Oct. 2007: BRGM and CNES working meeting on Database Inter-operability
- Sept 2007: CGGM Paris - Working meeting on World Gravity Map
- June 2007: CNES Paris - BGI annual coordinating committee

Theoretical and Software developments

- Spherical harmonic modeling to ultra-high degree of Bouguer and isostatic anomalies
- 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 analyses 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. Theoretical aspects are described in Balmino et al. (submitted to Journal of Geodesy).
- QUASPH-TC: Compution of spherical gravity terrain correction by prism integration (G. Balmino, G. Moreau)
- Sea Gravity Adjust (SGA): validation/adjustment of marine gravity data (T. Fayard)

Publication / Diffusion of the Newton's Bulletin

The issue n° 4 of the Newton's Bulletin, published jointly in collaboration with the International Geoid Service (IGeS) has been released in April 2009 (Special Issue: "External Quality Evaluation Reports of EGM08"). Online version on IGeS (http://www.iges.polimi.it) and BGI (http://bgi.omp.obs-mip.fr/index.php/eng/Publications) websites.

International Schools (Participation or Organization)

- BGI/GRGS summer school "Mesure et modélisation du champ de gravité" (see program and presentation at http://grgs.obs-mip.fr/index.php/fre/formation/Ecole-d-ete/2010)
- International Geoid School – IGeS/BGI (La Plata, Argentina, Sept. 2009)
- International Geoid School – IGeS/BGI (Como, Italy, Sept. 2008)

Absolute or relative gravity surveys

Scientific teams associated to BGI have also contributed during period 2007-2011 to various field surveys for absolute or relative gravity measurements in South America (Chile, Peru, French Guiana), Africa (Niger, Benin, Djibouti) and Europe.

2.6 Permanent Staff Central Bureau, Toulouse)

Three persons retired from BGI in the period 2007-2009 (B. Langelier, S. Pecquerie, M. Sarrailh. At the same time, BGI had two new entries (S. Bonvalot, A. Briais) and a third one (F. Reinquin) in Oct. 2009.

BGI permanent staff (full or part time)

S. Bonvalot	*Geophysicist, IRD France (Director)*
G. Balmino	*Geodesist, CNES France*
A. Briais	*Marine Geophysicist, CNRS France*
R. Biancale	*Space geodesy, CNES France*
N. Lestieu	*Secretary, CNRS France*
T. Fayard	*Software developer, CNES France*
F. Reinquin	*Database manager / Software developer, CNES France*
G. Moreaux	*Geodesist, CLS France*

Others contributors

BKG Germany (H. Wziontek, H. Wilmes) / BRGM Orléans (G. Martelet, A. Peyrefitte) / ESGT Le Mans (J. Cali, L. Polidori) / EOST Strasbourg (J. Hinderer, M. Amalvict, B. Luck) / Géosciences Montpellier (R. Bayer, N. Le Moigne, C. Champollion)/ IFREMER Brest (E. Moussat, L. Petit de la Villeon) / IGN LAREG Marne-la-Vallée (O. Jamet, I. Panet, G. Pajot) / IPG Paris (M. Diament, S. Deroussi, J. Penguen) / SHOM Brest (M.F. Lalancette, D. Rouxel, L. Pineau-Guillou).

Publications 2007-2011

Publications (selected articles related to BGI activities)

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International Gravity Field Service (IGFS)

http://www.igfs.net

Chairman: Rene Forsberg (Denmark)
Director of the Central Bureau: Steve Kenyon (USA)

Overview

The International Gravity Field Service (IGFS) is an "umbrella service", coordinating the gravity-related services under the International Association of Geodesy (IAG). The primary purpose of the IGFS is - in addition to the service coordination - to represent gravity field geodesy more unified in relation to other parts of geodesy, notably in connection with the IAG project GGOS – Global Geodetic Observing System.

Current structure of the IGFS

The following service entities are presently active under the IGFS umbrella:

- International Gravimetric Bureau (BGI) – *director S. Bonvalot, France, http://bgi.omp.obs-mip.fr*
- International Geoid Service (IGeS) – *director R. Barzaghi, Italy, http://www.iges.polimi.it*
- International Center for Earth Tides (ICET) – *director J. P. Barriot, Tahiti, http://www.astro.oma.be/ICET/index.html*
- International Center for Global Earth Model (ICGEM) – *director F. Barthelmes, Germany, http://icgem.gfz-potsdam.de/ICGEM/*
- International Digital Elevation Model Service (IDEMS) – *director P. Berry, UK, http://www.cse.dmu.ac.uk/EAPRS/iag/index.html*

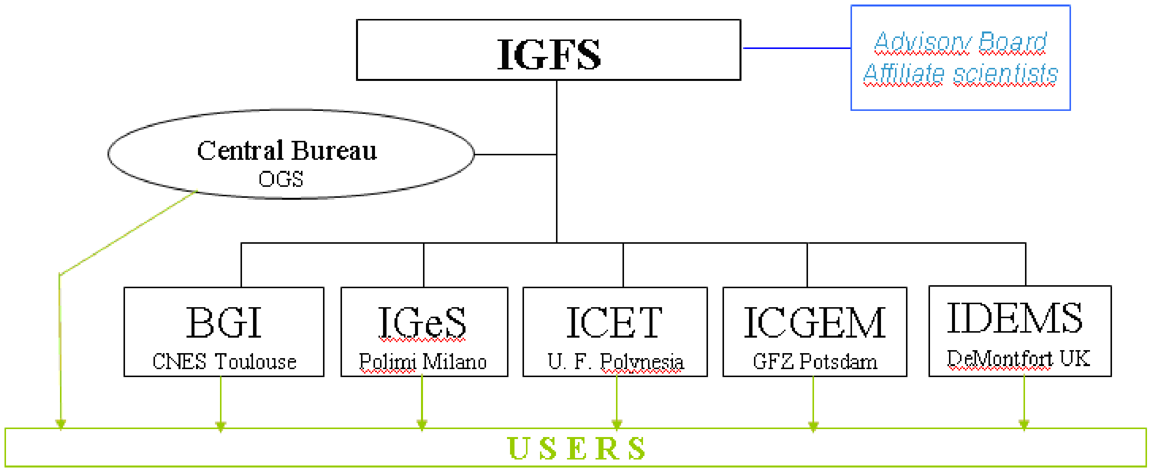
The IGFS *Central Bureau*, under the leadership of *Prof. I. Marson* and *Dr. F. Coren*, is currently being implemented at the OGS (L' Istituto Nazionale di Oceanografia e di Geofisica Sperimentale,), Trieste, Italy, after a successful open bid process. The kick-off for the CB preparations was held in Trieste on March 29, 2011.

In addition the Geodesy and Geophysics Department at National Geospatial-Intelligence Agency (NGA, *chief geodesist S. Kenyon*), serve a special role as an IGFS Technical Center, interacting both with the IGFS services and directly with the scientific community, supplementing especially BGI and IGeS activities in terms of collecting and disseminating gravity and geoid data. The activities of the IGFS is governed by an Advisory Board, consisting of the service directors, IAG representatives (*Y. Fukuda, M. Sideris*) and two members of the IGFS affiliates (*S. Bettadpur and H. Denker).*

In the period 2007-11 the IGFS has had two working groups:

1) *Working Group on Absolute Gravimetry – H. Wilmes, BKG, Germany*
2) *Working Group on Evaluation of Global Earth Gravity Models – J. Huang, NRCan, Canada*

The working groups have 1) coordinated international absolute gravity measurements, including the establishment of standards and a new data base, and 2) set up independent comparisons and validation activities of global spherical harmonic models, notably the ultra-high resolution EGM08 model of the US National Geospatial-Intelligence Agency.



Structure of the IGFS

Activities 2007-11

IGFS has during the period focussed its activities on service coordination, arrangement of scientific meetings, and the participation in the establishment of GGOS. Since the IGFS do not distribute data per se, only a rudimental web site has been maintained, and mainly with formal administrative contents.

A strategy workshop and retreat was held in connection with the GGOS retreat in Bertinoro, Italy, March 2008. This workshop pointed out the need of a more active IGFS, both on the coordination level, and the general outreach. The workshop also identified service activities needing attention, such as establishing a global absolute fundamental gravimetry network, implementing a global vertical datum, making joint satellite gravity field "standard" solutions, the need for conventions and standardization of gravity field products, and establishing a general one-stop portal for non-gravity field specialists, linking to the relevant gravity field services.

To implement the actions, a call was issued through IAG for agencies or universities wishing to host a new IGFS Central Bureau. After some first-round delays, the call was re-issued in spring 2010, and the CB awarded in Sept 2010 to OGS, Trieste, Italy, a major geophysical-oceanographic research organization. The CB is currently initiating its services, with first step being the development of a new IGFS web site, and the subsequent tasks including

- The design and realization of global absolute and superconducting gravimetry
- networks for GGOS and regional densifications
- The facilitation and coordination of regional gravity field determination and data
- exchange projects in order to improve medium to short wavelengths (e.g. Arctic and Antarctica)
- The definition and realization a global vertical datum

- The evaluation and calibration of satellite-derived temporal gravity field variations as well as the improvement of processing of satellite data
- Public outreach on the Earth's gravity field by
  - Organizing meetings and schools on gravity, geoid and related geophysics
  - Making software and tutorials for gravity and geoid analysis available.
  - Establishing and maintaining a web site with links to IGFS Centres

The IGFS participated in the scientific program planning for the "Gravity, Geoid and Earth Observation" meeting in Chania, Greece, June 2008. More than 200 scientists participated in this symposium. The 2nd IGFS gravity field symposium was held in Fairbanks, Alaska, Sept 2009. More than 80 scientists participated in this event. A 3rd symposium is currently being planned in Venice, 2012, as one of the actions of the new CB.

On the coordination side, the IGFS has actively helped in providing information on data sources for the new geopotential reference model EGM08, released by the US NGA (IGFS Technical Centre) in 2008, as well as provided an independent evaluation on pre-release models through the evaluation working group. The EGM08 will serve as a de facto standard for global gravity field and geoid information for a foreseeable future, and also indirectly provides a practical definition of a global vertical datum (to be defined by a dedicated working group under the IAG). A special task has been the improvement and activity coordination of the polar gravity fields, both in the Arctic and Antarctica, in the latter case closely related to the SCAR/IAG special work group on the Antarctic Geoid (M. Scheinert).

Other main activities carried out together with the services include

- Joint bulletin: Newton's Bulletin – joint electronic journal of the BGI and IGeS.
- Geoid schools: New IGeS Geoid School successfully held in Como, Italy and St. Petersburg, Russia (Sept 2008 and June 2010). The IGFS has also been represented in numerous GGOS-related directing board meetings.

Meetings of the IGFS advisory board was held at the IAG 2007 General Assembly in Perugia, as well as at the IGFS Retreat, held in Bertinoro, Italy, March 24-25, 2008, and during the 2nd IGFS Meeting, Fairbanks, Alaska, Sept. 2010.

International Laser Ranging Service (ILRS)

E. C. Pavlis[1], C. E. Noll[2], J. Müller[3], M. R. Pearlman[4], G. Appleby[5]

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[2] *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA3*
[3] *University of Hannover/Institut für Erdmessung, Hannover, GERMANY*
[4] *Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA USA 02138, USA*
[5] *NERC Space Geodesy Facility, Herstmonceux Castle, Hailsham, East Sussex, BN27 1RN, UK*

Contributions of the ILRS

The ILRS was organized as one of the IAG measurement services in 1998. The service collects, merges, analyzes, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets to satisfy the objectives of scientific, engineering, and operational applications and programs. The basic observables are the precise two-way time-of-flight of an ultra-short laser pulse to a retro-reflector array on a satellite or the Moon and the one-way time of flight to a space borne receiver (transponder). These data sets are made available to the community 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. The ILRS generates a standard weekly product of station positions and Earth orientation for submission to the IERS, and produces LAGEOS combination solutions for maintenance of the International Terrestrial Reference Frame (ITRF). The ILRS participates in the Global Geodetic Observing System (GGOS) organized under the IAG.

Organization and Role of the ILRS

The ILRS accomplishes its mission through the following permanent components:

- Tracking Stations and Sub-networks
- Operations Centres
- Global and Regional Data Centres
- Analysis and Associate Analysis Centres
- Central Bureau

The ILRS Tracking Stations range to a constellation of Earth satellites, the Moon, a lunar satellite, and eventually interplanetary spacecraft with state-of-the-art laser ranging systems and transmit their data on an hourly basis to an Operations or Data Centre. Stations are *expected to meet ILRS data accuracy, quantity, and timeliness standards; their data must be regularly and continuously analyzed by at least one Analysis or mission-specific Associate Analysis Centre. Each Tracking Station is typically associated with one of the three regional sub-networks: National Aeronautics and Space Administration (NASA), EUROpean LASer Network (EUROLAS), or the Western Pacific Laser Tracking Network (WPLTN). Many of the stations are now involved with one-way transponder and time transfer activities.*

Operations Centres collect and merge the data from the tracking sites, provide initial quality checks, reformat and compress the data if necessary, maintain a local archive of the tracking data, and relay the data to a Data Centre. Operational Centres may also provide the Tracking Stations with sustaining engineering, communications links, and other technical support. Tracking Stations may perform part or all of the tasks of an Operational Centre themselves.

Global Data Centres are the primary interfaces between the Tracking Stations and the Analysis Centres and outside users. They receive and archive ranging data and supporting information from the Operations and Regional Data Centres, and provide these data on-line to the Analysis Centres. The Data Centres also receive and archive ILRS scientific data products from the Analysis Centres and provide these products on-line to users. Regional Data Centres reduce traffic on electronic networks and provide a local data archive.

Analysis Centres retrieve data from the archives and process them to produce the official ILRS products. They are committed to follow designated standards and produce data products on a routine basis for delivery to the Global Data Centres and the IERS. Analysis Centres routinely process the global LAGEOS-1 and LAGEOS-2 data and compute weekly solutions of station positions and Earth orientation for combination and submission to the IERS. Analysis Centres also provide a second level of data quality assurance in the network. Analysis and Associate Analysis Centres produce station coordinates and velocities, geocentre coordinates, time-varying gravity field measurements, fundamental constants, satellite predictions, precision orbits for special-purpose satellites, regional geodetic measurements, and data products of a mission-specific nature. Associate Analysis Centres are also encouraged to perform quality control functions through the direct comparison of Analysis Centre products and the creation of "combined" solutions using data from other space geodetic techniques. Based on the longest observation time series of all space geodetic techniques, lunar laser ranging (LLR) analysis centres provide results for several dynamic parameters in the Earth-Moon system, e.g., orbital and liberation parameters, reflector and station coordinates, and lunar physics quantities. Moreover, LLR is sensitive to nutation/precession, Earth rotation UT0, and polar motion. Also a variety of relativistic features are studied, like the strong equivalence principle, variation of the gravitational constant, metric or preferred-frame effects.

Central Bureau

The ILRS Central Bureau (CB) is responsible for the daily coordination and management of ILRS activities. It facilitates communications and information transfer and promotes compliance with ILRS network standards. The CB monitors network operations and quality assurance of the data, maintains all ILRS documentation and databases, and organizes meetings and workshops. In order to strengthen the ILRS interface with the scientific community, a Science Coordinator and an Analysis Coordinator within the CB take a proactive role to enhance dialogue, to promote SLR goals and capabilities, and to educate and advise the ILRS entities on current and future science requirements related to SLR. The Science Coordinator leads efforts to ensure that ILRS data products meet the needs of the scientific community and that there is easy online access to published material relevant to SLR science and technology objectives.

The Central Bureau has been actively providing new facilities to expedite communication and performance review, and adding to the technical and scientific database. The Central Bureau maintains the ILRS website, *http://ilrs.gsfc.nasa.gov*, as the primary vehicle for the distribution of information within the ILRS community. The website features details on the ILRS, the satellites and campaigns, individual SLR station characteristics, a scientific and technical bibliography on SLR and its applications, current activities of the Governing Board, Working Groups, and Central Bureau, meeting minutes and reports (including annual reports), tracking plans, and more. Reports and charts are available on the Station Information pages to monitor station and network performance and as a means of providing engineering insight and as a tool for operational planning. Station operators, analysts, and other ILRS groups can view these reports and plots to quickly ascertain how individual stations are performing as well as how the overall network is supporting the various missions. Detailed information on satellites supported by the ILRS is also available on the ILRS website, organized by mission.

Governing Board

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. There are sixteen members of the Governing Board (GB) - three are ex-officio, seven are appointed, and six are elected by their peer groups (see Table 1). A new Board was installed in May 2011 at the 17th International Workshop on Laser Ranging in Bad Kötzting, Germany. We remember with sadness that over the past three years the ILRS has lost three of its founding colleagues: Werner Gurtner (Chair of the ILRS Governing Board from 2002-2009), Wolfgang Seemüller (Data Centre representative from 1998-2010), and Yang Fumin (WPLTN representative for several years since 1998).

Working Groups

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG) carry out policy formulation for the ILRS. At its creation, the ILRS established four standing WGs: (1) Missions, (2) Data Formats and Procedures, (3) Networks and Engineering, (4) Analysis, and (5) Transponders for lunar and planetary ranging. 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.

The Missions WG, with a set of evolving formal and standardized documentation, works with new satellite missions that seek approval for SLR observing support. The WG makes its recommendation based on whether such support is deemed necessary for the success of the mission and that the requested support is within the operational capabilities of the network. The WG also calls upon the expertise of the Analysis Working Group and Signal Processing Study Group to make a proper assessment during this process, and works with the new mission personnel and campaign sponsors to develop and finalize tracking plans and to establish recommended tracking priorities.

The Data Formats and Procedures WG completed the implementation of the Consolidated Prediction Format (CPF) for improved predictions on a much wider variety of laser ranging targets including (1) Earth-orbiting retro-reflector satellites, (2) Lunar reflectors, (3) asynchronous and synchronous transponders. The new expanded format capability, with more complete modeling representation, removes the need for drag and special manoeuvre files as well as virtually all satellite time-bias corrections, a great benefit particularly on lower orbiting satellites. The working group also designed and implemented the Consolidated laser Ranging Data format (CRD), which accommodates full rate, sampled engineering, and normal point data types for artificial satellite, lunar, and now, one-way transponder ranging data. This format change was required to incorporate higher precision fire times for transponder ranging and to more efficiently represent full rate data from kHz laser-repetition-rate stations. It was designed to be flexible and expandable and to incorporate additional statistical and configuration data unavailable in the earlier formats. Implementation and validation of the CRD format is being monitored by the WG through a cooperative effort with the OCs, DCs, and AGs (organized through the Analysis WG). The Working Group has also coordinated the implementation of new features to support mission support restrictions for accommodate satellite vulnerability.

Table 1. ILRS Governing Board (as of May 2011)

Zuheir Altamimi	Ex-Officio, President of IAG Commission 1	France
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 Carter	Appointed, NASA	USA
Jan McGarry	Appointed, NASA	USA
Ramesh Govind	Appointed, WPLTN	Australia
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	UK
Georg Kirchner	Elected, At-Large, Networks and Engineering Working Group Coordinator	Austria

The Networks and Engineering WG is assisting stations to upgrade to high repetition rate lasers and to implement some adaptations to the exiting normal point format to accommodate this high rate data. Software has been made available to the stations for on-site normal point data quality verification. Work continued on the bias problems with the Stanford SR620 counters, but laboratory calibrations did not prove to be sufficiently stable to reduce biases below the several cm level. The Signal Processing Study Group completed its modeling of the LAGEOS and Etalon retro-reflector arrays and the AWG is now evaluating the new models.

The Networks and Engineering WG is spearheading a number of engineering procedural studies for the improvement of network operations.

The Analysis WG completed its pilot projects to assess, document and resolve differences among analysis products from the Analysis and Associate Analysis Centres. Nine institutions have qualified as Analysis Centres; additional centre has expressed interest. A Combination Centre and a Backup Combination Centre have been in operation since 2004. In June 2010, DGFI retired was no longer able to continue in its role as the Backup Centre and the activity, and software and associated scripts were transferred to the JCET. The transfer process was completed in October 2010, and JCET has been producing the backup combination product since that time. The WG has developed and implemented the process to deliver LAGEOS and Etalon derived site positions and EOP to the IERS as required on a weekly basis. A 1983-2008 reanalysis of the LAGEOS-1 and -2 and Etalon-1 and -2 data were provided to the IERS in support of the development of ITRF2008. Over the past three years an analogous daily product was developed, based on the data from the immediate prior seven days. This product is primarily for use by the IERS EOP Prediction Service at USNO, providing as fresh as possible SLR-derived EOP. Work is underway to add additional official ILRS products including precision orbits and certified data corrections, and the improvement of the underlying models. During the ILRS/AWG meetings LLR activities are also reviewed.

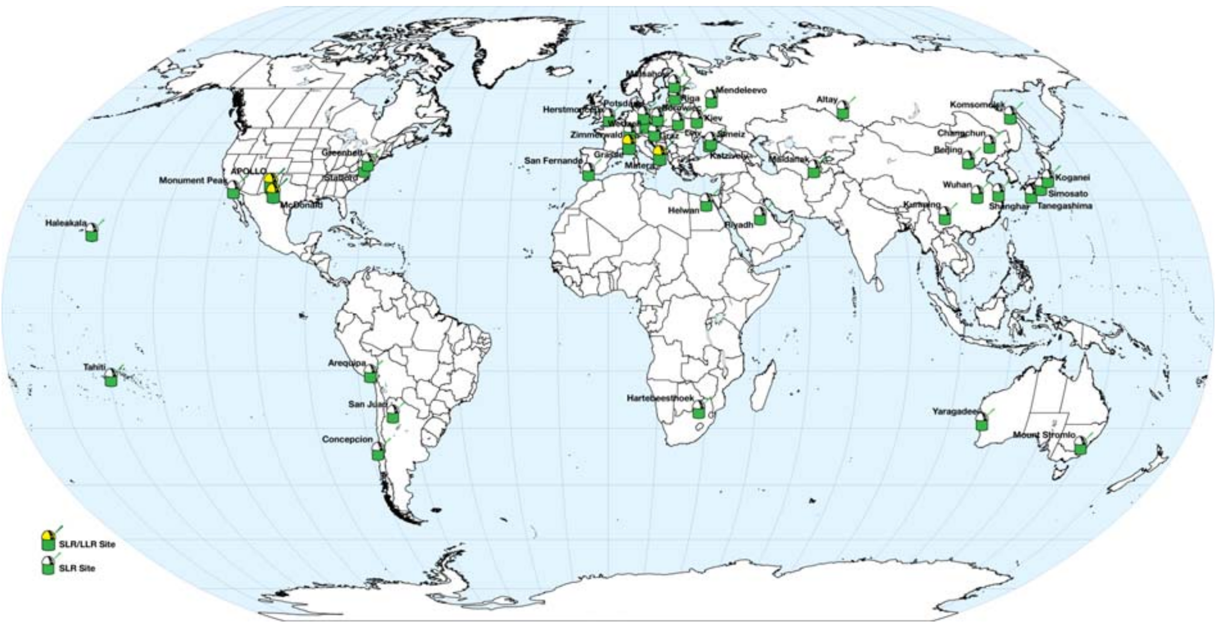

Figure 1. ILRS network (as of May 2011).

The Transponder Working Group has been involved in one-way ranging and time transfer programs. The first time transfer experiment T2L2 is under way on the satellite Jason-2; 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 transponder working group also actively supports LRO, where one-way laser ranging from the ILRS Network is being used to improve the orbit calculations for the laser altimeter and surface positioning. Ground-based hardware simulations for planning and designing laser transponder operations at interplanetary distances have been successfully carried out within the frame of the Transponder Working Group. Results are promising and currently under review at "Planetary and Space Science". A BLITS type satellite at 1000 – 2000 km altitude could help this activity with its low satellite signature characteristics.

ILRS Network

Satellite Laser Ranging (SLR) Network

The present ILRS network includes over forty stations in 23 countries (see Figure 1). Stations designated as operational have met the minimum ILRS qualification for data quantity and quality. Several stations dominated the network with the Yarragadee, Mt Stromlo, Zimmerwald, and Changchun stations being the strongest performers. From start-up in 2005, the San Juan station performance has been dramatic and is now second in performance to Yarragadee. There has also been noticeable improvement at Matera, Graz, Concepcion, Shanghai, Herstmonceux and Monument Peak. The improved orbital coverage over the Pacific region should have a very fundamental impact on our ILRS data products. In addition to San Juan, the rest of the Chinese SLR network continues its very strong support for the ILRS network. The Riyadh station had been doing very well, but it is now down for major renovations. This station is very critical to the ILRS network because it is the only SLR station on the Arabian Peninsula. Data started flowing again from the Russian Stations, including the new station at Altay and most recently Arhiz. New stations are currently being installed in Zelenchukskaya and Irkutsk. The TIGO system in Concepción, Chile amazingly returned to operation within three months following the nearby magnitude 8 earthquake in February 2010. SLR data are again flowing from the new MEO station at Grasse, France; the French Transportable Laser System (FTLRS) conducted a campaign in Ajaccio, France in 2009 to support altimeter calibration and validation for Jason; other occupations were performed in Grasse and Paris, France. The station is now in Tahiti for a co-location with Moblas-8.

Several stations have moved to higher repetition rate lasers. In the spring of 2008, the Zimmerwald station introduced its new 100 Hz system and rapidly became one of the major data producers in the network. The Graz system continues its impressive performance with 2 kHz operations. A 2 kHz laser has been added to the Herstmonceux station; several Chinese stations have upgraded to 1 kHz systems and several other stations have similar upgrades underway. High repetition rate systems will be the model of the future with SLR; requirements to track many GNSS satellites coupled with the additional Geosynchronous and LEO satellites anticipated over the next several years will require the network stations to accumulate normal points much faster and rely more heavily on rapid interleaving.

A number of stations using the Stanford Counter have experienced timing (range) errors in some cases as large as a centimetre. Calibration procedures have not been successful in addressing the problem, and time-dependent, empirical, range corrections have been made under the guidance of the Analysis WG. Several of these stations have now installed new epoch timing units – in particular the units now made by the University of Latvia. Additional stations have also moved to using SPAD detectors.

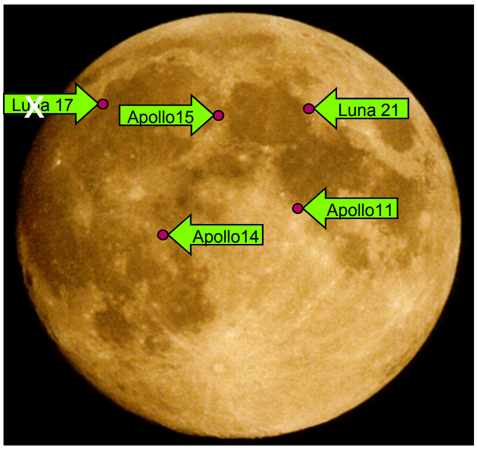

Figure 2. Retro-reflector sites on the Moon, Luna 17 had never been successfully tracked, until it was "rediscovered" from LRO images in 2010.

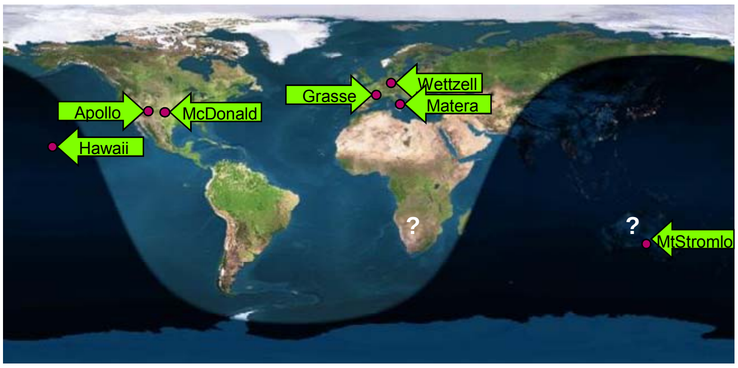

Figure 3. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future.

Lunar Laser Ranging (LLR) Network

During three U.S. American Apollo missions (11, 14, and 15) and two un-manned Soviet missions (Luna 17 and Luna 21), retro-reflectors were deployed near the landing sites between 1969 and 1973 (Figure 2). LLR ranging has continuously provided data for about 41 years, generating about 17000 normal points. LLR is used to determination parameters describing lunar ephemeris, lunar physics, the Moon's interior, various reference frames, Earth orientation parameters and the Earth-Moon dynamics. LLR has also become one of the strongest tools for testing Einstein's theory of general relativity in the solar system; no violations of general relativity have been found so far. However, the basis for all scientific analyses is more high quality data from a well-distributed global LLR network.

From all of the ILRS observatories (nearly 40), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (Figure 3). The McDonald Observatory in Texas, USA, the Apache Point Observatory, New Mexico, USA, and the Observatoire de la Côte d' Azur, France are the only currently operational LLR sites. The latter returned to action in September 2009, after several years of renovation. The McDonald observatory has had major LLR funding problems, and as a result, LLR operations have recently slowed to a much reduced level. The new Apache Point Lunar Laser Observatory (APOLLO) in New Mexico, USA, became operational in 2005 and has since been by far the largest producer of lunar ranging data. Built with a 3.5 m telescope, the station is designed for mm accuracy ranging. A new set of data from APOLLO was released in 2011 with a total of ~940 normal points. The data are now available in the newly adopted ILRS CRD data format through a reformatting effort at the McDonald Observatory. The measurement statistics of the major lunar observatories between 1970 and 2011 is shown in Figure 4.

Other modern laser ranging stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station in Italy in 2010, but all of them suffer from technical problems or funding restrictions. The Wettzell observatory in Germany plans to resume lunar tracking by end of 2011. The Australian station at Mt. Stromlo is expected to participate in the future, and there are plans for establishing lunar capability at the South African site at Hartebeesthoek.

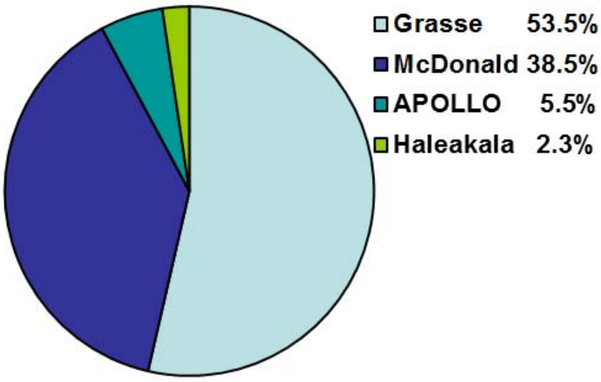

Figure 4. Measurement statistics of lunar observatories between 1970 and 2011

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.
At the Observatoire de Paris, an "assisting tool" (http://polac.obspm.fr/PaV) has been developed to support lunar tracking by providing predictions of future LLR observations as well as a validation of past LLR normal points.

ILRS Tracking Priorities and Mission Support

The ILRS is currently tracking 30 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions (see Table 2). The stations with lunar capability are also tracking the lunar reflectors. In response to tandem missions (e.g., GRACE-A/-B) 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.

Table 2. ILRS Tracking Priorities (as of May 2011)

Satellite Priorities					
Priority	**Mission**	**Sponsor**	**Altitude (km)**	**Inclination (degrees)**	**Comments**
1	GOCE	ESA	295	96.7	
2	GRACE-A, -B	GFZ/JPL	485-500	89	Tandem mission
3	CryoSat-2	ESA	720	92	
4	TanDEM-X	Infoterra/DLR/ GFZ/CSR	514	98	Tandem with TerraSAR-X
5	TerraSAR-X	Infoterra/DLR/ GFZ/CSR	514	97.44	Tandem with TanDEM-x
6	Envisat	ESA	796	98.6	Tandem with ERS-2
7	ERS-2	ESA	800	98.6	Tandem with Envisat
8	BLITS	Russia	832	98.77	
9	Jason-1	NASA/CNES	1,350	66.0	Tandem with Jason-2
10	Jason-2	NASA, CNES,	1,336	66.0	Tandem with Jason-1

		Eumetsat, NOAA			
11	Larets	IPIE	691	98.2	
12	Starlette	CNES	815-1,100	49.8	
13	Stella	CNES	815	98.6	
14	Ajisai	NASDA	1,485	50	
15	LAGEOS-2	ASI/NASA	5625	52.6	
16	LAGEOS-1	NASA	5850	109.8	
17	QZS-1	JAXA	32,000-40,000	45	WPLTN tracking only
18	Beacon-C	NASA	950-1,300	41	
19	Etalon-1	Russian Federation	19,100	65.3	
20	Etalon-2	Russian Federation	19,100	65.2	
21	COMPASS-M1	China	21,500	55.5	
22	GLONASS-115	Russian Federation	19,100	65	Replaced GLONASS-99 on 03/31/2009
23	GLONASS-125	Russian Federation	19,100	65	Replaced GLONASS-120 on 05/04/2011
24	GLONASS-102	Russian Federation	19,100	65	Replaced GLONASS-89 on 05/04/2007
25	GPS-36	US DoD	20,100	55.0	
26	GIOVE-A	ESA	29,601	56	
27	GIOVE-B	ESA	23,916	56	
28	GLONASS-109	Russian Federation	19,100	65	
29	GLONASS-110	Russian Federation	19,100	65	
30	GLONASS-118	Russian Federation	19,100	65	

Lunar Priorities

Priority	Retroreflector Array	Sponsor	Altitude (km)
1	Apollo 15	NASA	356,400
2	Apollo 11	NASA	356,400
3	Apollo 14	NASA	356,400
	Luna 21	Russian Federation	356,400
	Luna 17	Russian Federation	356,400

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 5). New missions added during this reporting period included: ANDE, CryoSat-2, TanDEM-x, BLITS, QZS-1, and additional GLONASS satellites. The network continued to support the GLONASS program: GLONASS-125 replaced GLONASS-120 in May 2011. Three additional GLONASS satellites were added to the ILRS tracking list in September 2010 at the request of the Centre for Orbit Determination (CODE). ANDE Castor and Pollux, NRL satellites that monitored the thermosphere neutral density, were tracked from August 2009 until March and April 2010 when the two satellites re-entered the Earth's atmosphere. PROBA-2, an ESA mission validating spacecraft technology concepts, has been tracked in campaign mode by the ILRS network in 2010 and 2011. CHAMP, launched in July 2000 re-entered Earth's atmosphere in September 2010.

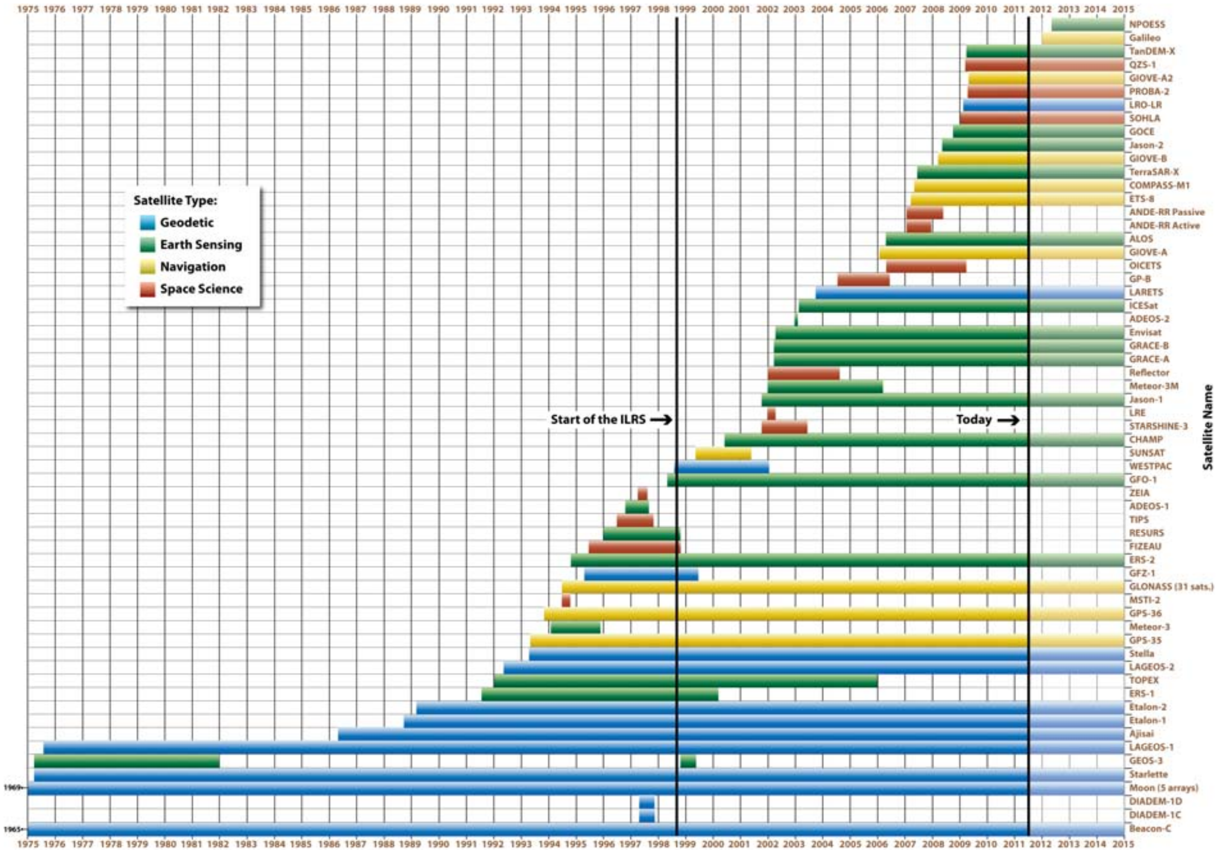

Figure 5. The past, current, and future tracking roster for the ILRS network.

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 retro-reflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important inter-comparison and calibration data with onboard microwave navigation systems.

At one time, the main task of the international SLR Network was the tracking of dedicated geodetic satellites (LAGEOS, Starlette, etc.). Although the ILRS has had requests to revive tracking on older satellites already in orbit (e.g., Beacon-C) to further refine the gravity field with improved accuracy laser data, new requests for tracking are now coming mainly for active satellites including those in the GNSS complexes. The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS website. 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 retro-reflector 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 3 along with their sponsors, intended application, and projected launch dates.

Table 3. Upcoming Missions (as of May 2011)

Mission	Sponsor	Planned Launch Date	Mission Duration (years)	Altitude (km)	Inclination (degrees)	Application
KOMPSAT-5	KARI	2011	5	550	97.6°	Earth observation
RadioAstron	Lavochkin Assoc., Russia	2011	5	500-350,000	51.4°	Interferometry
SARAL	CNES, ISRO	2011	5	814	98.55°	Altimetry, water surfaces
NPOESS	NOAA, NASA, DoD	2013	7	833	98.7°	Sea surface height

Once tracking support is approved by the Governing Board, the Central Bureau works with the new missions to develop a Mission Support Plan detailing the level of tracking, the schedule, the points of contact, and the channels of communication. New missions normally receive very high priority during the acquisition and checkout phases and are then placed at a routine priority based on the satellite category and orbital parameters. After launch, reports with network tracking statistics and operational comments are issued weekly. The Central Bureau monitors progress to determine if adequate support is being provided. New mission sponsors (users) are requested to report at the ILRS meetings on the status of ongoing campaigns, including the responsiveness of the ILRS to their needs and on progress towards achieving the desired science or engineering results.

One interesting application for SLR is the tracking support of the Lunar Reconnaissance Orbiter (LRO), launched June 17, 2009. The LRO mission objective is to conduct investigations that are targeted to prepare for and support future exploration of the Moon. The LRO Laser Ranging (LR) system uses one-way range measurements from laser ranging stations on the Earth to LRO to determine LRO position at sub-meter level with respect to Earth and the centre of the Moon (on the lunar near-side or whenever possible). The LR aspect of the mission allows for the determination of a more precise orbit than possible with S-band tracking data alone. The flight system consists of a receiver telescope, which captures the uplinked laser signal and a fiber optic cable, which routes it to the LOLA instrument. The LOLA instrument captures the arrival time of the laser signal records that information and provides it to the onboard LRO data system for storage and/or transmittal to the ground through the RF link. As of May 2011, ten stations have provided over 1,070 hours of one-way laser ranging data.

Official Analysis Products

The ILRS products consist of SINEX files of weekly station coordinates and daily Earth Orientation Parameters (x-pole, y-pole and excess length-of-day, LOD) estimated from 7-day arcs. Two types of products are distributed each week: a loosely constrained estimation of coordinates and EOP and an EOP solution, derived from the previous one and constrained to an ITRF, currently ITRF2005S. 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 May 2011. Each official weekly ILRS solution is obtained through the combination of weekly 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
- GFZ, GeoForschungsZentrum Potsdam
- GRGS, Observatoire de Cote d'Azur
- JCET, Joint Center for Earth Systems Technology
- NSGF, NERC Space Geodesy Facility

These ACs have been certified through a benchmark process developed by the AWG. The official Primary Combination Centre (ASI) and the official Backup Combination Centre (DGFI through 2010, JCET since 2011) follow strict timelines for these routinely provided products.

In addition to operational products, solutions have been provided covering the period back to 1983. A new activity has been established to provide similar solutions on a daily basis, with a minimal 2-day delay, possibly even one day, primarily to provide IERS' NEOS center with robust EOP observations for their weekly predictions. 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*).

ILRS Contribution to ITRF2008

The time series of weekly solutions from 1983 to the end of 2008, produced by the Primary Combination Centre, was delivered to IERS/ITRS as an official ILRS contributed data set for ITRF2008. Several months of joint work within the ILRS AWG were devoted to the quality assessment of the contributed solutions from the ILRS ACs as well as the final combined solutions from the ILRS CCs. The preliminary version of the combined ILRS time series was submitted in April 2009, and through continuous interaction with the ITRS Combination Centres, revised versions were contributed through the summer, until a satisfactory combination was reached. Figures 6 and 7 show a summary and illustration of the origin and scale rate differences with respect to the old ITRF realization, ITRF2005S (actually the SLRF2005 frame, a derivative of ITRF2005, scaled for compliance to the SLR scale and merged with the ITRF2000 normal equations to cover all sites tracking in the early 80's which were not part of ITRF2005S.

The new time series take advantage of improved modeling of systematic errors derived after an extensive AWG effort to explain all systematic differences from the previous ITRF and to account for all known engineering corrections. All this information have been compiled into a database that is now online in the form of a quasi-SINEX-formatted file, accessible from the ILRS web pages on "Data Corrections". The database is maintained with future releases indicated in the file with a "Release Date" for the benefit of all SLR data users. The description of the official contribution to ITRF2008 is available on the ILRS and ITRS web pages upon finalization and adoption of ITRF2008. In addition to ITRF2008, the ILRS AWG has compiled a companion TRF, SLRF2008, which will be accessible from the ILRS web pages and will replace SLRF2005. This TRF will be a "living" version of ITRF2008 in the sense that new sites will be incorporated as they come online, using ILRS-derived coordinates from the initial set of data they provide and improved at infrequent intervals to maintain the uniform quality of the data set.

Tx	Tx_dot mm/yr	σ_Tx_dot mm/yr	WRMS (res) mm	Ty	Ty_dot mm/yr	σ_Ty_dot mm/yr	WRMS (res) mm
asi	-0,35	0,02	5,37	asi	-0,12	0,02	4,50
dgfi	-0,57	0,03	6,27	dgfi	0,09	0,03	5,78
ga	0,05	0,02	4,18	ga	0,17	0,02	4,29
gfz	-0,49	0,03	5,46	gfz	0,11	0,02	4,98
grgs	-0,32	0,03	4,50	grgs	0,04	0,03	3,71
jcet	-0,18	0,02	4,19	jcet	0,10	0,02	3,99
nsgf	-0,41	0,03	6,70	nsgf	-0,08	0,03	7,26
C	-0,29	0,02	4,16	C	0,06	0,02	3,82

Tz	Tz_dot mm/yr	σ_Tz_dot mm/yr	WRMS (res) mm	D_Sc	D_Sc_dot mm/yr	σ_D_Sc_dot mm/yr	WRMS (res) mm
asi	0,24	0,06	10,38	asi	-0,31	0,02	4,26
dgfi	0,88	0,08	13,07	dgfi	-0,48	0,03	4,98
ga	0,83	0,04	8,58	ga	-0,22	0,01	3,64
gfz	0,36	0,06	10,89	gfz	-0,08	0,03	4,71
grgs	0,06	0,02	7,11	grgs	-0,46	0,02	3,34
jcet	0,25	0,04	8,32	jcet	-0,23	0,01	2,88
nsgf	0,11	0,08	14,06	nsgf	-0,62	0,03	6,00
C	0,38	0,03	7,45	C	-0,30	0,01	3,15

Figure 6. Origin offset rates of the weekly product from each AC and the combination (C) with respect to SLRF2005 (ITRF2005S): 1983-2009.

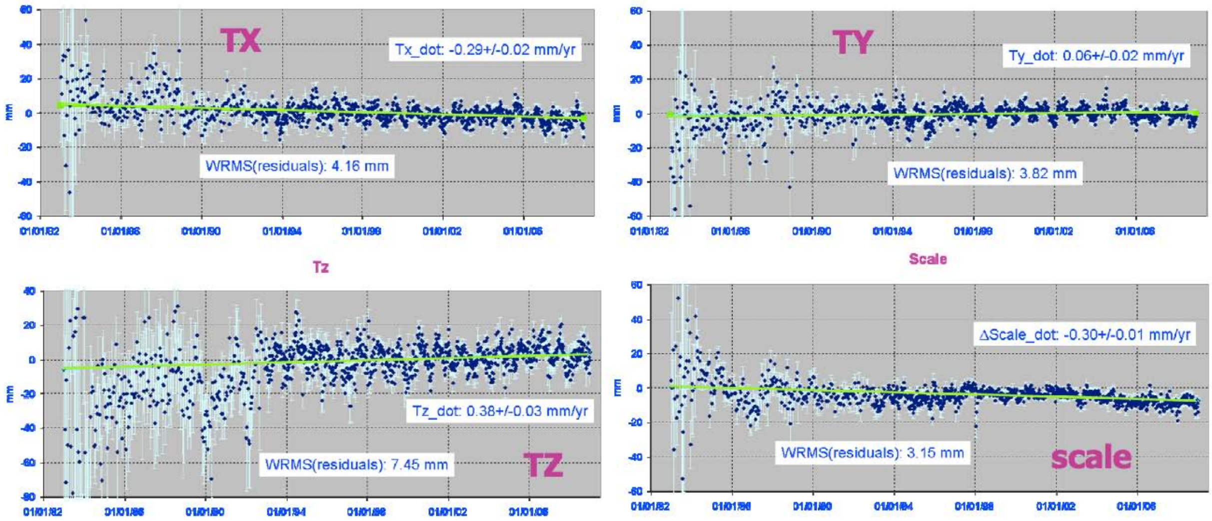

Figure 7. Origin and scale differences of the weekly combination product with respect to SLRF2005 (ITRF2005S): 1983–2009.

The Official ILRS Combination (ILRSA)

ASI produces the official ILRSA combination solution and it is routinely compared with the backup combined solution ILRSB produced by DGFI (by JCET since 2010) following a fundamentally different approach. Comparisons show a good agreement between the two solutions and absence of any systematic differences.

1. mean 3D wrms of the site coordinates residuals with respect to SLRF2005 (Table 4 and Figure 8);
2. mean differences of the translation and scale parameters with respect to SLRF2005 (Table 5);
3. EOP residuals with respect to EOP 05 C04 (Table 6) for the year 2008.

Table 4. 3D wrms of the site coordinates residuals w.r.t. SLRF2005

	ILRSA(mm)	
	1983-1993	1993-2008
All sites (mean)	52	10
Core sites (mean)	15	7

Table 5. Translation and scale differences between ILRSA and SLRF2005

	TX(mm)	TY(mm)	TZ(mm)	Scale(mm)
Weighted Mean	-2 ± 4	0 ± 4	0 ± 9	6 ± 4
WRMS	3	3	6	2

Table 6. EOP daily residuals with respect to EOPC04 for ILRSA

ILRSA	1983-1993		1993-2008	
	WMEAN	**WRMS**	**WMEAN**	**WRMS**
EOP-X (mas)	-0.058	0.468	-0.024	0.156
EOP-Y (mas)	-0.092	0.434	0.030	0.131
LOD (ms)	-0.012	0.061	0.001	0.024

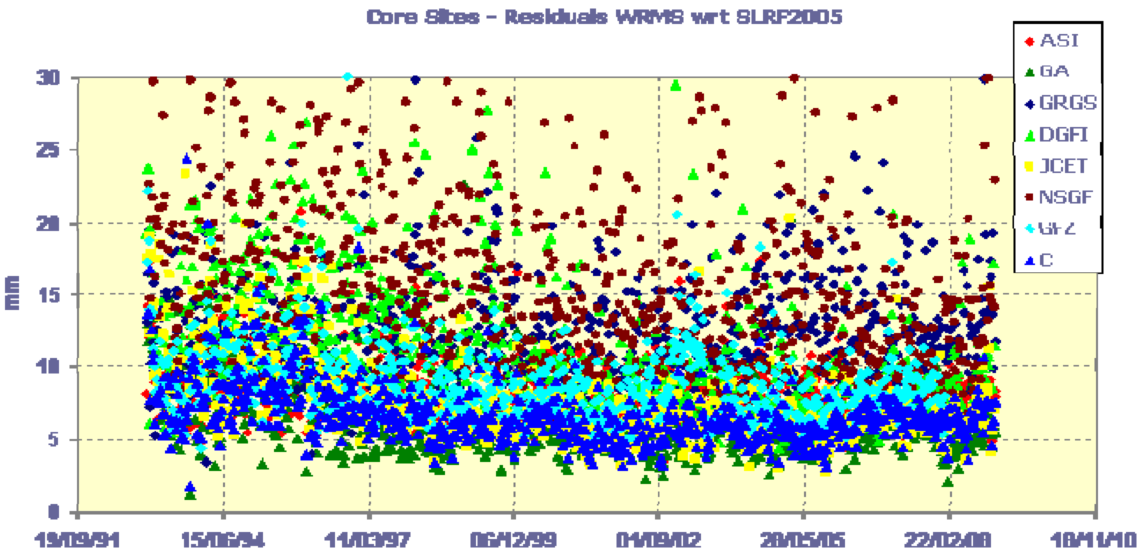

Figure 8. 3D wrms of the core site coordinates residuals with respect to SLRF2005.

The individual as well as the combinations of the ILRS ACs and CCs are monitored on a weekly basis with a graphical and a statistical presentation of these time series through a dedicated website hosted by the JCET AC at http://geodesy.jcet.umbc.edu/ILRS_QCQA/.

Table 7. Recent ILRS Meetings (as of May 2011)

Timeframe	Location	Meeting
September 2009	Metsovo, Greece	International Technical Laser Workshop on SLR Tracking of GNSS Constellation
December 2009	San Francisco CA, USA	ILRS Governing Board Meeting
May 2010	Vienna, Austria	ILRS Governing Board Meeting ILRS Working Group Meetings Analysis Working Group Meeting
May 2011	Bad Kötzting, Germany	17^{th} International Workshop on Laser Ranging 15^{th} ILRS General Assembly and WG Meetings ILRS Governing Board Meeting Analysis Working Group Meeting ILRS Working Group Meetings

Meetings and Reports

The ILRS organizes regular meetings of the Governing Board and General Assembly; General Assemblies are open to all ILRS Associates and Correspondents. 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 7. 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.

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: Harald Schuh (Austria)
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 2007−2011. In March 2009 the IVS completed its 10th year of its existence. The anniversary was celebrated in a special event in Bordeaux, France. Two Directing Board elections were held, one in Dec2008/Jan2009 and the other in Dec2010/Jan2011. The VLBI2010 Committee (V2C) published a progress report on the "Design Aspects of the VLBI2010 System". The frequency range for the next generation system was fixed to ~2.2–14 GHz. The VLBI2010 Project Executive Group (V2PEG) was formed to give strategic leadership to the VLBI2010 project. The Second Realization of the International Celestial Reference Frame (ICRF2) was adopted by the International Astronomical Union (IAU) and replaced the previously used first realization (ICRF) effective 1 January 2010. The IVS contributed to the generation of the ITRF2008 reference frame with session-wise, datum-free normal equations based on a combination of the results from seven IVS Analysis Centers.

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. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing the 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. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI's technical limitations. VLBI, as the unique technique for providing a celestial reference frame and for deriving the full set of Earth rotation parameters, plays the fundamental role of generating the basis for many applications and research in the geo-sciences.

Table 1. Members of the IVS Directing Board during the report period (2007−2011).

a) *Current Board members (June 2011)*

Directing Board Member	Institution, Country	Functions	Recent Term
Dirk Behrend	NVI, Inc./NASA GSFC, USA	Coordinating Center Director	—
Alessandra Bertarini	IGG Bonn, Max Planck Institute for Radio Astronomy, Germany	Correlators and Operation Centers Representative	Feb 2011 − Feb 2015
Patrick Charlot	Bordeaux Observatory	IAU Representative	—
Jesús Gómez González	National Geographical Institute, Spain	At Large Member	Feb 2011 − Feb 2013
Rüdiger Haas	Onsala Space Observatory, Sweden	Technology Development Centers Representative	Feb 2009 − Feb 2013
Hayo Hase	BKG, Germany; TIGO, Chile	Networks Representative	Feb 2007 − Feb 2015
Ed Himwich	NVI, Inc./NASA GSFC, USA	Network Coordinator	—
Shinobu Kurihara	Geospatial Information Authority, Japan	At Large Member	Sep 2010 − Feb 2013
Chopo Ma	NASA Goddard Space Flight Center, USA	IERS Representative	—
Axel Nothnagel	University of Bonn, Germany	Analysis Coordinator	—
Harald Schuh	Technical University Vienna, Austria	IAG Representative, Chair	—
Fengchun Shu	Shanghai Astronomical Observatory, China	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	—

b) *Previous Board members in 2007−2011*

Andrey Finkelstein	Institute of Applied Astronomy, Russia	At Large Member	Feb 2007 − Feb 2011
Yoshihiro Fukuzaki; Kazuhiro Takashima	Geospatial Information Authority, Japan	Networks Representative	Feb 2007 − Feb 2009
Kerry Kingham	U.S. Naval Observatory, USA	Correlators and Operation Centers Representative	Feb 2007 − Feb 2011
Arthur Niell	Haystack Observatory, USA	Analysis and Data Centers Representative	Feb 2005 − Feb 2009
Ray Norris	CSIRO Australia Telescope Nacional Facility, Australia	FAGS Representative	—
Bill Petrachenko	Natural Resources Canada	Technology Development Centers Representative	Feb 2005 − Feb 2009
Kazuhiro Takashima	Geospatial Information Authority, Japan	At Large Member	Feb 2009 − Sep 2010
Xiuzhong Zhang	Shanghai Astronomical Observatory, China	At Large Member	Feb 2007 − Feb 2011

Being tasked by IAG and IAU with the provision of timely, 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. During the report period two Directing Board elections were held.

The IVS organizes biennial General Meetings and biennial Technical Operations Workshops. Other workshops such as the Analysis Workshops and VLBI2010 Working 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 (2007-2011).

Time	**Meeting**	**Location**
14 April 2007	8th IVS Analysis Workshop	Vienna, Austria
15 April 2007	2nd VLBI2010 Working Meeting	Vienna, Austria
30 April – 3 May 2007	4th IVS Technical Operations Workshop	Westford, MA, USA
14 September 2007	3rd VLBI2010 Working Meeting	Bonn, Germany
3-6 March 2008	5th IVS General Meeting	Saint Petersburg, Russia
5 March 2008	VLBI2010 Committee Meeting	Saint Petersburg, Russia
7 March 2008	9th IVS Analysis Workshop	Saint Petersburg, Russia
11-12 September 2008	VLBI2010 Committee Meeting	Penticton, BC, Canada
18-20 March 2009	VLBI2010 Workshop on Future Radio Frequencies and Feeds	Wettzell, Germany
21 March 2009	VLBI2010 Committee Meeting	Wettzell, Germany
25 March 2009	IVS 10th Anniversary Celebration	Bordeaux, France
26 March 2009	10th IVS Analysis Workshop	Bordeaux, France
27-30 April 2009	5th IVS Technical Operations Workshop	Westford, MA, USA
7-10 February 2010	6th IVS General Meeting	Hobart, TAS, Australia
11 February 2010	VLBI2010 Developers Meeting and 11th Analysis Workshop	Hobart, TAS, Australia
13 February 2010	Mini Technical Operations Workshop	Hobart, TAS, Australia
31 March 2011	12th Analysis Workshop	Bonn, Germany
9-12 May 2011	6th IVS Technical Operations Workshop	Westford, MA, USA

The IVS completed its first ten years of being a service for geodetic and astrometric VLBI on March 1, 2009. To commemorate the first decade a 10th Anniversary Celebration event was held in Bordeaux, France on March 25, 2009. The event included a symposium featuring the history of VLBI and the IVS, the interrelation of the IVS with the other space geodetic services (IGS, ILRS, IDS), and IVS' place among the other VLBI networks (EVN, VLBA, Asian networks). The event was live broadcast over the Internet. A recording of the various presentations is available at http://canalc2.u-strasbg.fr/video.asp?idvideo=8558.

Working Groups

ICRF2. The Second Realization of the International Celestial Reference Frame (ICRF2) was adopted at the XXVII General Assembly of the International Astronomical Union (IAU) in Rio de Janeiro, Brazil as Resolution B3. The ICRF2 replaced the previously used first realization (ICRF) effective 1 January 2010. The determination of the new frame was an effort of a joint IERS/IVS working group and was overseen by an IAU working group. ICRF2 contains precise positions of 3,414 compact extragalactic radio sources, more than five times the number in the ICRF. Further, the ICRF2 is found to have a noise floor of ~40 µarcseconds, some 5−6 times better than ICRF, and an axis stability of ~10 µarcseconds, nearly twice as stable as ICRF. Alignment of ICRF2 with the International Celestial Reference System (ICRS) was made using 138 stable sources common to both ICRF2 and ICRF-Ext2.

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 2007–2011 included the following sessions:

- EOP: Two rapid turnaround sessions each week, mostly with 7 stations, some with 6 or 8 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: Quarterly (2007) and bi-monthly (2008−2011) TRF sessions with 12–14 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 1200 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.

CONT08

In August 2008, a 15-day continuous VLBI observation campaign called CONT08 was observed. The network consisted of eleven IVS stations (see Figure 1). Unlike the CONT05 campaign, CONT08 was observed on the basis of UT days, i.e., an observing day was run from 0 UT to 24 UT. Observational gaps between the single observation days (30 min in the CONT05 case) were avoided by performing the daily station checks (e.g., pointing) not at the change of schedules but at well-coordinated, staggered times for all stations (i.e., different daily check times for each station). In the CONT05 campaign the 30-min gaps had resulted in unrealistic peaks in the sub-daily EOP time series. The CONT08 data set is of excellent quality and will be the basis for studies of inter-technique comparisons, searches for geo-physical signals, and technique improvement. A special issue of Journal of Geodesy with several peer-reviewed publications about the scientific use of CONT08 data is under preparation and will be published in 2011.

Figure 1. Geographical distribution of the eleven IVS stations that participated in the CONT08 campaign in August 2008.

IYA09 Very Large Astrometry Session

As an activity for the International Year of Astronomy 2009 the IVS organized the largest astrometric VLBI session observed to date. On 18 November 2009, thirty-five stations (see Figure 2) observed 243 out of the 295 defining sources of the ICRF2. All scientific, outreach, and ancillary goals (see Table 3) that were staked out for the session were successfully accomplished.

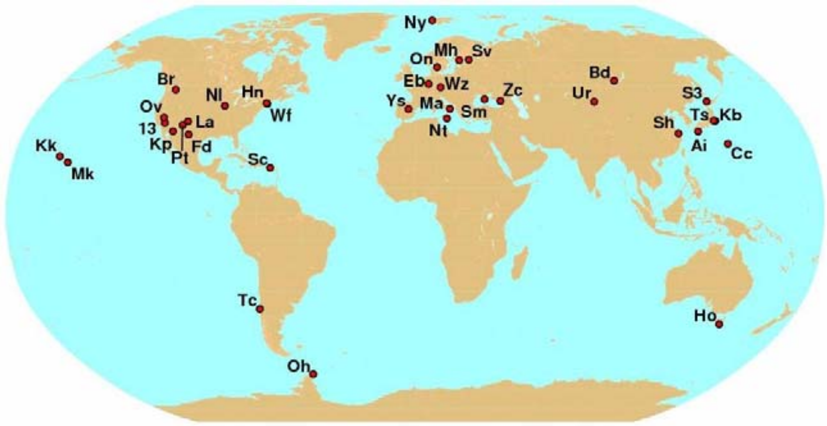

Figure 2: Observational network of the IYA09 Very Large Astrometry Session.

Analysis

Earth Orientation Parameters.

The official IVS Earth orientation parameter (EOP) series were produced and published by the IVS Analysis Coordinator's office at the Institute of Geodesy and Geoinformation of the University of Bonn, Germany until October 2009 when this operational task was taken over by the IVS Combination Center at the German Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt a.M. Two separate series are computed: one as a rapid product with the emphasis on fast correlation and data reduction based on special observing sessions every Monday (IVS-R1) and every Thursday (IVS-R4), the other one as a complete series of all geodetic VLBI sessions and generated every three months. In January 2007 the combination of the input of up to six IVS Analysis Centers was changed from a combination on the level of EOP results to a combination on the basis of datum-free normal equations in SINEX format. The new approach improved the robustness and quality of the combination product significantly.

Table 3. Key goals of the IYA09 session.

Scientific goals	Strengthen ICRF2 by observing as many sources as possible in a single session. / Measure arc-lengths between observed sources.
Outreach goals	Press releases through IYA2009 (IAU), IVS, and other organizations. / News coverage in regional and national media. / Open doors at stations.
Ancillary goals	Celebrate 40 years of geodetic and astrometric VLBI. / Demonstrate capability of handling large networks. / Tie stations into global frame.

The advantages of the new combination strategy are (1) that the full variance-covariance information of the individual input solutions is rigorously carried over and (2) that one common terrestrial reference frame is applied after the combined datum-free normal matrix is generated. Thus, it is guaranteed that an identical datum is used in the combination process for all input series. After datum definition, the combined system of normal equations is solved (inverted) and the full set of EOP (pole components, UT1−UTC, and their time derivatives as well as two nutation offsets in dψ, dε w.r.t. the IAU2000A model) are extracted into separate files. These results are then added to the two EOP time series, the rapid solution file and the quarterly solution file, in the IVS EOP Exchange format. Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process. Today, the input of the Analysis Centers agrees to better than 60 µarcseconds, while the combined IVS polar motion results agree with the IGS pole at the 100-130 µarcsecond level.

Comparisons of Long-term Station Position Time Series

As part of the quality assessment for the IVS combined products, long-term time series of station positions of each individual IVS Analysis Center, derived from the submitted normal equations, have been compared with each other. Through this, systematic offsets in the height component of up to 1 cm have been detected between solutions analysed with the VLBI analysis software packages OCCAM and CALC/SOLVE. In order to find the reason for these discrepancies several models used in both software packages have been compared. It turned out that the systematic offsets were mainly caused by differences in the pole tide model. In the CALC/SOLVE solutions, the annual mean pole offset was set to zero until early 2007, which was not in agreement with the IERS Conventions 2003. Therefore, all analysis centers using CALC/SOLVE reprocessed their solutions in 2007 with the conventional pole tide model according to the IERS Conventions 2003 and most of the discrepancies disappeared. Since the IVS input to ITRF2005 was affected by the same inconsistency, the ITRF2005 was affected by this oversight, though not to the full extent.

Contribution to ITRF2008.

The IVS contribution to the ITRF2008 was generated at the IVS Analysis Coordinator's office. It consists of session-wise datum-free normal equations which are the result of a combination of individual series of session-wise datum-free normal equations provided by seven IVS Analysis Centers (BKG, DGFI, GSFC, IGGB, OPA, SHAO, and USNO). All these individual series are completely reprocessed following homogeneous analysis options according to the IERS Conventions 2003 and the IVS Analysis Conventions.

Based on the experience gathered since the combination efforts for ITRF2005, the consistency of the individual VLBI solutions has improved considerably. The agreement in terms of the WRMS of the terrestrial reference frame (TRF) horizontal components is 1 mm and of the height component is 2 mm. Comparisons between ITRF2005 and the combined TRF solution for ITRF2008 yielded systematic height differences of up to 5 mm with a zonal signature. These differences can be related to the pole tide correction mentioned above which was referenced to a zero mean pole used by four of the five IVS ACs in the ITRF2005 contribution instead of a linear mean pole path as recommended in the IERS Conventions. Periodic annual variations in scale are reduced considerably from 2.7 mm to 1.7 mm due to the correction for thermal expansion of the radio telescopes.

Thermal Expansion of Radio Telescopes

Thermal expansion effects have been considered already for a long time but concerted activities to include it in IVS data analysis have only started in 2008. At the Ninth IVS Analysis Workshop in St. Petersburg, it was decided to make thermal expansion modeling the first chapter of the IVS Analysis Conventions. This should serve as a proper reference for all analysis descriptions. In addition, a decision was made to use the GPT model (Boehm et al. 2007) to compute the reference temperature for each telescope. Any expansion effect can and should now be computed relative to these mean temperatures. In the meantime, the current status of thermal expansion modelling has been documented in a refereed paper (Nothnagel, 2008) which is the written documentation of Chapter 1 of the IVS Analysis Conventions.

One of the necessary parts of a model for expansion effects is a list of all telescopes' construction dimensions. In such a list, all dimensions like effective height of the elevation axis above the ground for azimuth-elevation telescopes or height of primary axis above secondary axis for polar or XY antennas, just to name a few, have to be tabulated for all telescopes. Quite some effort has been invested to collect the information for this list and further efforts are still necessary to gather the missing information for a few more telescopes. The list is available under http://vlbi.geod.uni-bonn.de/IVS-AC/Conventions together with the reference paper.

Since the reference temperatures of all telescopes are long-term means from a model, no effective change in the realizations of terrestrial reference frames are expected. However, annual variations in station coordinates, especially in the height component, are expected to reduce. Consequently, Earth orientation parameters from VLBI observations may also be affected, mainly with an annual signature.

Technology Development

VLBI2010

The IVS VLBI2010 Committee (V2C) published a Progress Report with the title "Design Aspects of the VLBI2010 System" about the status of the development of the next generation geodetic VLBI system (VLBI2010 system), which summarizes the progress made in the development of the new system up to the end of 2008. The report covers Monte Carlo simulations showing the impact of the new operating modes on the final products. A section on system considerations describes the implications for the VLBI2010 system parameters by considering the new modes and system-related issues such as sensitivity, antenna slew rate, delay measurement error, RFI, frequency requirements, antenna deformation, and source structure corrections. This is followed by a description of all major subsystems and recommendations for the network, station, and antenna. Then aspects of the feed, polarization processing, calibration, digital back end, and correlator subsystems are covered. A section is dedicated to the NASA proof-of-concept demonstration. Finally, sections on operational considerations, on risks and fallback options, and on the next steps complete the report. The report was published as a NASA Technical Memorandum and is available online on the IVS Web site at ftp://ivscc.gsfc.nasa.gov/pub/misc/V2C/PR-V2C_090417.pdf.

An important meeting organized by the V2C was the VLBI2010 Workshop on Future Radio Frequencies and Feeds (FRFF), which was held over a period of three days in Wettzell, Germany and brought together experts from many VLBI areas. An outcome of the FRFF was recommendations pertaining to the choice of frequencies for and backward compatibility of the VLBI2010 system. The recommendations have been endorsed by the IVS Directing Board and read as follows:

- The initial implementation of the VLBI2010 system needs to be capable of observing the broadband frequency range of ~2.2−14 GHz.
- The VLBI2010 system needs to be capable of S/X operation.
- The antenna should allow for a possible future inclusion of Ka-band (32 GHz) operation.
- The complete end-to-end operation of the VLBI2010 system should be demonstrated in a campaign in early 2012. As many antennas as possible should participate.
- A plan should be established for the transition from the legacy S/X system to the VLBI2010 broadband delay system. Such a transition plan can be beneficial for obtaining future funding and will support a timely changeover.

In spring 2012 it is foreseen to hold a similar meeting intended to fully define the VLBI2010 system. The capability of VLBI2010 will be demonstrated in a campaign in 2012 or 2013.

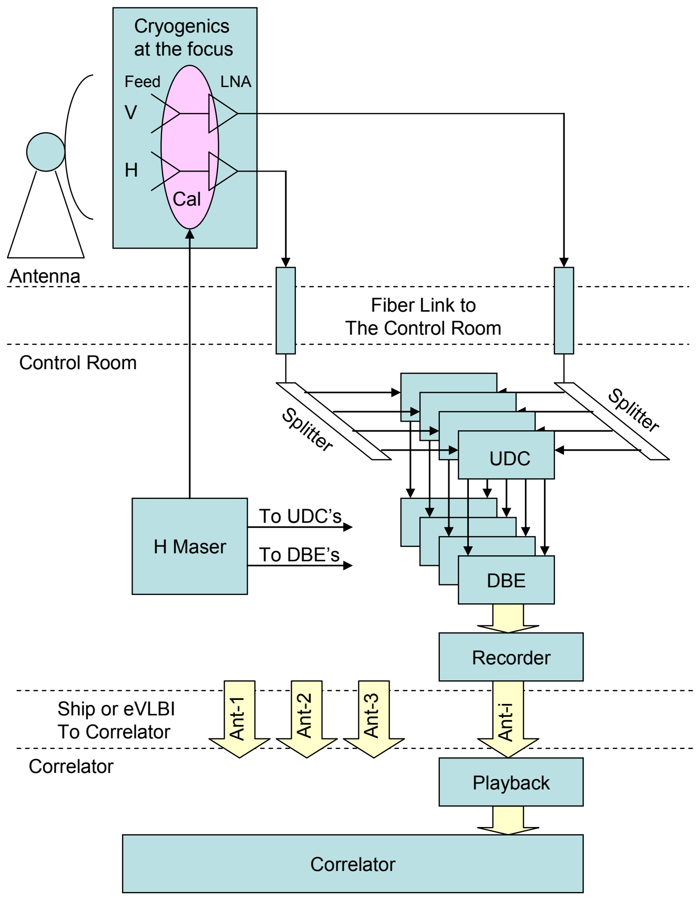

Figure 3: VLBI2010 block diagram. The architecture differs significantly from the existing geodetic VLBI systems. This is driven by the needs for short source-switching intervals, improved delay measurement precision, smaller drifts of the electronics, and improved automation and operational efficiency. Of particular note is the change from a system with two fixed bands (S and X band) to a system with four bands, each of which can be placed anywhere in the 2−14 GHz range.

In spring 2009 the IVS created the VLBI2010 Project Executive Group (V2PEG) in order to provide strategic leadership to the VBI2010 project. Many VLBI2010 developments were carried out by the different stakeholders of the IVS in a loosely organized manner. The V2PEG is tasked with coordinating and streamlining these activities and functions as the focal point for gathering and disseminating information about VLBI2010 and for promoting the new system.

Digital Back End and Recorder

A next generation of digital back end (DBE2) and recorder (Mark 5C) are under development at Haystack Observatory. Two important features of this system are a) the ability to record at 4096 Mbps and b) communication via 10 Gbps Ethernet. The DBE2 board was completed in 2008 and received at Haystack Observatory. The board was powered up and initial communication was achieved. Much of the digital signal processing firmware has been simulated, and programming of the Power PC is about to begin.

The Mark 5C is derived from a Mark 5B+ by the addition of a daughter board containing the 10 GigE interface and the deletion of the I/O board. The daughter board has recently been completed and tested, thus enabling testing of communication between the DBE2 and the Mark 5C.

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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 Liverpool University in the UK. 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).

The PSMSL was established in 1933 by Joseph Proudman who became its first Secretary. Thus 2008 marked the 75th anniversary of the founding of PSMSL. To celebrate this milestone, PSMSL organised or co-organised three meetings: gathering experts to discuss continuing research into sea level during special Interdivision Session at the European Geophysical Union General Assembly, co-sponsoring the Geological Society's William Smith Meeting, "Observations and Causes of Sea-Level Changes on Millennial to Decadal Timescales" and "Liverpool, Home of Sea Level Science: Sea Level Rise and Climate Change", a one-day session at the British Association Festival of Science in Liverpool.

The primary aim of the PSMSL is providing 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 4 years over 7000 station-years of data were entered into the PSMSL database, increasing the total PSMSL data holdings to over 60000 station-years. 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. Approximately 1400 site years of high-frequency delayed-mode were received during the period June 2007 to April 2011.

The entire PSMSL data set is available from the new website: www.psmsl.org, which was launched on 1st April 2010. The redevelopment of the website, along with a redesign of the underlying PSMSL database, aims to facilitate the ease of accessing and exploring the data held by PSMSL. In addition the GLOSS web pages (www.gloss-sealevel.org) have been completely modernised and updated.

The PSMSL has been closely involved in the development of a sea level network in Africa (through the Ocean Data and Information Network for Africa – ODINAfrica - project). This has included delivery of sea level hardware for a number of stations in Africa and the western Indian Ocean. Currently eleven tide gauges have been installed in Africa and the Indian Ocean with the real-time data transmitted to the IOC Sea Level Station Monitoring Facility (www.ioc-sealevelmonitoring.org), and the delayed-mode quality controlled 15 minute data with documentation are available for download from the Africa and Western Indian Ocean Sea Level Data section of the GLOSS web-site.

The PSMSL and NOC have investigated the use of the Inmarsat BGAN (Broadband Global Area Network) system for real-time transmission of tide gauge data from remote stations, and especially for data of interest for tsunami warning. BGAN has the potential to improve the speed of tsunami warnings, and therefore to save lives.

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, WCRP, and EGU over the last 4 years. In addition, they have answered many enquires relating to sea level and have appeared on radio and television discussing aspects of sea level change. Short training course have been run at PSMSL, in cooperation with NOC, for technicians and visitors taking part in the IOC Indian Ocean Tsunami Warning System (IOTWS) fellowship scheme. The former Director of the PSMSL, Dr Philip Woodworth was awarded the EGU Vening Meinesz medal for distinguished research in geodesy in 2010, in part for his contribution to PSMSL.

Activities

1. Introduction

The Permanent Service for Mean Sea Level (PSMSL) is based at the National Oceanography Centre (formerly Proudman Oceanographic Laboratory (POL)) on the campus of Liverpool University in the UK. 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).

As a result of the Priority Area Assessment on Data and Information in 2004, ICSU is reorganizing FAGS and the World Data Centre System. This takes into account the recommendations of the *ad hoc* Strategic Committee on Scientific Information and Data which were approved by the ICSU General Assembly in October 2008. An ICSU World Data System will be established and to smooth the way a FAGS-WDC Transition Team was formed, with Dr. Philip Woodworth, the previous PSMSL Director and FAGS Secretary, as a member. Dr. Lesley Rickards is a member of the more recently formed World Data System Scientific Committee. Methods of accreditation to the WDS have been established and the PSMSL will apply to become a member of that new System in 2011.

The PSMSL was established in 1933 by Joseph Proudman who became its first Secretary. Thus 2008 marked the 75th anniversary of the founding of PSMSL. To celebrate this milestone, PSMSL organised or co-organised three meetings: gathering experts to discuss continuing research into sea level during special Interdivision Session at the European Geophysical Union General Assembly, co-sponsoring the Geological Society's William Smith Meeting, “Observations and Causes of Sea-Level Changes on Millennial to Decadal Timescales” and “Liverpool, Home of Sea Level Science: Sea Level Rise and Climate Change”, a one-day session at the British Association Festival of Science in Liverpool.

PSMSL has continued to provide strong support to the Global Sea Level Observing System (GLOSS) and to related projects such as the Ocean Data and Information Network for Africa (ODINAfrica). It has provided advice and assistance to a large number of people with interests in sea level science, thereby fulfilling its overall obligations as a FAGS Service. Finally, and most importantly, it has redoubled its efforts in its primary aim of providing the global data bank for long term sea level information from tide gauges.

In September 2008, the PSMSL Advisory Board met in Liverpool. Members of PSMSL staff provided an overview of current and planned activities including restructuring of the database to bring it up to modern standards, a new web-site, and development of a wider range of scientific and practical products.

2. Staffing and funding

In April 2007, there was a change of PSMSL Director from Dr. Philip Woodworth to Dr. Lesley Rickards. Dr. Rickards has been responsible for the GLOSS Delayed-mode Sea Level data bank and until recently was chair of the International Oceanographic Data and Information Exchange (IODE) programme of the IOC. Dr Woodworth remains closely involved with PSMSL and together with Drs. Simon Holgate and Svetlana Jevrejeva, makes up the main PSMSL scientific staff concerned with the collection and analysis of monthly mean sea level data. In the same month, Dr Mark Tamisiea joined the PSMSL. He contributes primarily to links between PSMSL and geodetic and geophysical programmes (e.g. GGOS), to the provision of geophysical information in PSMSL web pages, and to analysis of sea level data which requires geophysical insight. Mrs. Kathy Gordon continues to be responsible for management of the mean sea level data set. In February 2008, Dr Andrew Matthews joined the PSMSL staff. He is contributing to clearing the backlog of GLOSS delayed-mode high frequency data, re-structuring the database and improving data delivery and provision of new tools to aid data input, quality control and reporting.

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); this has seen a modest expansion for the current five year period. A major aspect of that application was the merger as far as possible of the PSMSL and GLOSS delayed-mode activities. The proposal was graded as "alpha-5", the highest possible, which provided a clear way forward. During 2010 a document was prepared by PSMSL for NERC as part of its review of National Capability to aid future funding decisions. The document highlights PSMSL's unique role and the synergy generated by its co-location with NOC.

3. PSMSL Data Receipts for the period 2007 to 2010

The primary aim of the PSMSL is providing the global data bank for long term sea level information from tide gauges. Data are carefully quality controlled. Where possible, data for each station are reduced to a common datum, known as the Revised Local Reference (RLR), which ensures they are suitable for use in research quality time series analysis.

PSMSL has continued to increase its efforts in this regard and between 2007 and 2010 over 7000 station-years of data were entered into the PSMSL database, increasing the total PSMSL data holdings to approximately 60000 station-years of monthly and annual mean sea level from about 2050 stations, supplied by 200 authorities worldwide. Most data originated from Europe and North America, including the Arctic. However, large data sets were also obtained from Asia, Australasia and southern Africa (see Figures 1 and 2). Major gaps in data receipts persist in other parts of Africa which are receiving special attention through ODINAfrica (see section 4.4 below), where data are beginning to flow.

Revised monthly sea level data for 18 tide gauge stations in Russian Arctic were downloaded from the Arctic and Antarctic Research Institute (Russia) website, covering the period 1950 to 1990. These new time series from the official data authority have replaced the existing records. Additional data from 1991 to 2009 have also been added to the PSMSL data set.

In addition, PSMSL has received historical monthly mean sea level data for four new locations in Russian Arctic. Some of these records span more than 50 years, including Polyarniy (1906-1990), the earliest observation in the Arctic region. The three other stations are Burgino, Mys Pikshueva, and Teriberka. PSMSL is grateful to project team of the International Polar Year project "Long-term Sea Level Variability in the Nordic Seas (LEVANS)" for providing the data to PSMSL. This project ran from 2007-2009 and was funded by the Research Council of Norway and included the Norwegian Polar Institute and the Arctic and Antarctic Research Institute (Russia).

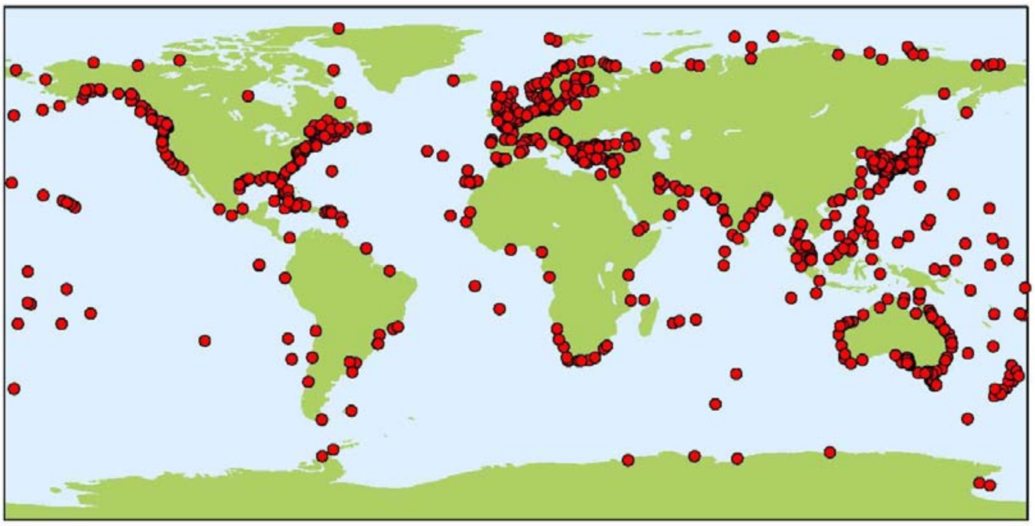


Figure 1: New PSMSL data received between 2007 and 2010

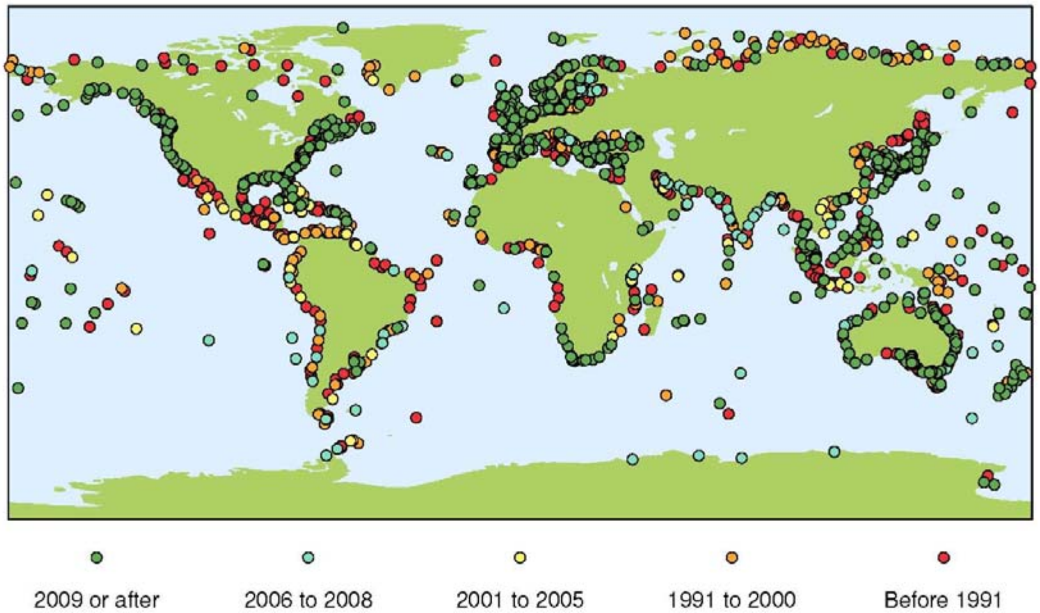


Figure 2: Year of most recent data received by PSMSL

Although data have been contributed from across the globe, large gaps in the network still exist in Africa, Asia and South America, especially for long time series (e.g. over 50 years). Consequently, the Southern Hemisphere is heavily under represented. Series of over one hundred years in length are found almost exclusively in Europe and North America.

Africa is particularly poorly represented, with only two continental time series over 50 years long. In the past thirty years, there has been a gradual decline in the number of stations providing data to the PSMSL. All regions have seen a decline in contributions, but the decrease has been particularly apparent in South America (see the red line in Figure 3).

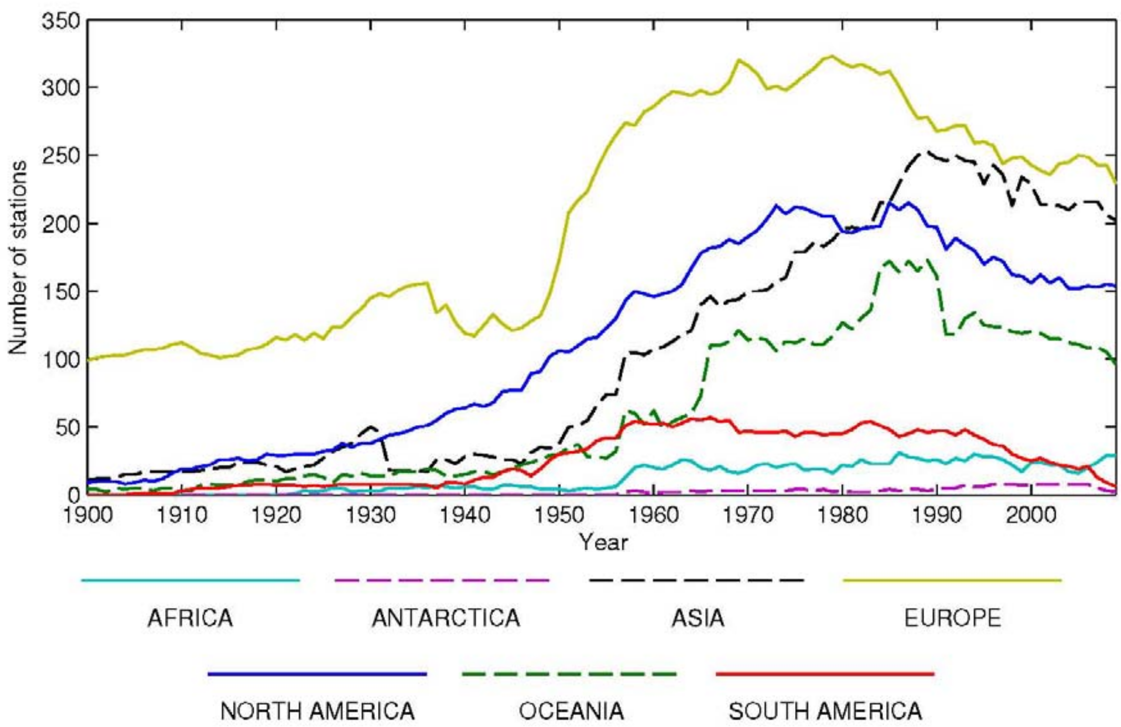


Figure 3: Regional distribution of data held by the PSMSL

4. New PSMSL web-site

The entire PSMSL data set is available from the new website: www.psmsl.org, which was launched on 1st April 2010. The redevelopment of the website, along with a redesign of the underlying PSMSL database, aims to facilitate the ease of accessing and exploring the data held by PSMSL.

Each station now has its own dedicated web page, displaying metadata, documentation, a location map and data plots, as well as links to obtain the station time series. The data files on the website are updated every Wednesday morning, allowing users prompt access to the latest PSMSL data.

The PSMSL is also developing interactive products to allow website users to explore the PSMSL data set more easily. The website currently includes a KML file that allows the RLR catalogue to be imported into Google Earth.

New products soon to be launched will allow the user to explore the PSMSL data set interactively. The first wave of these will allow the user to examine sea level trends.

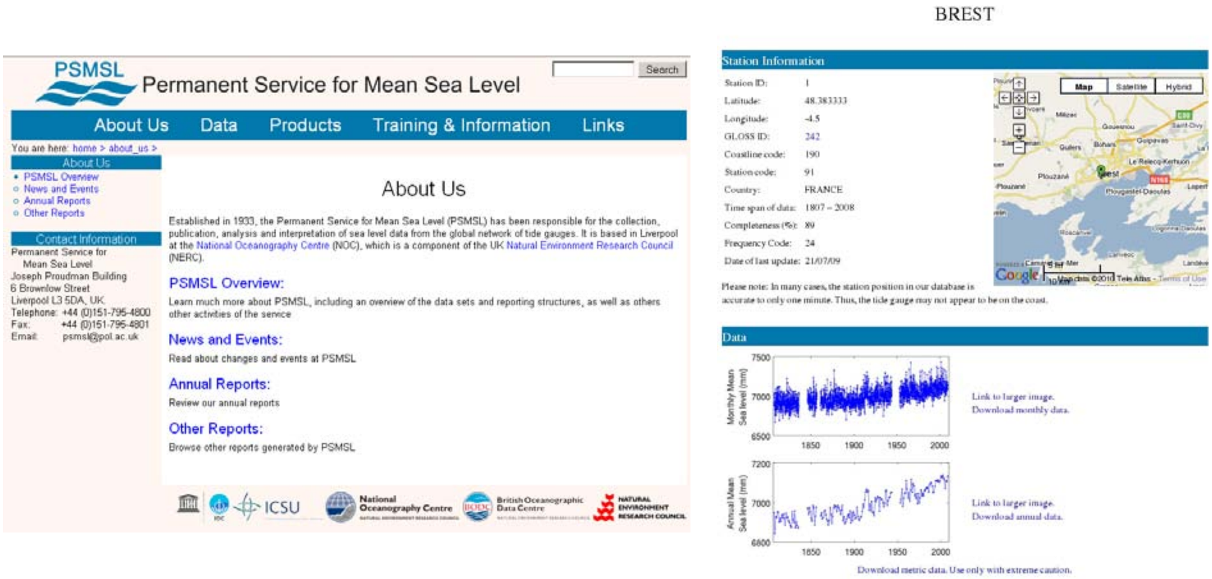


Figure 4: New PSMSL web-site: Home page (left) and individual station page (right)

5. Delayed Mode High Frequency (DM HF) Data Receipts for June 2007 - April 2011

The PSMSL and BODC are responsible for the archive of delayed-mode higher-frequency sea level data (e.g. hourly values and higher frequency) from the GLOSS core network of 290 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). Following the successful completion of WOCE, the Delayed-mode Sea Level DAC was designated a GLOSS Archive Centre. Approximately 1400 site years of high-frequency delayed-mode were received during the period June 2007- April 2011, adding to the 5000 site years already held.

Once again data have been received from some important data sparse regions. The data from ODINAfrica gauges described below are being added to the data set. The Polar Regions are also an area of interest where there are few tide gauges. There has been data submitted from the new gauge at Thule, in Greenland, as well as more recent data from other more established Greenland gauges.

There has been a complete revision of the historic South African tide gauge dataset, with some sites having over 45 years worth of data. There was also a submission of more recent data from the region. Portugal also submitted long time series, with the GLOSS station of Funchal (Madeira) having nearly 50 years worth of data. Further updates have been received from Australia, Canada, Japan, UK and USA.

6. GLOSS Activities

6.1 New GLOSS Web Site

The GLOSS web pages (www.gloss-sealevel.org) have been completely modernised and updated. The GLOSS Station Handbook has also been revised and updated and has been merged with the GLOSS web-site. New material has been added to the GLOSS web pages including training material and national reports from the GLOSS Group of Experts meetings (GE-GLOSS-X and GE-GLOSS-XI). Much of the information text has been reviewed and revised. A new page providing quality controlled data from ODINAfrica and the Indian Ocean has been added. The web-site continues to be maintained by the PSMSL and BODC on behalf of GLOSS.

6.2 GLOSS Status from a PSMSL Viewpoint (December 2010)

For a number of years, the PSMSL has provided an annual summary of the status of the GLOSS Core Network (GCN) from its viewpoint. During 2010 the latest revision of the GLOSS Core Network has been 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 (65% of the stations are category 1, having reported their data from 2006 or more recently to PSMSL). However, although improvements to the network, some following on from the considerable investments being put into sea level recording in Africa and in the Indian Ocean following the Sumatra tsunami, 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. A review of its status as of December 2010 can be found at the above GLOSS web-site.

6.3 GLOSS Training Courses and IOC Indian Ocean Tsunami Warning System (IOTWS) fellowships

GLOSS training courses have been held in many countries since the mid-1980s. In May 2007 PSMSL organised a short training course at POL for technicians from Egypt, Germany and Iran which was most useful preparation for the recent tide gauge installations.

In 2007 PSMSL hosted two visitors under the IOC Indian Ocean Tsunami Warning System (IOTWS) fellowship scheme. These were Dr. E.M.S. Wijeratne from the National Aquatic Resources Research and Development Agency (NARA) in Sri Lanka and Mr. D. Sundar from the National Institute of Oceanography in India. This was followed in 2008 by a further three visitors under the same Fellowship scheme: Mr Naimatullah Sohoo from the National Institute of Oceanography, Pakistan, Dr Parluhutan Manurung from National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL), Indonesia and Mr Rene Ibara from Pointe Noire, Republic of Congo.

6.4 New GLOSS and ODINAfrica Tide Gauges

Improvements have been made to the African network in the past ten years. Between 1960 and 2000, there were roughly equal number of stations from the islands around Africa, stations in South Africa, and stations from other countries around the African coastline. Most of the improvement in the African network in the past ten years has been due to an increase in the number of island stations. The number of continental stations dropped sharply in the early

2000s, but efforts of programmes such as ODINAfrica have increased the number of available stations to pre-2000 levels.

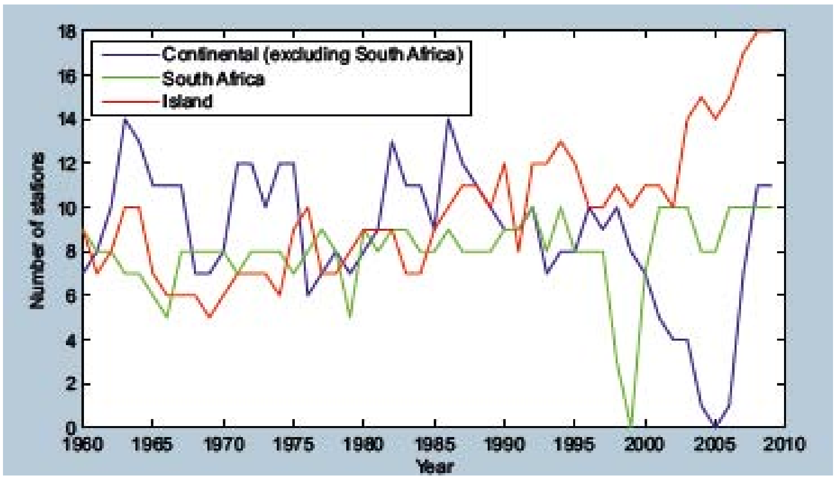


Figure 5: African stations available in the PSMSL data set, and their availability over the past fifty years

The PSMSL has been closely involved in the delivery of sea level hardware for a number of stations in Africa and the western Indian Ocean, particularly in the frame of the ODINAfrica project. Currently eleven tide gauges have been installed in Africa and the Indian Ocean. These are: Aden (Yemen), Alexandria (Egypt), Chabahar (Iran), Djibouti (Djibouti), Inhambane (Mozambique), Karachi (Pakistan), Nouakchott (Mauritania), Pemba (Mozambique), Pointe Noire (Republic of Congo), Port Sonara (Cameroon) and Takoradi (Ghana). All of these gauges are currently providing data to the real-time Sea Level Station Monitoring Facility (www.ioc-sealevelmonitoring.org) operated by the Flanders Marine Institute (VLIZ), Belgium, and delayed-mode quality controlled 15 minute data with documentation are available for download from the Africa and Western Indian Ocean Sea Level Data section of the GLOSS web-site. PSMSL is moving towards devising effective methods for maintenance and assurance of data flow from the newly installed sites.

7. BGAN Satellite Transmission

The PSMSL and POL took a major interest in 2006 in the use of the Inmarsat BGAN (Broadband Global Area Network) system for real-time transmission of tide gauge data from remote stations, and especially for data of interest for tsunami warning. This telemetry enables always-on broadband internet connections to tide gauges, providing higher bandwidth and reduced latency in data transfer than available at present by systems such as Meteosat. Inmarsat have been very helpful in providing test equipment.

In December 2007, Dr. Philip Woodworth attended a ceremony at Inmarsat headquarters in London which included the signing of an agreement between IOC and Inmarsat for the use of the Inmarsat BGAN system in the IOTWS. The use of BGAN in this way had been suggested by PSMSL and other POL staff (notably Dr. Simon Holgate, Mr. Peter Foden and Mr. Jeff Pugh) and subsequently demonstrated in a series of tests. BGAN has the potential to improve the speed of tsunami warnings, and therefore to save lives.

8. European and other international projects

8.1 Tsunami Projects

PSMSL staff contributed to UK-organised tsunami warning activities (e.g. for the UK Defra ministry), European Union ones (TRANSFER) and those coordinated under the auspices of the IOC (e.g. Indian Ocean (IOTWS) and North East Atlantic and Mediterranean (NEAMTWS) Tsunami Warning Systems). These activities have included leading a survey of European sea level infrastructure leading to a report that includes the technical requirements for detecting tsunamis, studies of optimum networks and hardware and modelling of tsunami propagation. PSMSL also contributed to the IOC Global Meeting of the Intergovernmental Coordination Groups for Tsunami Warning Systems held in Paris in March 2009.

8.2 European Projects

The PSMSL took the lead, with the Danish Meteorological Institute (DMI), in initiating a web page for real time sea level data from the European Atlantic coastline (www.sleac.org). In addition, it took part in an IOC study group on access to real time data from across Europe. The PSMSL continues to provide input to the European Sea Level Service (ESEAS) through its Governing Board and has also contributed proposals to the Chair of the ESEAS Governing Board through which the delivery of delayed mode sea level data from the region can be placed on a more reliable basis. Subsequently funding has been secured and an ESEAS Data Portal developed which is currently undergoing testing.

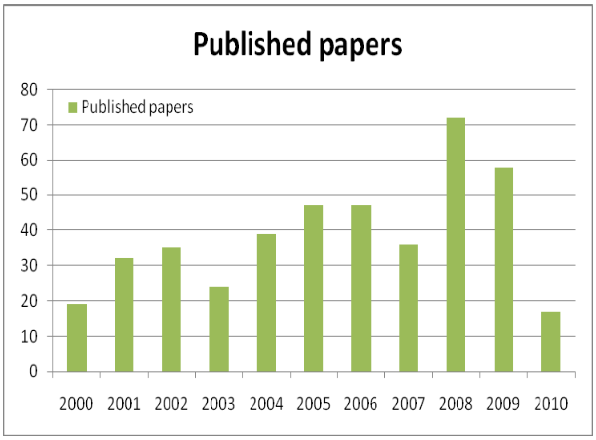
9. Publications

The PSMSL has a responsibility to not only collect and redistribute sea level information, but also to analyse data and publish scientific results. The main papers published each year are listed in PSMSL Annual Reports.

In order to assess the usage of PSMSL and its data, a search has been carried out for the number of occurrences of PSMSL in the scientific literature since the year 2000. The histograms below illustrate (i) the number of "papers" published in each year and (ii) the number of citations for papers that were published in a given year (i.e. not the number of citations per year). Of the 504 references to PSMSL since 2000, there are 425 that count as books or papers which have, in total, been cited 5481 times between them. This is equivalent to an h-factor of 35. It is also worth noting that in the IPCC Fourth Assessment Report, references for Chapter 5, Observations: Oceanic Climate Change and Sea Level, includes 28 references which use the PSMSL dataset.

Table 1: PSMSL related papers and citations

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	**Total**
Papers	19	31	35	24	39	47	47	36	72	58	17	**425**
Citation	633	1029	500	329	846	676	610	339	445	63	9	**5541**



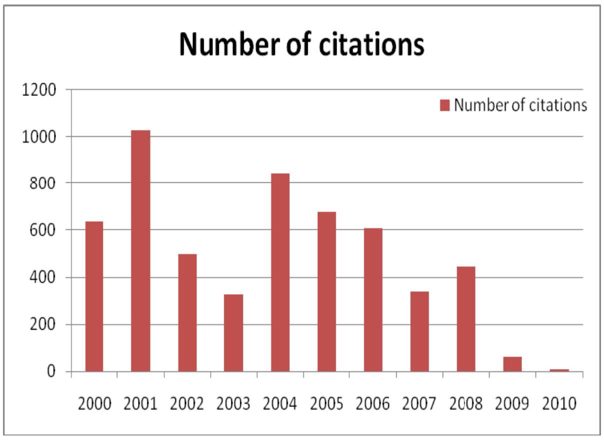


Figure 6: PSMSL related papers and citations
Note: "Number of citations" shown for a given year are the citations of papers published in that year, not the year that the citing paper was published. This is not the true citation profile through time.

10. PSMSL-Related Scientific Meetings, Activities and Events

PSMSL staff have continued to be active in GE-GLOSS meetings and workshops and GGOS meetings over the last 4 years, co-convened sea level sessions at the EGU and contributed to IOC coordination groups tsunami warning system meetings. In addition, PSMSL staff attended an international meeting in February 2011 organised by the World Climate Research Programme focusing on regional rather than global sea level variability.

PSMSL contributes to the IPCC not only through the provision of data but also with direct scientific input. Dr Philip Woodworth was a lead author on the sea level chapter of the 3rd Assessment Report and a contributing author to the 4th Assessment Report. In addition, papers by PSMSL staff were cited in the 4th Assessment Report. PSMSL staff contributed to the IPCC meeting on sea level and cryosphere held in Malaysia in 2010 and Dr Svetlana Jevrejeva will be a lead author on the 5th Assessment Report, with others PSMSL staff also contributing.

PSMSL undertook the task of electronically scanning and converting to pdf form the historical IAPO and IAPSO reports that are in the NOC Liverpool library. This covers all of the reports from 1 to 35, with the exception of number 21. This work is now complete and the pdf files passed to Professor Rodhe, Secretary General, IAPSO.

The former Director of the PSMSL, Dr Philip Woodworth was awarded the EGU Vening Meinesz medal for distinguished research in geodesy in 2010, in part for his contribution to PSMSL. He was also was awarded the Member of the Order of the British Empire (MBE) "For service to Science" in the 2011 New Year's Honours list. PSMSL staff have worked alongside engineers and technologists at NOC undertaking real-time telemetry which has been adopted by the IOC as the basis for the Indian Ocean Tsunami Monitoring System IOTWS: this work has received the Denny medal (awarded by the Institute of Marine Engineering Science and Technology, IMarEST) and was highly commended by the Institution of Engineering and Technology (IET) and the North West Regional Development Agency (NWRDA) in their North-West Innovation Awards of 2009.

11. Summary

It can be seen that the last four years have been a further active period with regard to important workshops and conferences, and a busy one with regard to data acquisition and analysis. The functions provided by the PSMSL are in as much demand as ever, and several successful events were organised to celebrate the 75th anniversary of the Service in 2008. The PSMSL database has been restructured, new software tools developed, and a new web-site launched with improved data dissemination. 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.

International Association of Geodesy (IAG) Quadrennial Report 2007 – June 2011

Home: http://www.iag-aig.org, Office: http://iag.dgfi.badw.de

Hermann Drewes, IAG Secretary General

Introduction

The main objective of IAG is to study all geodetic problems related to Earth observation and global change. This includes the determination of reference systems, gravity field, Earth rotation, surface positions and crustal deformation, and sea level. To accomplish the objectives, IAG is divided into four Commissions, fifteen Scientific Services, the Global Geodetic Observing System (GGOS), the Communication and Outreach Branch (COB), and the Inter-Commission Committee on Theory (ICCT). The administration is supervised by the Council and operated by the Bureau, the Executive Committee and the Office. The outreach is done by the COB. All these entities are in steady contact and inform about their activities through the IAG Newsletter and the bi-annual IAG Reports (Travaux de l'AIG).

Administration

IAG Council

The Council met twice during the IUGG General Assembly 2007 in Perugia. The list of national correspondents forming the IAG Council was regularly updated in contact with the IUGG Secretary General. Doubtful nominations (double, questionable) were cleared up. The Council was informed by e-mail about activities of the Bureau and the Executive Committee.

IAG Executive Committee (EC)

The Executive Committee is composed by the IAG President, Vice-President, Secretary General, immediate Past-President, the four Commission Presidents, the Chairperson of GGOS, the President of the COB, three representatives of the Services, and two members at large. Seven IAG EC meetings were held during the legislative period from 2007 to 2010: Perugia 2007, San Francisco 2007, Vienna 2008, San Francisco 2008, Buenos Aires 2009, Vienna 2010, and San Francisco 2010. The meeting summaries were published in the IAG Newsletter in the IAG Journal of Geodesy (Springer-Verlag) and are available online in the IAG Homepage (http://www.iag-aig.org) and IAG Office Homepage (http://iag.dgfi.badw.de).

Main agenda items at the EC meetings were the regular reports of the Commissions, Services, GGOS, ICCT, COB, and the Editor in Chief of the Journal of Geodesy. They were followed by the discussion on specific scientific issues, changes in the structures of GGOS and Services, and IAG publications. Other important topics were the IAG Scientific Assembly 2009 in Buenos Aires, the preparation of the Symposia with IAG participation during the IUGG General Assembly 2011 in Melbourne, the discussion of the bi-annual IAG Reports (Travaux de l'AIG), sponsoring of symposia, and the links to other organizations, e.g. FIG, GEO, JBGIS, IHO, ISO, and UNOOSA (see below).

IAG Bureau

The IAG Bureau, consisting of the President, the Vice-President and the Secretary General, held regular teleconferences and met in general before each of the IAG Executive Committee meetings. The President and Secretary General participated in the IUGG Executive Committee Meetings in Karlsruhe, 4-6 August 2008 and in Melbourne, 9-11 October 2009. Bureau members represented IAG at various international scientific meetings and in several anniversaries, e.g. the 50th anniversary of Bundesamt für Geowissenschaften und Rohstoffe (BGR), Hannover, Germany, 25 November 2008, the 50th anniversary of the International Cartographic Association, Bern, Switzerland, 9-10 June 2009, the 10th anniversary of the International VLBI Service (IVS), Bordeaux, France, 25-26 March 2009, the Centenary of the International Society of Photogrammetry and Remote Sensing (ISPRS), Vienna, Austria, 4 July 2010, and the 150th anniversary of the Swiss Geodetic Commission, Zürich, Switzerland, 10 June 2011.

Activities

IAG Office

The former IAG Central Bureau was renamed IAG Office according to the new IAG Bylaws adopted in Perugia 2007. As a result of the election of the new Secretary General, it moved with all the files including budget, homepage and databases from Copenhagen, Denmark, to Munich, Germany in the second half of 2007. The main task of the office is the administrative organization of all IAG business and events. This includes the budget management, the record keeping of the individual IAG memberships, and the preparation and documentation of all Council and Executive Committee meetings with detailed minutes for the EC members and meeting summaries published in the IAG Newsletters and the IAG Homepages.

Specific duties were the preparation and execution of the IAG Scientific Assembly 2009 and the IAG part of the IUGG General Assembly 2011, the edition of the Geodesist's Handbook 2008 as the organizational guide of IAG with the complete description of the IAG structure (reports, terms of reference, documents), and the Mid-Term Reports 2007–2009 (Travaux de l'AIG Vol. 36). Publications of the Journal of Geodesy and the Proceedings in the IAG Symposia series, both in Springer-Verlag, were supervised. Travel grants were assigned to young scientists for participation in many IAG sponsored symposia.

Communication and Outreach Branch (COB)

The main task of the COB is maintaining the IAG Homepage and publishing the monthly Newsletter online and in the Journal of Geodesy. It also keeps track of all IAG related events by the meetings calendar. Since July 2010 the IAG newsletter is also sent to the Presidents and Secretaries General of the IUGG Associations and JBGIS members The COB prepared, printed and distributed a new IAG leaflet and a big IAG brochure and participated in the preparation of the Geodesist's Handbook 2008.

Commissions and Inter-Commission Committee

The four IAG Commissions and the Inter-Commission Committee on Theory compiled their final reports 2003 – 2007, the new structure descriptions for the period 2007 – 2011, and the mid-term reports 2007 – 2009 for publication in the IAG Reports (Travaux de l'AIG) and the Geodesists Handbook. The reports 2007 – 2011 were prepared for publication at the IUGG General Assembly 2011. The Commissions are maintaining their individual Homepages. Most of the Commissions held several symposia, workshops and other meetings during the period 2007-2011 (see below). They organized symposia at the IAG Scientific Assembly 2009 and the IUGG General Assembly 2011.

Services

There are fifteen IAG Services which may be split into three general fields: geometry (IERS, IDS, IGS, ILRS, IVS), gravity (IGFS, ICGEM, IDEMS, IGeS, BGI) and combination (IAS, IBS, BIPM, ICET, PSMSL). All of them maintain their own Homepages and data servers and hold their administrative meetings (Directing Board or Governing Board, respectively). They compiled their final reports 2003-2007, the new terms of reference for the period 2007 – 2011, the mid-term reports 2007-2009, and the final report 2007 - 2011 for publication in the IAG Reports (Travaux de l'AIG) and the Geodesists Handbook. Most Services held several international meetings (see below).

Global Geodetic Observing System (GGOS)

GGOS became a new component as the "flagship of IAG" in 2007. The mission of GGOS is to advance geodetic observing methods for Earth and planetary system science by defining and advocating for the establishment of the geodetic infrastructure; improving the quality and accessibility of geodetic observations and products; coordinating interaction between the IAG Services, Commissions, and stakeholders; and educating the scientific community about the benefits of geodetic research and the public about the fundamental role of geodesy in society.

The GGOS Reference Document (330 pages) was published in Springer-Verlag in 2009. It contains many individual articles with a description of all aspects of the Global Geodetic Observing System written by a very large number of authors. A total of 11 GGOS Steering Committee meetings were held in the period 2007 - 2011, and several GGOS Workshops and Retreats were performed. GGOS is representing IAG as a participating organization in the Group on Earth Observation (GEO) and participated in the GEO Plenary Assemblies and other GEO and GEOSS meetings. A GGOS Inter-Agency Committee is being established to support the sustainability of GGOS.

Coordination with other organisations

IAG maintains close cooperation with several organizations outside IUGG. There were meetings on a regular basis with the Advisory Board on the Law of the Sea (ABLOS, together with IHO), Group on Earth Observation (GEO, with IAG as a participating organization), International Standards Organization (ISO, with IAG represented in TC211 Geographic Information / Geomatics), Joint Board of Geospatial Information Societies (JBGIS), United Nations Offices for Outer Space Affairs (UN-OOSA, with participation in Space-based Information for Disaster Management and Emergency Response, UN-SPIDER, and International Committee on Global Navigation Satellite Systems, ICG).

Meetings

- Important meetings of IAG components and sponsored IAG meetings were in 2007 – 2011:
- Workshop on Conventions, Sèvres, France, September 17-19, 2007.
- Joint Internat. GRACE Science Team Meeting, Potsdam, Germany, Oct. 15-17, 2007;
- Unified Analysis Workshop, Monterey, CA, USA, December 5-7, 2007;
- International VLBI Service (IVS) 5th General Meeting and Analysis Workshop, St. Petersburg, Russia, 03-07 March 2008;

- Several Sessions co-organized by the Commissions at the EGU General Assembly, Vienna, Austria, 13-18 April 2008;
- FIG/IAG Symposium "Measuring the Changes", Lisbon, Portugal, 12-15 May 2008;
- SIRGAS General Meeting 2008, Montevideo, Uruguay, 26-29 May 2008;
- International GNSS Service Workshop, Miami Beach, Florida, USA, 02-06 June 2008;
- 7th International e-VLBI Workshop in Shanghai, China, 16-17 June 2008;
- Commission 4 participation in the FIG Working Week, 14-19 June 2008, Stockholm;
- Sub-commission 1.3a EUREF Symposium, Brussels, Belgium, 18-20 June 2008;
- Symposium Gravity, Geoid and Earth Observation, Chania, Greece, 23-27 June 2008;
- Sessions at the 37th COSPAR General Assembly, Montreal, Canada, 01-05 July 2008;
- 16th International Symposium on Earth Tides, Jena, Germany, 01-05 September 2008;
- Journées 2008 “Systemes de reference spatio-temporels”, Dresden, Germany, 22-24 September 2008;
- 9th European VLBI Network Symposium, Bologna, Italy, 23-26 September 2008;
- 16th International Workshop on Laser Ranging, Poznan, Poland, 13-17 October 2008;
- International DORIS Service (IDS) Workshop, Nice, France, 12-14 November 2009;
- Several Sessions co-organized by the Commissions at the AGU Fall Meeting, San Francisco, California, USA, 15-19 December 2008.
- 3rd Workshop Deformation and Gravity, Lanzarote, Spain, February 23–26, 2009;
- Workshop on Radio Frequencies and Feeds, Wettzell, Germany, March 18–21, 2009;
- 10th Anniversary of International VLBI Service, Bordeaux, France, March 25, 2009;
- International VLBI Service (IVS) Workshop, Bordeaux, France, March 26, 2009;
- 5th IVS Technical Operations Workshop, Westford, USA, April 27–30, 2009;
- European Reference Frame (EUREF) Symposium, Florence, Italy, May 27–30, 2009;
- Training School on GIA Modelling. Gävle, Sweden, June 1–5, 2009;
- 8th International Workshop on e-VLBI Science, Madrid, Spain, June 22–26, 2009;
- Global Geodetic Observing System Workshop, Espoo, Finland, June 23–26, 2009;
- VII Hotine-Marussi Symposium Theoretical Geodesy, Rome, Italy, July 6–10, 2009;
- IAG-SIRGAS School on Reference Systems, Bogotá, Colombia, July 13-17, 2009;
- 16th Advisory Board on the Law of the Sea (ABLOS) conference, Nusa Dua Bali, Indonesia, August 4–5, 2009;
- IAG Scientific Assembly 2009, Buenos Aires, Argentina, Aug. 31 – Sept. 4, 2009;
- SIRGAS General Meeting, Buenos Aires, Argentina, August 31 – September 4, 2009;
- International Geoid School, Buenos Aires, Argentina, Sept. 7–11, 2009;
- ILRS Technical Workshop on SLR Tracking, Metsovo, Greece, Sept 14–19, 2009;
- International Earth Rotation and Reference Systems Service (IERS) Workshop on EOP Combination and Prediction, Warsaw, Poland, October 19–21, 2009;

- 2009 Workshop on the North American Geoid, Boulder, USA, October 21–23, 2009;
- GGOS Intergovernmental Committee, Frankfurt, Germany, November 2–3, 2009;
- Second GGOS Unified Analysis Workshop, San Francisco, USA, Dec. 11–12, 2009;
- International VLBI Service for Geodesy and Astrometry (IVS) 2010 General Meeting, Hobart, Australia, February 07-14, 2010;
- V Congreso Internacional de Agrimensura, Havanna, Cuba, March 02-05, 2010;
- Geophysics, Geodesy and Tectonics of the North Africa Plate Boundary for Better Earthquake and Tsunami Hazard Assessment, Algiers, Algeria, May 15-21, 2010;
- European Reference Frame (EUREF) Symposium, Gävle, Sweden, June 02-06, 2010;
- Second Workshop on Application of Artificial Intelligence and Innovations in Engineering Geodesy, Braunschweig, Germany, June 16, 2010;
- Beacon Satellite Symposium, Barcelona, Spain, June 07-11, 2010;
- IAG School on Reference Frames, Mytilene, Lesvos, Greece, June 07-12, 2010;
- IAG Symposium on Terrestrial Gravimetry: Static and Mobile Measurements, St. Petersburg, Russia, June 22-25, 2010;
- 10th International Geoid School, St. Petersburg, Russia, June 28 – July 02, 2010.
- IGS Workshop and Special Workshop on Vertical Rates from GPS, Newcastle, UK, June 28 – July 2, 2010;
- 15th General Assembly of WEGENER, Bogazici University, Istanbul, Turkey, September 14-17, 2010;
- 2nd General Assembly of the IGFS - International Gravity Field Service Fairbanks, Alaska, USA, September 20-22, 2010;
- IAG Commission 1 Symposium 2010. Reference Frames for Applications in Geosciences (REFAG2010), Marne-La-Vallée, France, October 04-08, 2010;
- 9th International e-VLBI Workshop, Perth, Australia, October 10-20, 2010;
- IGCP 565 Workshop 3: Separating Hydrological and Tectonic Signals in Geodetic Observations, Reno, Nevada, USA, October 11-13, 2010;
- International DORIS Service (IDS) Workshop, Lisbon, Portugal, October 21-22, 2010;
- Observing and Understanding Earth Rotation, Shanghai, China, October 25-28, 2010;
- Sixth ABLOS Conference, Monaco, Monaco, October 25-27, 2010;
- Second SIRGAS School on Reference Systems, Lima, Peru, November 08-10, 2010;
- SIRGAS 2010 General Assembly, Lima, Peru, November 11-12, 2010.
- Cryosat Validation Workshop, Frascati, Italy, February 1-3, 2011.
- 20th EVGA Meeting &12th Analysis Workshop, Bonn, Germany, March 29-31, 2011.
- 4th GOCE Workshop, Munich, Germany, March 31 - April 1, 2011.
- 1st International Workshop on The Quality of Geodetic Observation and Monitoring Systems, Garching/Munich, Germany, April 13-15, 2011.
- Third Conference on Earth Observation for Global Changes (EOGC2011), Munich, Germany, April 13-15, 2011.

- 17th International Workshop on Laser Ranging and 23rd General Assembly of the International Laser Ranging Service, May 15-20, 2011, Bad Kötzting, Germany.
- EUREF 2011 Symposium, Chisinau, Republic of Moldova, May 25-28, 2011.
- 2nd GIA Modeling Training School, Gävle, Sweden, 13-17th June 2011.

Publications

The Journal of Geodesy, the official IAG scientific periodical with an Editorial Board approved by the IAG Executive Committee, was continuously published with monthly issues in Springer-Verlag. In the IAG Symposia Series, with the IAG President as the Series Editor, and also published in Springer, the following volumes were published:

132: VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy (2008);

133: Observing our Changing Earth, Proceedings of the IAG General Assembly (2009);

134: Geodetic Reference Frames, Proceedings of Commission 1 Symposium (2009);

135: Gravity, Geoid and Earth Observation, Proc. of Commission 2 Symposium (2010).

136: Geodesy for Planet Earth, Proceedings of the IAG Scientific Assembly (2011).

The Reference Book on GGOS was published as a monograph in Springer-Verlag, and the IAG Reports (Travaux de l'AIG) 2007 – 2009 were published by the IAG Office.

Awards, anniversaries, obituaries

The following medals and prices have been awarded:

- Levallois Medal to C.C. Tscherning, Denmark (2007);
- Bomford Prize to M. Furuya, Japan (2007);
- Young Author Award to Steffen Schön, Germany (2007);
- Order of Merit of the Federal Republic of Germany to Hermann Drewes (2008);
- Young Authors Award to Franziska Wild-Pfeiffer, Germany (2009).

The Levallois Medal, the Bomford Prize, and the Young Author Award will also be granted at the IUGG General Assembly, Melbourne 2011.

The following anniversaries were celebrated with IAG participation:

- 70^{th} Birthday of the former IAG and IUGG President, Helmut Moritz, Berlin, 15 November 2008;
- 50^{th} Anniversary of the German IUGG adhering body "Bundesamt für Geowissenschaften und Rohstoffe", Hannover, Germany, 25 November 2008;
- 10^{th} Anniversary of the International VLBI Service for Geodesy and Astrometry, Bordeaux, France, 25 March 2009;
- 80^{th} Birthday of the former IAG President, Wolfgang Torge, Hannover, Germany, 7 June 2011.
- 150^{th} Anniversary of the Swiss Geodetic Commission, Zürich, Switzerland, 10 June 2011.

Obituaries were written for former IAG officers and outstanding geodesists who passed away:

- István Joó, Hungary (2007);
- Carlo Morelli, Italy (2008);
- Lubomir Wlodzimerz Baran, Poland (2009);
- Kurt Bretterbauer, Austria (2009);
- Werner Gurtner, Switzerland (2009);
- Irene Fischer, USA (2009);
- Leif Svensson, Sweden (2010);
- Arne Bjerhammar, Sweden (2011).

Meetings-Annual-Reports
– Overview –

The IAG Office provides regularly reports on its activities as well as IAG EC Meetings. All texts are freely available from the IAG Website *http://www.iag-aig.org/* see "IAG Office" or directly at *http://iag.dgfi.badw.de/*

The following texts have been compiled within the last period:

title	link
The **Geodesist's Handbook** is published in four year intervals on the occasion of the IUGG General Assemblies. It contains the IAG Statutes, Bylaws and Rules, a compendium of the IUGG General Assembly, and the detailed structures and descriptions for the upcoming period.	
Geodesist's Handbook 2008, Springer Online	http://www.springerlink.com/content/g8710278767l84l2/ fulltext.pdf
Geodesist's Handbook 2008 (frequently updated internet version)	http://iag.dgfi.badw.de/index.php?id=298
The **IAG Reports (Travaux de l'Association Internationale de Géodésie)** comprise the reports of all the IAG components and sub-components presented at the IAG General and Scientific Assemblies. They were published as printed volumes from 1923 to 1995. Since 1999 the IAG Reports are available in digital form (CD and/or online).	
IAG Reports 2007-2009 (Travaux de l'AIG Vol. 36)	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Travaux_ 2007-2009.pdf
The **IAG Annual and Quadrennial Reports** are prepared by the IAG Office to inform the IUGG on the activities of the IAG Components and Administration.	
IAG Annual Report to IUGG 2007.pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/IAG_Annual_ Report_2007.pdf
IAG Annual Report to IUGG 2008.pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/IAG_Annual_ Report_2008.pdf
IAG Annual Report to IUGG 2009.pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/IAG_Annual_ Report_2009.pdf
IAG Annual Report to IUGG 2010.pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/IAG_Annual_ Report_2010.pdf
IAG Quadrennial Report to IUGG 2011.pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/IAG_ Quadrennial_Report_2007-2010.pdf

The summaries of the **Meetings of the IAG Executive Committee** are to inform the geodetic community on the principal discussion and decisions. The full texts are available by password for EC-Members only.	
Meeting Summary 1st IAG EC 2007-2011 (Perugia, July 10, 2007)	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_1st_IAG_EC_2007-2011.pdf
Meeting Summary 2nd IAG EC 2007-2011 (San Francisco, Dec. 8, 2007).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_2nd_IAG_EC_2007-2011.pdf
Meeting Summary 3rd IAG EC 2007-2011 (Vienna, Apr. 19, 2008).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_3rd_IAG_EC_2007-2011.pdf
Meeting Summary 4th IAG EC 2007-2011 (San Francisco, Dec. 14, 2008).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_4th_IAG_EC_2007-2011.pdf
Meeting Summary 5th IAG EC 2007-2011 (Buenos Aires, Aug. 30, 2009).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_5th_IAG_EC_2007-2011.pdf
Meeting Summary 6th IAG EC 2007-2011 (Vienna, May 2, 2010).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_6th_IAG_EC_2007-2011.pdf
Meeting Summary 7th IAG EC 2007-2011 (San Francisco, December 12, 2010).pdf	http://iag.dgfi.badw.de/fileadmin/IAG-docs/Meeting_Summary_7th_IAG_EC_2007-2011.pdf