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Introduction

The reports of the International Association of Geodesy are published continuously since 1923 (Tome 1). At the beginning these reports were called “Travaux de la Section de Géodésie de l’Union Géodésique et Géophysique Internationale“, and since 1938 “Travaux de l’Association de Géodésie”. They were published on 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. Until 1995 (Volume 30) the reports were published 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 36 contains the reports of all IAG components for the period 2007 to 2009 and is presented to the IAG Scientific Assembly in Buenos Aires/Argentina, August/September 2009. In addition, the annual reports of the IAG Secretary General and the meetings summaries of the IAG Executive Committee are included; thus a complete overview of the activities of the past two years is presented.

The editors thank all the authors for there work and ask for a feedback of the readers. 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
IAG Secretary General

Helmut Hornik
Assistant Secretary

Commission 1 - Reference Frames

http://iag.ensg.ign.fr

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

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Overview

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.

Introduction

The main activities of Commission 1 during the period 2007-2009 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 president's sub-commissions and sub-component to reflect changes and continuous activities of all commission entities.
- A Steering Committee meeting was 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.
- Participation in COSPAR GA held in Montreal, July 2008 and in Hotine Marussi symposium in Rome, July 2009.
- It goes without saying that the main activities were undertaken by the commission sub-components as presented in the rest of this mid-term 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 main activities of SC-1.2 are: increase of the number of GNSS permanents stations within the 6 regional sub-commissions; the establishment within SIRGAS of five associated analysis centres under the responsibility of Latin American and Caribbean institutions; for NAREF, realization of densifications of the ITRF and IGS global networks by weekly combinations of six different regional weekly solutions using different GPS processing software packages; for AFREF, creation of an Operational Data Centre (ODC) for AFREF with an open data policy, expected to be operational within the second half of 2009; for Asia & Pacific, 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; and finally for Antarctica, the realization of SCAR GPS Campaigns in

2008 and 2009 where the data of 34 Antarctic sites are collected in the SCAR GPS database beginning with the year 1995.

Additionally, one of the main new initiatives of SC-1.3 is the creation of an inter-regional 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. A first set of preliminary regional combined solutions is prepared for June 2009. The preliminary solution resulting from the combination of the preliminary regional SINEX solutions with long-term solutions from global networks will serve to identify problems and help to set strategic choices and guidelines. Some problems encountered up to now are being solved. A new solution is expected to be issued in 2010-2011.

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

The main highlight of SC-1.4 activities includes the analysis of ICRS definition in view of the latest development in astrometry and space geodesy as well as the analysis to generate the next realization of the ICRS (ICRF2) at microwave frequencies using VLBI data.

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.

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 geocentre 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), geocentre 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.
- JPL is studying a satellite project specifically dedicated to the co-location of the space geodetic techniques onboard a new satellite. This will be complementary to the co-location efforts on the ground.
- A new IERS Working Group has been formed 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.

Working Group SC 1.1 - WG 1: Comparison and Combination of Precise Orbits Derived from Different Space Geodetic Techniques

Chair: Henno Boomkamp (Germany)

The main interest of the Working Group remains to improve techniques of comparing and combining precise orbit solutions based on different space geodetic techniques, in support of the more generic objectives of IAG Commission 1 and GGOS. As a result of propositions and discussions held during the reporting period, a new approach is proposed in this field and will be the main subject of this report.

The DANCER project

The DANCER system forms an internet-based solution approach to construct least squares estimation processes for an *unlimited* station network size. In this method, the normal matrix contributions from individual geodetic instruments are accumulated on a local PC at the ground station. All station-dependent parameters (station coordinates, clocks, troposphere delays, etc.) are pre-eliminated from the normal equation system by the local estimation process (see Figure 1 and Eq. 1). The remaining global normal matrix partition is exchanged among all participating computers via internet, using a highly efficient scheme called *square dancing*. This algorithm provided the name DANCER, which also reflects a close relation to the DIGGER project that will be revisited further below. After the square-dance matrix accumulation process, all PCs in the network hold the same global matrix partition. This allows every individual computer to solve the global parameter corrections $\vec{x}_A$ for Earth rotation parameters and satellite parameters. The global solution vector $\vec{x}_A$ is substituted in the pre-elimination equations (1) to find the local parameter corrections $\vec{x}_C$ of the station. The entire least squares solution is iterated to convergence.

The outcome of this distributed estimation process is mathematically identical to a single least squares solution for all involved observations and parameters, but can include many thousands of stations. While no individual analysis centre would be able to handle such a large estimation process, the DANCER processing effort at individual tracking stations is rather modest. The involved internet traffic is in the order of 50 megabytes per station per solution, which is a trivial load for modern internet connections. The DANCER solution process can span an arc of e.g. the most recent 48 hours and is repeated at regular intervals, e.g. every two hours, in analogy to current IGS products.

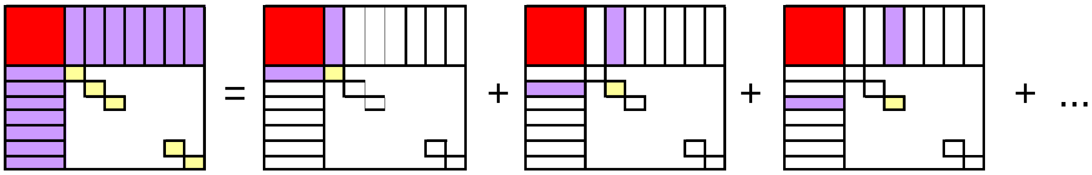

Figure 1: Normal matrix of a least squares process, written as the sum of contributions from individual geodetic instruments. The global (red) partition requires summation of many contributions, but other partitions (yellow, purple) are only relevant to a single receiver. These station-dependent partitions are pre-eliminated and only the global partitions are exchanged.

$$\begin{pmatrix} A & B \\ B^t & C \end{pmatrix}\begin{pmatrix} \vec{x}_A \\ \vec{x}_C \end{pmatrix} = \begin{pmatrix} \vec{b}_A \\ \vec{b}_C \end{pmatrix} \Rightarrow \begin{cases} A\vec{x}_A + B\vec{x}_C = \vec{b}_A \\ B^t\vec{x}_A + C\vec{x}_C = \vec{b}_C \end{cases} \tag{1}$$

$$\vec{x}_C = C^{-1}\left(\vec{b}_C - B^t\vec{x}_A\right) \Rightarrow \left(A - BC^{-1}B^t\right)\vec{x}_A = \vec{b}_A - BC^{-1}\vec{b}_C$$

Eq. 1: Pre-elimination of a station-dependent vector $\vec{x}_C$ provides an equation for the global parameter corrections $\vec{x}_A$ only. Matrix A corresponds to the red partition of Figure 1, matrix B is the purple correlation block, and matrix C is a yellow station-dependent partition.

Square dance method

It is clear that the DANCER solution depends on the efficiency with which the global normal matrix information can be exchanged via internet. This turns out to be remarkably simple with an accumulation method called square dancing. In this approach, pairs are formed among all computers in the network. The two computers in each pair exchange their matrix contributions and add the incoming matrix to their own matrix (step 1 of Figure 2). New pairs are now formed between pairs of the first cycle (step 2 of Figure 2). Each computer exchanges its matrix with a computer of the other pair, and adds the incoming matrix to its own matrix. The four computers in the *pair of pairs* now hold the same sum of the four original matrix contributions.

In a third cycle, new pairs are formed between clusters of four computers from the previous cycle (step 3 in Figure 2), etc. It will be clear how this pair-wise exchange can be repeated as many times as necessary. Each consecutive cycle doubles the size of clusters with identical matrix sums. For a network of size N, only ${}^2\log N$ complete cycles are required to accumulate the global sum of all initial matrix contributions at all participating computers. In practice, the network size will not be an exact power of two, but this problem is easily solved. For instance, in a network of $N = 10{,}000$ computers, we find that $2^{13} < N < 2^{14}$. The largest power of two for which a complete exchange process is possible is $2^{13} = 8192$. To form a sub-network of exactly this size, 1908 computers simply upload their matrix to another computer in the network at the start of the process. The receiving computers add the incoming matrix to their own matrix, after which only 8192 independent matrix contributions remain that are added together in 13 square dance cycles. After completion, the 1908 computers that were left out of the process download the global sum, which already includes their own contribution.

Because of the exponential rate with which the normal matrix information disperses through the network, the square dance approach is insensitive to an increase in network size. As shown above, an individual computer in a network of 10,000 computers will perform at most 14 exchange cycles to obtain the global sum of *all* matrix contributions. For a network of 80,000 computers, only three additional cycles would be required ($2^3 = 8$). This adds just a few minutes to the communication process, which is irrelevant in comparison to the overall process duration and its repeat rate (~hours). Individual computers only need to contact about

15 different computers in the network, which means that the involved socket connections can be kept open throughout the solution process for reducing wait states. The overall complexity and data volume involved with the square dance matrix accumulation process is comparable to that of reading a newspaper on the internet.

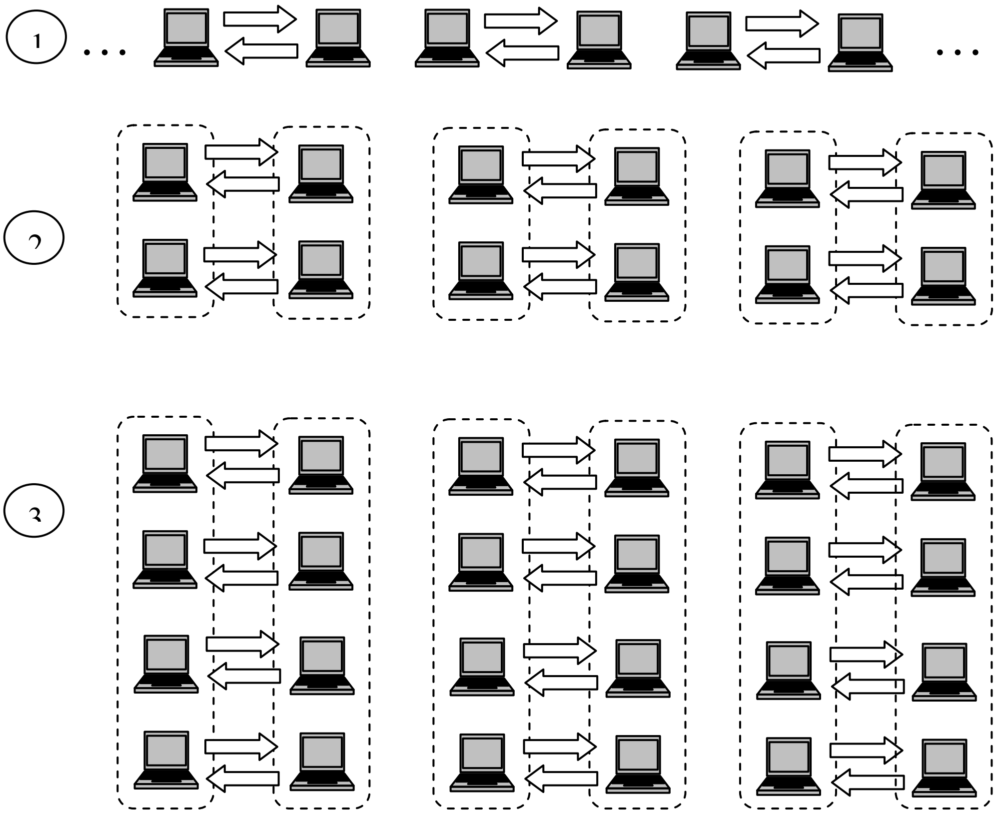

Figure 2: Square dance accumulation logic among a network of computers.

The above sections explain the basic concepts behind the DANCER solution, without going into all details. In practice, there are various complications that took some time to be solved. For instance, multiple layers of pre-eliminations and square dance exchanges are needed to cope with epoch-dependent parameters (GNSS clocks) and satellite-dependent parameters. A slightly different exchange mechanism is needed in support of GNSS ambiguity resolution. The DANCER system also involves a few centralized internet sites (hubs) where stations can *check-in* if they want to be part of the next global solution. The process needs various safety mechanisms, to cope with computers that go off-line in the middle of a solution process - etc. The concept is in fact conveniently redundant, because clusters of computers with the same intermediate matrix can immediately provide backup in case of unexpected loss of an individual computer, and spare computers can usually be found in a pool of unused participants (in the example above, there are 1908 spare computers). Such details fall outside the scope of this report, and do not change the principle of a distributed estimation process.

Consequences to IAG / GGOS

In terms of efficiency and possible solution size, distributed processing is expected to be orders of magnitude more powerful than the traditional centralized processing approach at Analysis Centres. The DANCER system does not really have any network size limit, because it is perfectly scalable: every new receiver brings its own computer, so that the workload for individual computers is only affected by a possible increase in exchange cycles – however, this will only add a few percent to the process duration. It could therefore be concluded that the centralized product generation of the current IAG services could benefit from such solutions and that in the long term such distributed estimation software could even be fully integrated with the software of high-end GNSS receivers and similar geodetic instruments: global estimation products like Earth rotation parameters will then become output products *of the receivers*.

The implications of a distributed processing approach for the current IAG and its services can be profound. Some effects will be:

- *All* permanent geodetic GNSS receivers in the world can be included in a single, coherent ITRF solution. The differences between regional networks and global networks disappear: all receivers become part of the same global GNSS network. This can lead to ITRF solutions based on ten thousands of receivers, as opposed to currently only 400. This solves most of the network densification issues.
- Most elements of the centralized IAG Services (data centres, analysis centres, product centres) could significantly benefit. The DANCER software transforms an individual geodetic instrument into a mini data centre, a mini analysis centre, and a mini product centre. Data and products may still be published by the station operator on a voluntary basis, but stations can also participate *anonymously* in the DANCER solution, sharing neither their data nor their products. It seems obvious that stations that want to be in a formal ITRF solution must always publish their data and their position coordinates, in order to allow independent validation.
- Combination solutions seem no longer required if all observations can be processed in a single, mathematically clean least squares solution. The DANCER solution may provide perfectly coherent estimation products for all involved receivers and tracking stations, and consistency between local and global estimation products.
- With DANCER, all GNSS processing is expected to be possible at a higher data rate than what is typically done by the IGS Analysis Centres today. This improves the signal-to-noise ratio and therefore the solution quality. A data rate of 30 seconds is foreseen, which also allows inclusion of data from orbiting receivers. To this purpose, the LEO download stations can run the DANCER software and the LEO orbit parameters become pre-eliminated "station" parameters. This conveniently avoids LEO data distribution issues (data publication latency) that in the past have lead to many discussions: the data does not have to be published at short latency, but can nonetheless contribute to the estimation of the pole in near real-time.
- High-end GNSS users anywhere in the world can run the DANCER software on their own PC, and join the next available global solution via internet. The user data is treated in exactly the same way as the observations from the reference sites (with the exception that no-net-rotation conditions etc. should only be derived from properly monumented geodetic sites). This means that users obtain precise ITRF coordinates and UTC time offsets for their own receiver from a *global* solution process, at accuracy levels that are currently only available to IGS stations. In other words: DANCER offers *direct access* to the ITRF and to UTC anywhere on the planet, maybe even replacing current techniques such as short-baseline differential GPS.
- Other geodetic instruments, in particular SLR stations, DORIS download stations and VLBI correlation centres can also join the global solution with their own data. These stations will then observe the *same* polar motion parameters that are estimated by the GNSS network, while their estimated station coordinates are subject to the *same*

Helmert constraints as the GNSS receivers. This global solution then provides perfect consistency among all space geodetic techniques, which forms the main objective of IAG Sub-Commission 1.1.

- *All* formal objectives of WG 1 may be accomplished simultaneously if the geodetic reference sites start using the DANCER software once available. The DANCER system would implement a true Global Geodetic Observation System by making all geodetic instruments *work together* via internet. This turns the network of instruments into a single sensor for polar motion, satellite orbits and other global parameters.

Implementation status of DANCER and DIGGER

The DIGGER project has been introduced via a previous report of the WG 1.1.1. (2007), and in a report to the IGS Governing Board (December 2007). It aims at fast reprocessing of space geodetic data by means of distributed processing (grid computing) on internet. DIGGER uses an iterative *conjugate gradient* solution to split a huge least squares process (spanning ~15 years of data) into thousands of manageable tasks. It uses a data exchange scheme similar to, but slightly different from, the DANCER square dance method to exchange the involved solution vectors.

The data traffic involved with DANCER is highly *in*sensitive to network size, but very sensitive to the size of the global matrix partitions. It would for instance be prohibitive to estimate a gravity field model with DANCER, while it is not a problem to include many thousands of stations in one solution. This means that DANCER is mainly suitable for computing large network solutions in near real-time, generating most of the typical products that are currently generated by IGS and other services, such as station coordinates, troposphere parameters, satellite orbits and polar motion parameters. DIGGER does not have a practical limitation on the number of global model parameters, as long as a sufficiently large number of computers participate in the process. This makes DIGGER suitable for estimating large geophysical models from long data periods (gravity field, tides, station velocities). The two projects are therefore complementary.

The implementation of the internet-based applications DIGGER and DANCER may be realised in C++ or JAVA, preferably in close collaboration between IAG Analysis Centres and industry.

The main element of both, DIGGER and DANCER, is compact, efficient and highly portable parameter estimation software. In fact, DIGGER really requires a single-binary / single control-file layout in order to be supported by the Berkeley Open Infrastructure for Network Computing (BOINC), which has been selected as the driver of the grid computing process for various strong reasons. For DANCER it is merely *convenient* if the software is as compact as a single binary, but this would not be strictly required. For both projects it is essential that the orbit estimation software is under strict configuration control, and that automatic updating via internet is supported. There are obvious advantages in using the same core parameter estimation software for DIGGER and DANCER:

- One development trajectory requires less effort than two separate trajectories
- The same modelling standards will automatically be used in re-processing and operational product generation
- Changes in (e.g.) IERS conventions or other processing standards only need to be implemented once and will always be consistent between the two systems

- The same computers that will be using DANCER might as well be used in the DIGGER project. If each station archives its own data, it can later reprocess that data for a DIGGER process, whenever requested. This means that a complete merge of the two systems may be an option in the long-term.

A suitable single binary orbit estimation system (ROBOD) is currently being implemented on behalf of ESOC, using state-of-art software engineering methods and several independent design optimizations. By the time of the previous IAG report (2007), this project was just moving from its prototype stage at ESOC towards formal implementation by industry. At the time of the current report, a first version was delivered, currently undergoing a critical design review. As soon as all relevant state-of-art precision levels are accomplished, such software could form the core of the DIGGER project. In fact, the prototype software had already been installed successfully under the BOINC grid computing software, showing the feasibility of the concept. However, a more comprehensive demonstration under realistic conditions combined with a thorough verification and validation campaign would be required in order to assess the full potential of the proposed solution.

Conclusion

Because the DANCER and DIGGER projects can accomplish most if not all objectives of WG 1 of Sub-Commission 1.1, and most objectives of other IAG sub-commissions and GGOS, it seems recommendable to pursue these two strategic targets further.

Working Group SC 1.1 - WG 2: Interactions and consistency between Terrestrial Reference Frame, Earth rotation, and gravity field

Chair: Detlef Angermann (Germany)

Objectives

Working Group 2 of Sub-Commission 1.1 "Coordination of Space Techniques" is a joint WG with Commission 2, Commission 3, and the Global Geodetic Observing System (GGOS).
The main research topics are:

- Study the theoretical and practical interactions/relationships between parameters and models describing the terrestrial reference frame (TRF), Earth rotation and the gravity field (e.g., low-degree spherical harmonic coefficients).
- 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

During the period of this report various activities related to the integration of geometry, Earth rotation and gravity, and the interactions between these three fields were carried out. 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. Two projects, that address various topics of this WG, are explicitly mentioned below:

- Within the GGOS-D project (funded by BMBF, 2005 – 2008), homogeneously processed observation time series have been generated for the different space geodetic observation techniques, as the basis for the computation of a GGOS-D terrestrial reference frame and for the generation of consistent, high-quality time series of site coordinates, Earth rotation parameters, quasar coordinates and low-degree harmonics of the Earth's gravity field. The project involves four institutions: GeoForschungsZentrum Potsdam (GFZ), Bundesamt für Kartographie und Geodäsie (BKG), Institut für Geodäsie und Geoinformation, Universität Bonn (IGG), and Deutsches Geodätisches Forschungsinstitut (DGFI), see Rothacher et al. (2007).

In the framework of 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" improvements have been achieved regarding the combination of geometric and gravimetric observations. A major focus was on the analysis of geophysical contributions to Earth rotation changes determined from geometric, gravimetric and altimetric space observations as well as from geophysical models (see for example Göttl and Seitz, 2009). The project started in 2006 and is now in the second funding period (2009-2012).

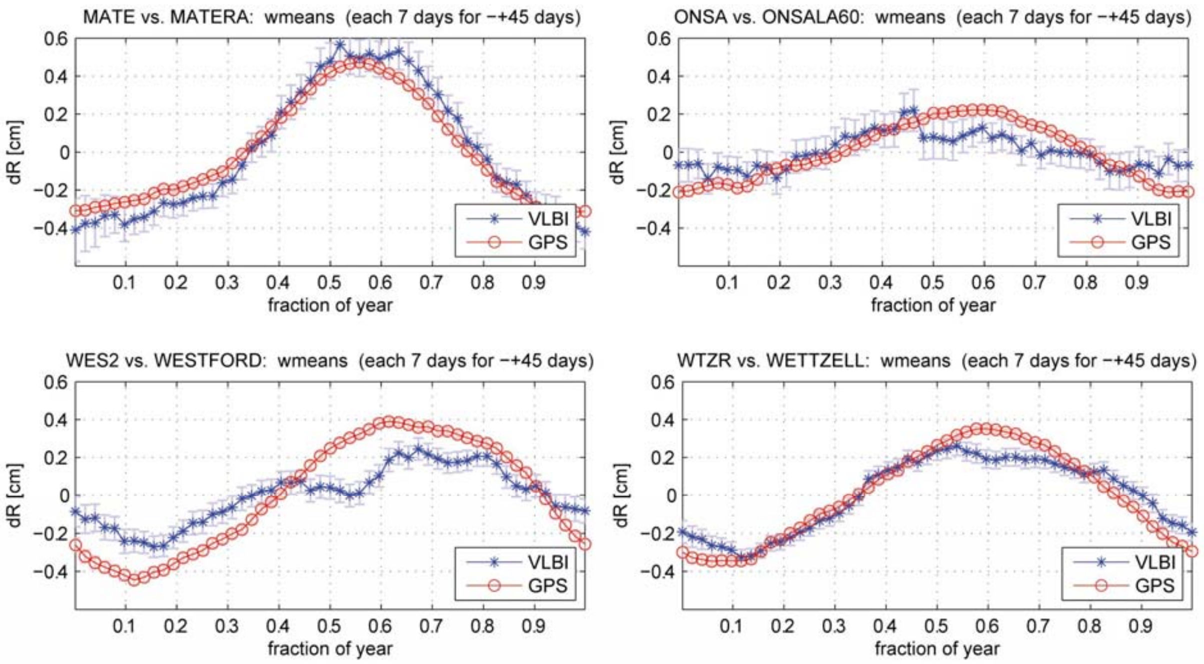

Fig. 1: Mean annual behavior of homogeneously processed VLBI (blue stars) and GPS (red circles) height time series at four co-location sites. The figures illustrate 90 days moving weighted means and their formal errors, computed each 7 days from the daily height estimates.

As an example for the working group activities we provide some results of the GGOS-D project. The time series analysis of station positions has shown non-linear variations of station positions, especially in the height component. Fig.1 shows the mean average of such annual variations for four GPS-VLBI co-location sites. The results were obtained from consistently processed VLBI and GPS observation time series, which have been generated in a joint effort by DGFI, GFZ Potsdam and Technische Universität München. The observed seasonal signals may be caused by atmospherical, hydrological and non-tidal oceanic loading effects, which are not reduced from the original observations.

A deficiency regarding the current strategy for the computation of long-term solutions is, that the temporal variations of station positions are described only by constant velocities. Deviations of the station motions from a linear model (e.g., seasonal variations) will produce errors in the products for the three fields (geometry, Earth rotation and gravity). A suitable handling of these seasonal variations in station positions is a challenge for the future.

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Working Group SC 1.1 - WG 3: Comparison and combination of atmospheric information derived from different space geodetic techniques

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.

As already summarized in the last Working Group 3 Report (Rothacher et al., 2007), 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. Snajdrova et al. (2005), Ichikawa et al. (2006), and Krügel et al. (2007) for the 15-days continuous VLBI campaigns CONT02 and CONT05, or Steigenberger et al. (2007) and Heinkelmann et al. (2007) for long time series from VLBI and GPS. In recent years, a common research project by several German institutions has dealt with the *Integration of Space Geodetic Techniques as the Basis for a Global Geodetic-Geophysical Observing System* (GGOS-D, Rothacher et al., 2009). More information about this project is available at the webpage *http://www.ggos-d.de*.

Some PhD. theses (partly in German) were finished in the last 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, and some results are extracted from them.

Troposphere delay comparisons

The best agreement of zenith delays between two techniques is found for GPS and VLBI with a standard deviation of about 5 mm, and it is shown by Schmid et al. (2005) and Schmid (2009) that the biases between the techniques decrease when using absolute phase centre patterns for GPS. However, there remains a significant influence on the zenith delays at those GPS antennas covered by a random.

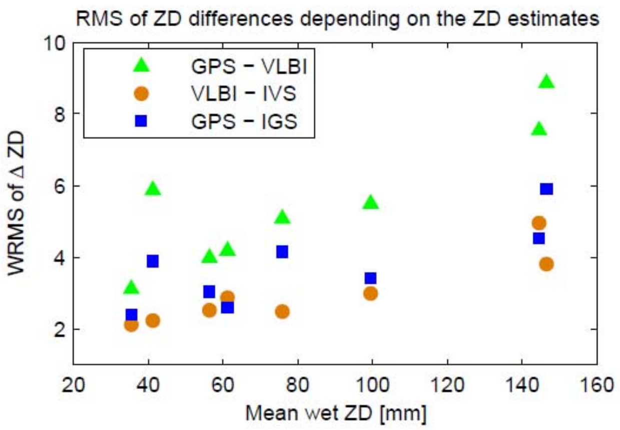

Figure 1 (from Thaller, 2008). WRMS of the zenith delay differences depending on the size of the estimated wet zenith delays. IVS refers to the combined solution of the International VLBI Service for Geodesy and Astrometry, VLBI is a dedicated VLBI solution using exactly the same geophysical models as the dedicated GPS solution.

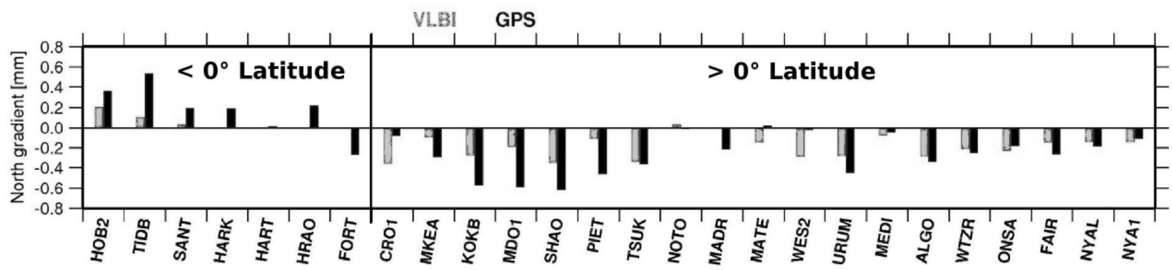

Figure 2 (from Nothnagel et al., 2009). Mean gradients in north-south direction of co-located VLBI and GPS stations.

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 recently developed GPT model (Boehm 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 (Boehm et al., 2006a) are more accurate, but new empirical mapping functions like GMF (Boehm 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.

For the combination of troposphere parameters from different space geodetic techniques, the normal equations have to be set up properly: the time intervals for the troposphere parameters should start at integer hours (e.g. 18:00 UTC) and at integer fractions of it (e.g. 18:15, or 18:30, ...), offset and rate should be set up for each interval, and the time intervals should be rather short because they can be concatenated at a later stage if necessary (Thaller, 2008). It is recommended to use piecewise linear offsets for the representation of troposphere parameters because these can easily be combined at a later stage.

Thaller (2008) concludes in her PhD. 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.

Within the 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. A first comparison between STEC values predicted by the IGS combination and the observed ones by DORIS (on board JASON) resulted in a standard deviation better than 1 TECU over all latitudes (Hernándes-Pajares, 2005). Hobiger et al. (2006) provided comparisons of TEC values between GPS and VLBI over the VLBI radio telescopes. They found a mean bias (VLBI minus GPS) above all sites of −2.8 TECU and an RMS of ±10 TECU.

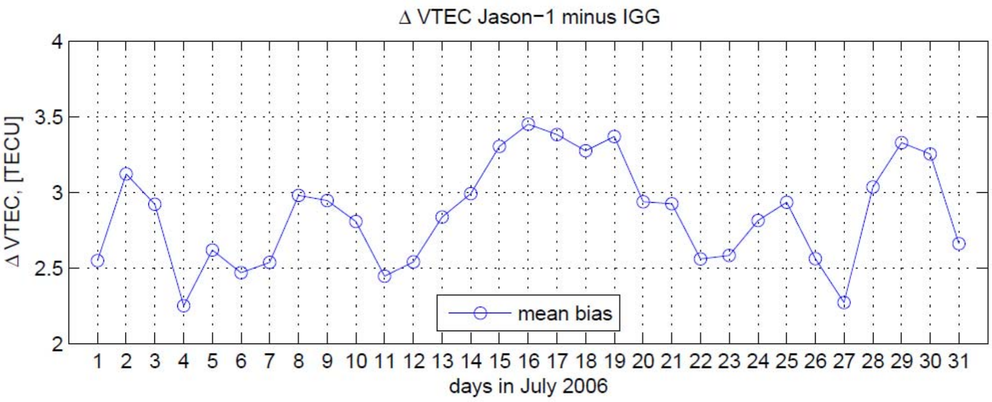

Figure 3 (from Todorova, 2009). Daily mean VTEC of the difference Jason-1 minus IGG VTEC in July 2006.

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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.
- 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.

The GGOS-D project has started some work at these frontiers, but 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 1n 2003 as a part of the new structure of the International Association of Geodesy (IAG).

Terms of Reference and Objectives for 2007-2010

Sub-Commission 1.2 is engaged in scientific research and practical aspects of the global reference frames. It investigates the requirements for the definition and realization of the terrestrial reference systems (TRS) and frames (TRF), addresses fundamental issues closely related to TRS, such as multi-technique global geodetic observatories (local ties, site effects, interdisciplinary use…) or methods for the combined processing of heterogeneous observation data. The work will be done in close cooperation with the International Earth Rotation and Reference Systems Service (IERS), in particular with the ITRS Product Centre, the other relevant IAG services (IGS, ILRS, IVS, IDS), and the IAG Global Geodetic Observing System (GGOS). Theoretical aspects (e.g., quality measures, relativistic modeling) will be investigated in cooperation with the Inter-Commission Committee on Theory.

The following research topics will form the fundamental objectives during the next period:

- Basic concepts and related terminology
- Improvement of relativistic modeling
- Fundamentals of the realization of the global terrestrial reference frames: co-location problems, local ties, datum problems (origin, scale and orientation, time evolution), coordinates origin, geo-centre, time series approach, long-term consistency with EOPs and ICRF…
- Analysis of strengths, weaknesses and systematic differences (biases) of individual techniques (VLBI, SLR, GPS, DORIS) related to their contribution to global combined TRF
- Combination methodologies of individual techniques' solutions and analysis of the underlying models, parameters, datum definitions etc.
- TRF by multi-technique data analysis
- Global Geodetic Observatories, concepts and practical implementation

Structure

President: Claude Boucher (France)

The sub-commission has an open membership. Current list is given in the list of members given below. Details about its activities will be given in its web page accessible through the IAG links.

Study Groups and Working Groups linked to SC1.2 :

IC-SG1: **Theory, implementation and quality assessment of geodetic reference frames** (jointly with ICCT) Chairman: Sakis Dermanis (Greece)

IC-WG3: **Concepts and terminology related to Geodetic Reference Systems** Chairman: Claude Boucher (France)

IC-WG4: **Site Survey and Co-location** (jointly with IERS) Chairman: Perguido Sarti (Italy) Link to IAG Commission 1: http://iag.ensg.ign.fr/

Activities for the period 2007-2009

This report provides only summaries of activities related to the Sub-commission. For more details or references, visit the web pages hosted by the IAG Commission 1 website.

Terminology

The IC-WG2 was specifically devoted to this subject. The group published a summary report detailed as a separate report in this document. In addition, a scientific paper is under preparation.

The new release of the IERS Conventions actually implement this terminology, through the active contribution of several members of the SC, either in drafting or within the IERS Convention Advisory Board chaired by Jim Ray.

Site survey and co-locations

This IERS Working Group is considering to reactivate its involvement in research topics, and therefore its re-link with the SC activities, thanks to Perguido Sarti who is now chairing this group.

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 geosciences 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 in the frame of 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.

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 in progress, ITRF2008.

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.

Members

Zuheir Altamimi (France)
Geoff Blewitt (USA)
Claude Boucher (France) President
Nicole Capitaine (France)
Xavier Collilieux (France)
David Coulot (France)
Sakis Dermanis (Greece)
Herman Drewes (Germany)
Johannes Ihde (Germany)
Sergei Klioner (Russia)
Gerard Petit (France)
Hans-Peter Plag (USA)
Jim Ray (USA)
Perguido Sarti (Italy)
Pascal Willis (France)

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 organisations.

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

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

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

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

In addition, 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 increase of the number of permanent GNSS tracking sites in Europe, (more than 200 EPN stations operated in 2009 by national European institutions) and of the number of sites which record GLONASS data simultaneously to GPS data and which stream real time data.
- The release of official updates of the ITRS/ETRS89 coordinates/velocities of the EPN (EUREF Permanent Network) stations in a regular mode, as a result of the ITRF densification in Europe.
- The creation of the EUREF Special Project "EPN Reprocessing" with the goal of reprocessing the long time series of numerous EPN stations, aiming on a consistent processing strategy and thus to receive more reliable results.
- The computation and publication of a new realization of the EVRS (European Vertical Reference System) under the name EVRF2007. This realization was proposed for adoption by the European Commission as the vertical reference for pan-European geo-information.
- 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) and in 2009 (Florence).

Sub-Commission 1.3 b: South and Central America

- The establishment of five associated analysis centres under the responsibility of Latin American and Caribbean institutions, and an additional experimental associated centre for computing ionospheric information based on the SIRGAS-CON.
- The organization of SIRGAS-CON in two hierarchical levels, the first one for providing the primary link to ITRF and the second one for densification at national level.
- The reprocessing of the SIRGAS-CON weekly solutions with absolute phase centre corrections and IGS05 as reference frame and the release of multiyear solutions.
- The start of a systematic study aiming at the improvement of the realization of the SIRGAS datum by three different strategies.
- The systematic adoption of official geodetic reference system at national level based on SIRGAS.
- The development of actions in order to promote SIRGAS in the countries that didn't adopt it yet, in particular the support to the establishment of new experimental associated analysis centres and the organization of the SIRGAS School on Reference Systems, under the sponsorship of the IAG and PAIGH.
- The Executive Committee met in Bogotá (2007) and in Montevideo (2008); the SC1.3b second workshop was held in Montevideo (2008).

Sub-Commission 1.3 c: North America

- The realization of densifications of the ITRF and IGS global networks by weekly combinations of six different regional weekly solutions using different GPS processing software.
- 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 centre variation models is underway.
- The continuation of the efforts aiming at the definition of a plate-fixed regional reference frame for North America stable at the sub-mm level. An updated version of the frame is currently under development and is expected to be released mid-2009. Two workshops on this subject were realized.
- The continuation of the activities related to the definition and maintenance of the relationships between international and North American reference frames/datums. Recent 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 one was a joint meeting held in June 2008 in Johannesburg which brought together representatives from the fields of seismology, meteorology, space weather, geophysics and geodesy.
- The progress made with the installation of permanent GNSS reference stations. These have been installed by National Mapping Agencies, Universities and research groups.
- The creation of an Operational Data Centre (ODC) for AFREF with an open data policy, expected to be operational within the second half of 2009.
- The realization of two training courses in 2007 and 2008 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. A similar course is to be held in August 2009 but with a greater emphasis on the practical aspects of the project.
- The application for funding submitted to the African Union Commission (AUC) and European Union (EU) for inclusion within the EU/ AU Lighthouse Projects.

Sub-Commission 1.3 e: Asia-Pacific

- 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 focussed on GPS observations but incorporated also other geodetic techniques, SLR and VLBI.
- The realization of additional annual, regional, GPS campaigns in 2007 and 2008, for both scientific research and local applications. Results from these campaigns have been submitted to the IAG Working Group on "Regional Dense Velocity Fields.
- 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 promotion of the application of new geodetic adjustment techniques and datum transformation parameters for regional spatial data integration and for geo-referencing cadastral information
- The support for the densification of continuous GPS installations in areas of earthquake and tsunami hazard.
- The meetings held in Seoul (2007), Kuala Lumpur (2008); the next meeting is planned for Bangkok (2009).

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. A first set of preliminary regional combined solutions is prepared for June 2009.
- The preliminary solution resulting from the combination of the preliminary regional SINEX solutions with long-term solutions from global networks will serve to identify problems and help to set strategic choices and guidelines. Some problems encountered up to now are being solved. A new solution is expected to be issued in 2010-2011.
- The WG met in Miami Beach (2008), San Francisco (2008) and Vienna (2009). 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.

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.

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". (www.euref-iag.net)

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 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 Euro-Geographics. The EUREF symposium 2008 took place in Brussels, Belgium and in 2009 in Florence, Italy.

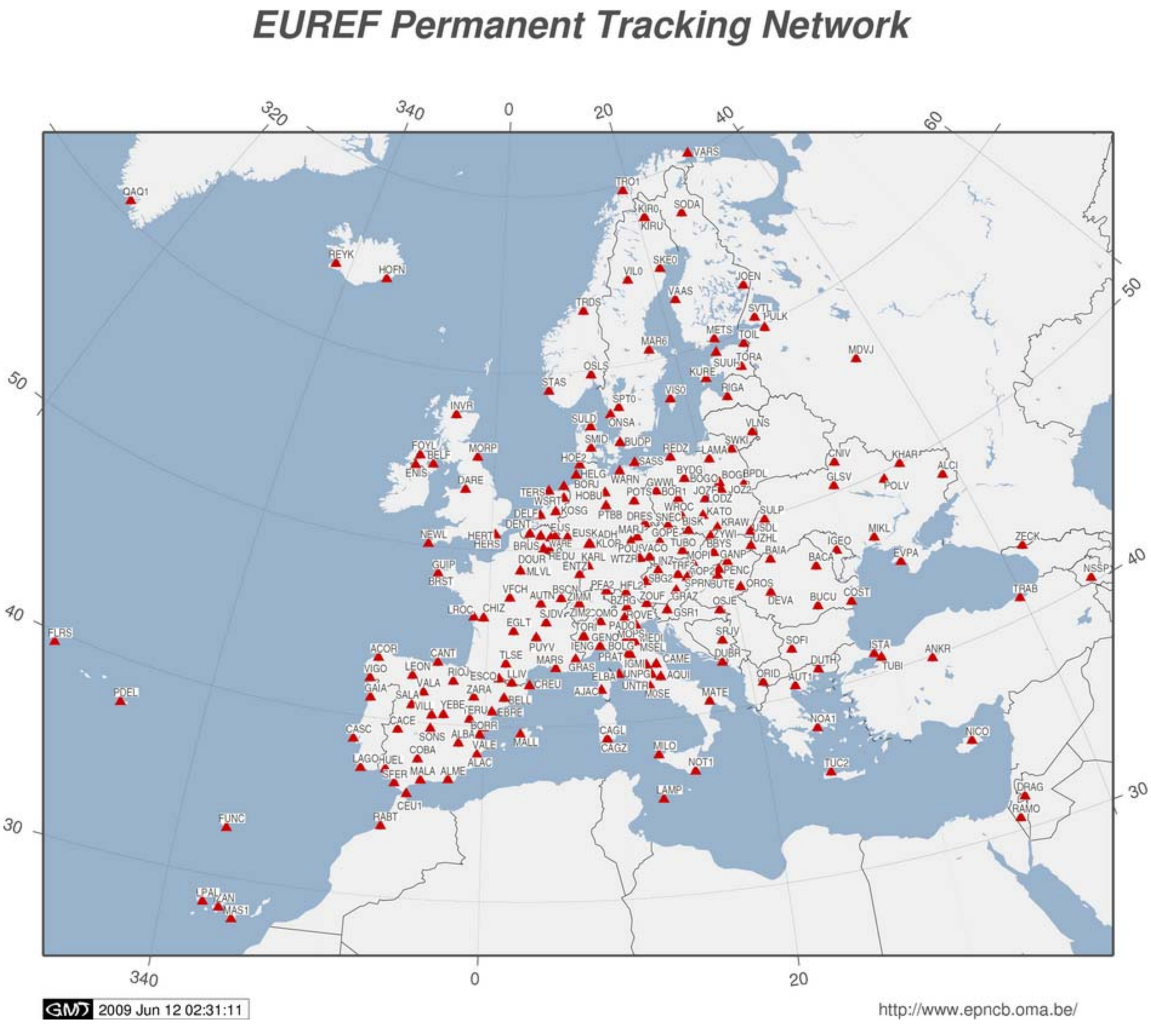
EUREF Permanent GNSS Network (EPN)

The EPN is a permanent GPS network created by the IAG Sub-commission for Europe (EUREF). Its primary objective is the creation and maintenance of the European Terrestrial Reference System 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 consists of a well-determined structure including GPS 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). As such, the EPN uses the same standards and exchange formats as the IGS.

Special Projects are set up by the EPN Coordination Group in order to introduce new applications into the EUREF Permanent Network 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. (www.epncb.oma.be)

The number of permanent GNSS tracking sites in Europe has grown considerably, more than 200 EPN stations are operated in 2009 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.



EUREF Permanent GNSS Network EPN

EUREF Densification of the ITRF

Even while the number of permanent GNSS tracking sites in Europe has grown considerably (more than 200 EPN stations in 2009), only a selection of these sites (mostly the ones belonging to the International GNSS Service – IGS) have coordinates included in recent ITRF realizations.

The latest realization of the ITRS, 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. In addition, the ITRF2005 has been computed with relative GNSS antenna models and coordinate offsets between solutions based on absolute antenna models and the ITRF2005 are significant. This problem will be resolved with the release of the ITRF2008 (expected for 2009) which will be compatible with absolute GNSS antenna models.

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 regular official updates of the ITRS/ETRS89 coordinates/velocities of the EPN stations. A first step in this process consisted in a densification of the ITRF2005 using all EPN data up to Dec. 2005 (the same observation period as covered by the ITRF2005). This release (Kenyeres, 2008) known as EPN_C1355 (ITRF2005) for the ITRS and the corresponding EPN_C1355 (ETRF2000) for the ETRS89 has been distributed to the EUREF community through EUREF mail 4142 on Dec. 12, 2008. As decided at the EUREF TWG meeting of Feb. 26-27 2009 in Budapest, this densification is replaced each 5 weeks by a new EUREF realization of the ITRF. The advantage of regularly updating the realization is that the most recent EPN results are taken as much as possible into account.

EPN reprocessing activities

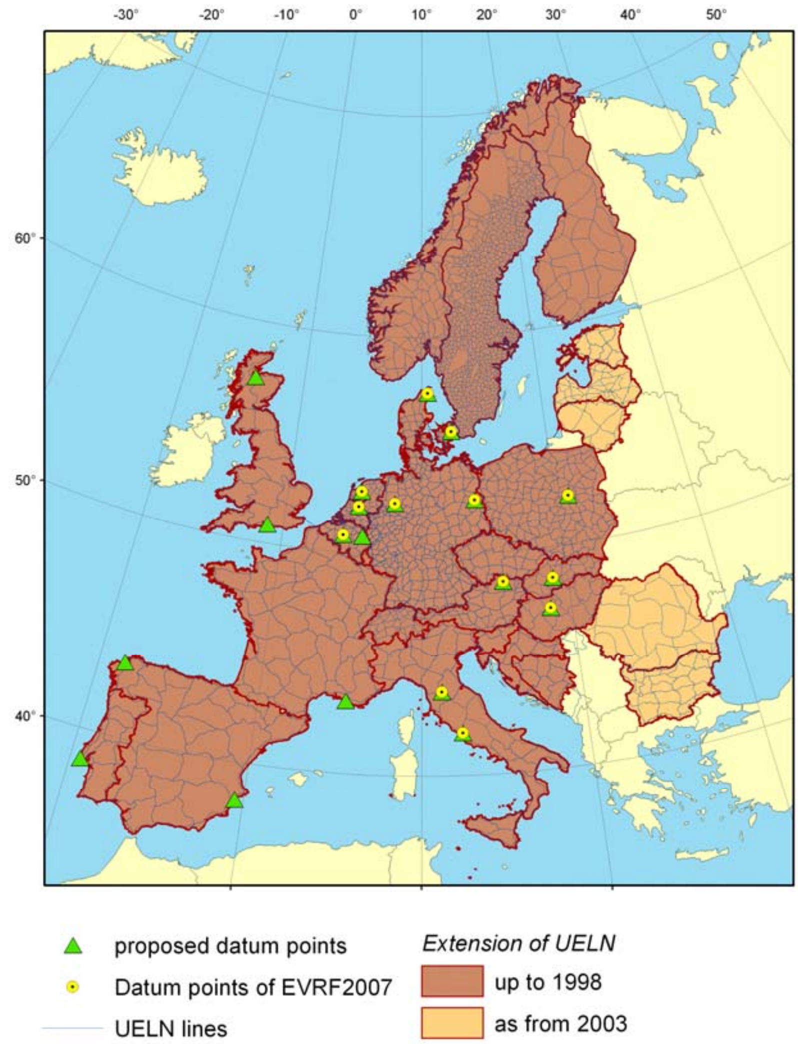
Inconsistencies in the long coordinates and time series are occurring, especially after changes of the modeling parameters. The plan to reprocess the long time series of numerous EPN stations aims on a consistent processing strategy and thus to receive more reliable results. A first attempt for reprocessing has been carried out by the Potsdam-Dresden-Group for the data sets from 1994 to 2007. On a call for participation all invited LACs declared to be willing to participate in this project. The majority of the EPN LACs is using the Bernese Software, some; however, make their data processing by other software packages. The comparison of the results basing on identical input data would be of special interest. The TWG finally decides to define a new EUREF Special Project "EPN Reprocessing". It is agreed that possibly several steps of subsequent solutions will be necessary to yield a satisfying result. The TWG has formed a Working Group with about 10 members (LACs, members of large) to investigate this problem in detail. A call for participation should be sent out inviting everybody who is interested and ready to contribute is invited to participate.

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). Half 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 uplift 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 which proposes to the European Commission that EVRF2007 is adopted as the vertical reference for pan-European geo-information.

The availability of EVRF2007 necessitates an update of the Geodetic Information and Service System CRS. Transformation parameters between national height systems and EVRF2007 will be calculated and provided at http://crs.bkg.bundde/crs-eu/ before the end of 2008. After providing the EVRF2007 results the development of the UELN will be continued.

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.



EVRF2007

ECGN continuation

The ECGN is considered as a European contribution to the IAG Project Global Geodetic Observation System (GGOS). The primary concern of the project consists in connecting the height component with the gravity determination while allowing for measuring data that are acquired in the European coastal regions and above adjacent seas. As objectives of the ECGN as an integrated European Reference System for Spatial Reference and Gravity are to be noted:

- maintenance of a long term stability of the terrestrial reference system with an accuracy of 10'-9 for Europe especially in the height component,
- in-situ combination of geometric positioning (GPS) with physical height and other Earth gravity parameters in 1 cm accuracy level,

- modeling of influences of time-dependent parameters of the solid Earth, of the Earth gravity field, the atmosphere, the oceans and the hydrosphere for different applications of positioning.
- the modeling of gravity field components to validate the satellite gravity missions CHAMP, GRACE and GOCE,
- present a platform for further geo-components (GMES, GEOSS. GGOS).

As input data the records of techniques such as VLBI, SLR, GNSS, DORIS, leveling, tides gauges, gravimeters (absolute, superconducting, spring) are mentioned. Initially about 70 stations were selected to form the ECGN, later the number was reduced to about 50 as the other ones turned out to be not suitable.

Sub-Commission 1.3b: Regional ReferenceFrame 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 unified 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 two opportunities for evaluating the ongoing and forthcoming activities. The first meeting was held in Bogotá (Colombia), on June 7 – 8, 2007 (reported in SIRGAS Newsletter No 12); and the second one in Montevideo (Uruguay), on May 28 – 30, 2008 (reported in SIRGAS Newsletter 13). In addition, the SC1.3b – WG1 held its second workshop in Montevideo (Uruguay), on May 26 – 27, 2008, intended to improve the strategy used by the associated analysis centres.

As already informed in the previous report of this SC, during the first SC1.3b – WG1 workshop (Rio de Janeiro, Brazil, August 16 – 18, 2006), five associated analysis centres were established under the responsibility of Latin American and Caribbean institutions, namely: IGN and IGG-CIMA (Argentina), IBGE (Brazil), IGAC (Colombia), and INEG (Mexico). Soon after, an experimental period started aimed to assess the reliability of those centres (in the meantime, the DGFI continued to be in charge of the official processing of the entire network as IGS – RNAAC – SIR). An additional experimental associated centre was established at the UNLP (Argentina) for computing ionospheric information based on the SIRGAS continuously observing GNSS network (SIRGAS-CON).

The results of the above mentioned experiment were evaluated during the second SC1.3b – WG1 workshop. Based on that assessment, the SIRGAS Executive Committee approved the following actions items that were immediately translated into the practice:

1. The status of the IGG-CIMA, IBGE, IGAC and UNLP associated analysis centres was changed from experimental to official.
2. SIRGAS-CON was divided in two hierarchical levels (Figure 1.3b.1): a core one (SIRGAS-CON-C), intended to provide the primary link to ITRF; and a densification one (SIRGAS-CON-D), which encompasses all the fundamental stations of the national networks and facilitates the accessibility to the reference frame. The D-network was further divided in three sub-networks identified as North (N), Middle (M) and South (S). All the stations included in C and Ds networks match the ITRF requirements.

3. The computation of the C-network was in-charged to DGFI, while the computation of the D-networks was in-charged to IGAC (D-N), IBGE (D-M), and IGG-CIMA (D-S).
4. All the networks (C+Ds) are weekly combined in a common solution by a combination centre under the DGFI responsibility; a second combination centre under the IBGE responsibility provides redundancy and back-up.

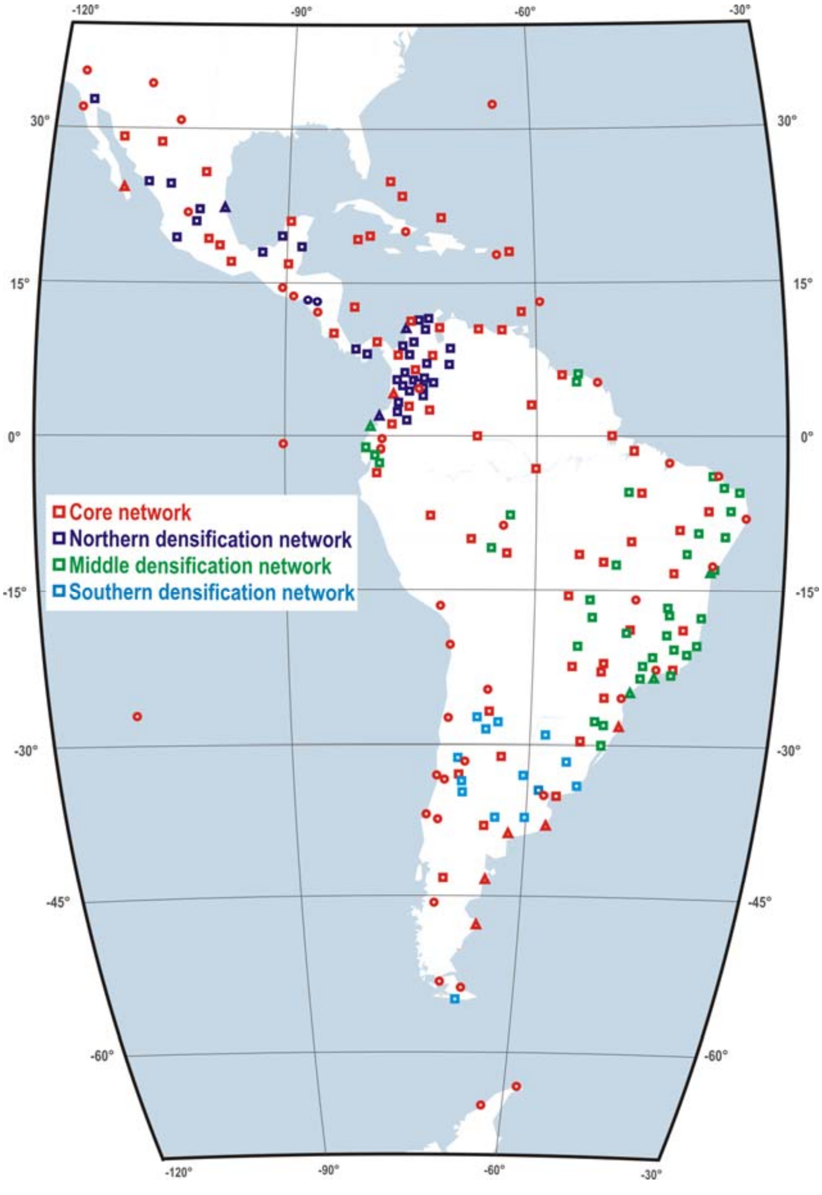


Figure 1.3b.1: SIRGAS-CON network: core and densification sub-networks.

Since August 31, 2008, each associated analysis centre delivers to the combination centres loosely constrained solutions for the assigned sub-network. All the sub-networks are individually aligned to the IGS05 reference frame by applying NNR + NNT conditions, and compared to IGS weekly values and to each other, in order to identify and reduce possible outliers from the individual normal equations. Later on, individual normal equations are accumulated and solved for computing a loosely constrained weekly solution for station coordinates, which is submitted to IGS for the global polyhedron and used to compute multiyear solutions for SIRGAS. Besides, a weekly solution constrained to IGS weekly coordinates is also computed and delivered to users.

At present, the main weakness of this strategy are caused by the facts that: i) SIRGAS-CON stations are unequally weighted in the weekly combinations because not all of them are included in the same number of individual solutions; ii) the redundancy to ensure that each station is processed by at least three processing centres is not fulfilled; iii) all the analysis centres use the same processing software. Actions are being undertaking for overcoming these limitations in the near future.

The SIRGAS-CON weekly solutions from January 2000 to November 2006 computed with relative phase centre corrections and referred to former ITRF solutions have been reprocessed including absolute phase centre corrections and IGS05 as reference frame. This provides homogeneously precise point positions and velocities for all SIRGAS-CON stations.

Periodically, as in-charged of the IGS-RNAAC-SIR, DGFI computes a new multiyear solution. The latest one, identified as SIR09P01, was released on June 2009 and encompasses all the weekly solutions provided by the associated analysis centres from January 2, 2000 (GPS week 1043) to January 3, 2009 (GPS week 1512). It is referred to IGS05 at 2005.0, precision was estimated to be better than ±0.5 mm (horizontal), ±0.9 mm (vertical) and ±0.8 mm/a (linear 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.

Recently, SC1.3b – WG1 performed a systematic study aimed to improve the realization of the SIRGAS datum. Three different strategies (NNR + NNT, constrained coordinates, and fixed coordinates) in combination with two different kinds of control coordinates (IGS weekly solutions, and IGS05 + linear velocities) were applied to a time series spanning from October 2006 (GPS week 1395) to December 2008 (GPS week 1512). Preliminary results have been described in an internal report that is being considered by the SIRGAS Steering Council with the aim of presenting some recommendation to the Executive Committee, during the next meeting that will be held in Buenos Aires, in conjunction with the IAG General Assembly.

At present, 13 of the 18 countries that participate in SC1.3b adopted an official geodetic reference system based on SIRGAS (Figure 1.3b.2). A great and successful effort is being carried out in order to increase the involvement in SC1.3b of a few South American countries and the majority of Central America and Caribbean countries, whose participation has not been as intense as desired. The expected target is that all the countries in the region can implement in-house facilities to maintain their national reference frames according to modern Geodesy the state-of-the-art. Two major actions are being performed in order to achieve that objective:

1. Promoting and supporting the establishment of new experimental associated analysis centres under the responsibility of Latin American and Caribbean institutions. At present, there are five centres in this category, namely: INEG (México), IGN (Argentina), IGM (Ecuador), LUZ (Venezuela), SGN (Uruguay). SC1.3b supports this enterprise by institutional agreements that facilitate the acquisition of processing software and providing training on its use. Training courses of this type have already taught for the experimental analysis centres installed or being installed in Ecuador, Uruguay, Peru and Chile.
2. The SIRGAS School on Reference System, which aims to provide the attendant with fundamental concepts needed for the appropriate generation and use of fundamental geodetic data. The first edition of this school will be held in Bogotá (Colombia), from July 13 to 17, 2009, under the sponsorship of the IAG and PAIGH. The program covers: i) geodetic reference systems; ii) coordinates determination from Global Navigation Satellite Systems (GNSS); iii) link between heights obtained from GNSS and those based on spirit levelling; iv) Geocentric Reference System for the Americas (SIRGAS); and v) spreading and application of SIRGAS products.

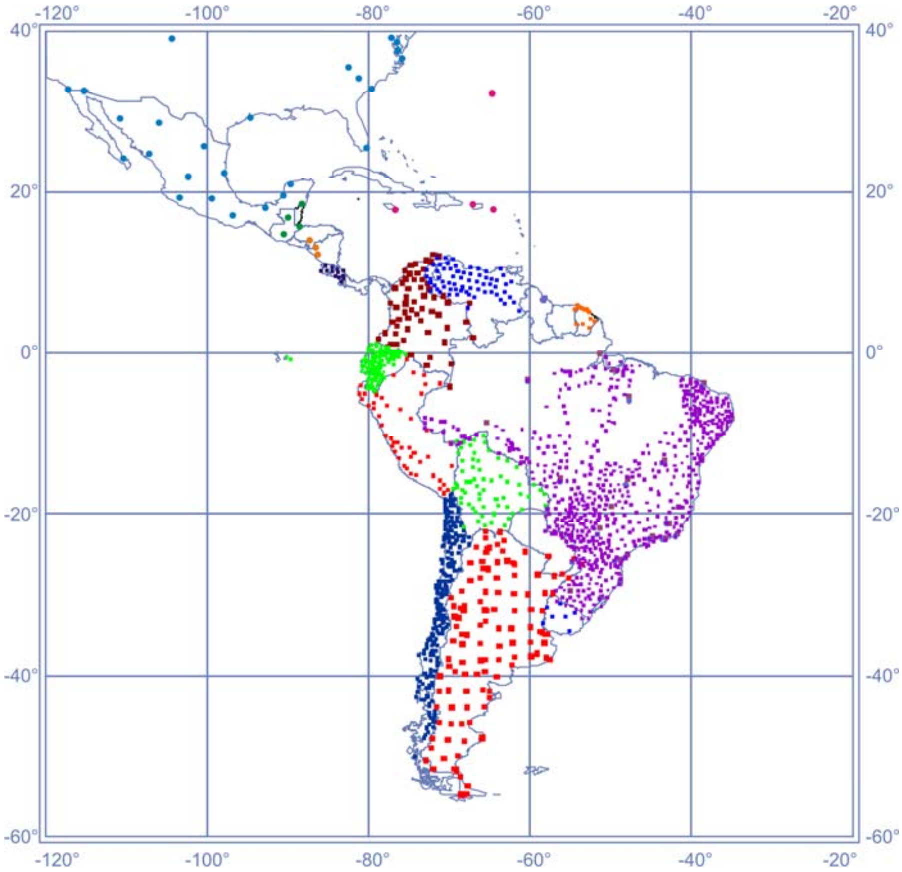


Figure 1.3b.2: National densification of SIRGAS.

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 neighbouring countries and the levelling of the 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.

SC1.3b has been represented in the following meetings:

SIRGAS: an international collaborative enterprise of the geodetic community in Latin America and the Caribbean. C. Brunini, L. Sánchez, H. Drewes, W. Martínez. In: 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.

SIRGAS: ITRF densification in Latin America and the Caribbean. L. Sánchez, C. Brunini, S. Costa, V. Mackern, W. Martinez, W. Seemüller, A. da Silva. In: European Geosciences Union, General Assembly 2009 (EGU 2009). Vienna, Austria. April 19 - 24, 2009.

SIRGAS: Base para las Geociencias, la Geoinformación y la Navegación. C. Brunini, L. Sánchez, H. Drewes. In: Reunión Científica 24 de la Asociación Argentina de Geodesia y Geofísica (AAGG). Mendoza, Argentina. April 14 - 17, 2009.

SIRGAS: Basis for Geosciences, Geodata, and Navigation in Latin America. C. Brunini, L. Sánchez. In: Semana Geomática Internacional. Barcelona, Spain. March 3 - 5, 2009.

SIRGAS report on the activities related to the IAG Working Group 'Regional Dense Velocity Fields' . L. Sánchez. In: Informal meeting of the IAG Working Group 'Regional Dense Velocity Fields'. AGU Fall Meeting. San Francisco, USA. December 15 - 19, 2008.

SIRGAS: reference frame for the GNSS applications in Latin America. L. Sánchez, C. Brunini. Presented by R. Neilan. In: Third Meeting of the International Committee on Global Navigation Satellite Systems (ICG). Pasadena, California, USA. December 8 - 12, 2008.

SIRGAS: Basis for Geosciences, Geodata, and Navigation in Latin America. L. Sánchez, C. Brunini. In: International Symposium on Global Navigation Satellite Systems, Space-based and Ground-based Augmentation Systems and Applications. Berlin, Germany. November 11 - 14, 2008.

Global vertical datum unification based on the combination of the fixed gravimetric and the scalar free geodetic boundary problems. L. Sánchez. In: IAG International Symposium on Gravity, Geoid and Earth Observation. Chania, Crete, Greece. June 23 - 27, 2008.

The Geocentric Reference System of the Americas (SIRGAS). C. Brunini, L. Sánchez. In: United Nations/Colombia/United States of America Workshop on the Applications of Global Navigation Satellite Systems. Medellin, Colombia. June 23 - 27, 2008.

IAG Sub commission 1.3b SIRGAS reference system: Ongoing activities. C. Brunini, L. Sánchez. Presented by M. Craymer. In: AGU 2008 Joint Assembly. Fort Lauderdale, Florida, USA. May 27 - 30, 2008.

The new position and velocity solution DGF07P01 of the IGS Regional Network Associate Analysis Center for SIRGAS (IGS RNAAC SIR). W. Seemüller, M. Krügel, H. Drewes, A. Abolghasem. In: AGU Fall Meeting. San Francisco, USA. December 10 - 14, 2007.

SIRGAS operations and the regional local cores network scene. S. A. Costa. In: 6th FIG Regional Conference. San Jose, Costa Rica. November 12 - 15, 2007.

SIRGAS: Sistema de Referencia Geocéntrico para las Américas C. Brunini. In: 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: Richard Snay (USA), Michael Craymer (Canada)

This sub-commission is composed of three active working groups and one inactive working group to be reactivated in 2009. The following summarizes the activities of each. For more information and publications related to these working groups, visit the regional Sub-Commission web site at <http://www.naref.org/>.

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

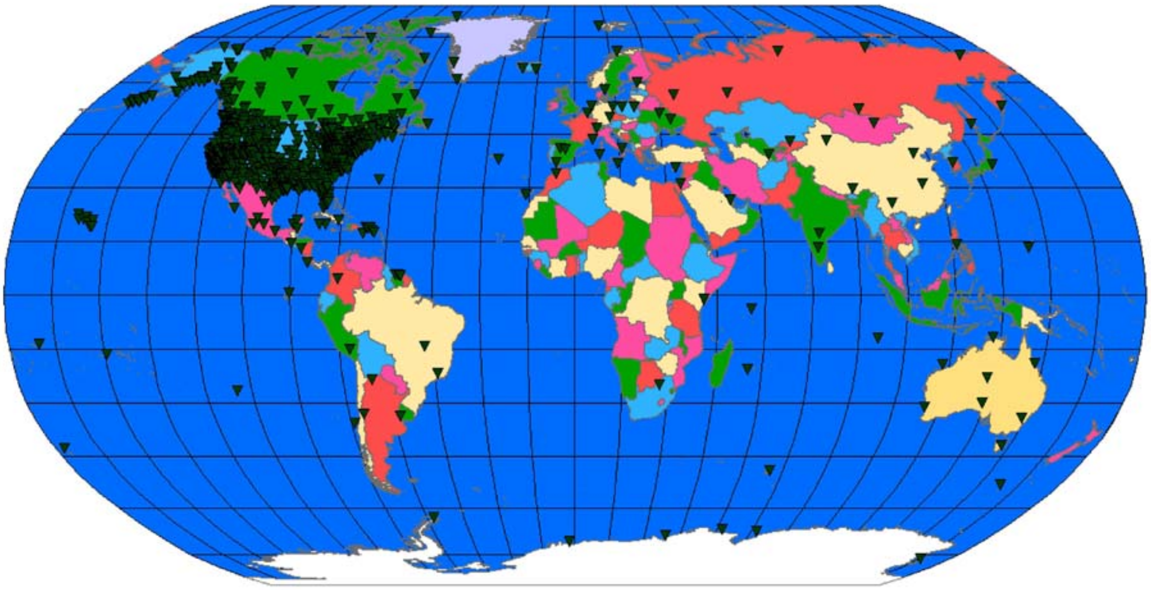
The objective of this WG is to densify the ITRF and IGS global networks in the North American region. The densification consists of weekly combinations of six different regional weekly solutions across the entire continent using four different GPS processing software. Current contributors and some details of their solutions are given in the following table.

NAREF weekly regional coordinate solution contributions.

Contributor	Software	Region	No. Stations (approx.)
MIT	GIPSY & Bernese Combo	Western North America	1100+ (~520+ used)
NGS	PAGES	US & territories & exico (CORS network)	1200+
NRCan/GSD	Bernese	Canada & border areas of US & Greenland	200
NRCan/GSD	GIPSY	Canada	45
NRCan/GSC	Bernese	Western Canada	75
Scripps	GAMIT	North America	1100+ (~625 used)

A number of sites have been omitted from the combination of submitted contributions due mainly to problems with antenna heights. Investigations are being planned to resolve these issues. Many other stations have been removed from the MIT and Scripps solutions because of 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. To better align the NAREF combinations to the ITRF, a subset of global sites have been included in all but the NRCan/GSC solutions since GPS Week 1400. Due to delays in submissions of some of the regional solutions since GPS Week 1400, the weekly combinations are not yet up to date. These weekly combination solutions are available from the IGS and the NAREF FTP archive.
To date, cumulative solutions (coordinates and velocities) based on the weekly NAREF combinations have been generated on an as required basis but the intention is to produce new solutions on an annual basis. The last cumulative solution based only on data up to GPS Week

1399 due to the change in IGS processing procedures and their adoption of absolute antenna phase centres.



NAREF network since GPS Week 1400 with global sites used to align with ITRF.

A major reprocessing effort of regional solutions prior to GPS Week 1400 is presently underway by Scripps and NGS using the new IGS procedures and absolute antenna phase centre variation models. These regional solutions have essentially been a densification of their global reprocessing efforts for the IGS. Both have already reprocessed several years of data. The other contributors plan to begin reprocessing their regional solutions using the final reprocessed IGS orbits once they become available.

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

Significant efforts continued under this joint working group 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.

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 is currently under development using several improved velocity solutions from the members of the WG, including the last official NAREF solution up to GPS week 1399. This version of SNARF is expected to be released mid-2009. In addition to a reference frame (coordinates and velocities) with uncertainties, a model for glacial isostatic adjustment and plate rotation rates with respect to ITRF2000 will also be provided.

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 fourteen parameter transformation from ITRF96. Transformations from/to other subsequent versions of ITRF are obtained by updating the NAD83-ITRF transformation with the official incremental fourteen parameter transformations between ITRF versions as published by the IERS. In 2006 the transformation was updated with the introduction of ITRF2005. Recent activities have focused more on education and outreach efforts.

Later in 2009 it is expected that a new ITRF2008 will be introduced. At that time, a revised version of the NAD83-ITRF transformation will be determined for use in both Canada and the U.S.

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.

This sub-commission has been inactive since the inception of the NAREF sub-commission. However, with 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, it has been decided to re-activate the working group in the near future to address the issued faced in adopting a new geoid-based IGLD.

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. Although stations have been installed in the name of AFREF, some groups are withholding data for their own use which defeats the objectives and principles of the IGS which are also the fundamental principles of AFREF.

At a recent AFREF Steering Committee meeting in Addis Ababa in April 2009, the Chief Directorate: Surveys and Mapping in South Africa offered to take on the role of Operational Data Centre (ODC) for AFREF. This will create a single data base for AFREF which will have an open data policy. Data will be mirrored to the Regional Data Centre at the Hartebeesthoek Radio Astronomy Observatory and one of the IGS Global Data Centres. It is trusted that the AFREF ODC will be operational within the second half of 2009.

Meetings and Training Courses

A number of Steering Committee meetings were held during the reporting period but perhaps the most significant was a joint meeting held in June 2008 in Johannesburg which 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.

Two training courses were held, one in August 2007 and the second in Aug 2008 both 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. A similar course is to be held in August 2009 but with a greater emphasis on the practical aspects of the project.

Funding for AFREF

Funding 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 partially successful but still requires refinement. 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 from receiver manufacturers.

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

Chair: Shigeru Matsuzaka (Japan)

Overview and Organisation

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 GPS 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 GPS installations in areas of earthquake and tsunami hazard and strongly encourage nations to make their geodetic data readily available.

Outputs

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 focussed 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). In the period 2007-2009, four geodetic VLBI campaigns have been undertaken in the region for the APRGP, namely APSG-20 (11 Sep 2007) APSG-21 (10 Oct 2007), APSG-22 (09 Sep 2008) and APSG-23 (08 Oct 2008).

Two additional annual, regional, GPS campaigns were undertaken in 2007 and 2008. APRGP campaigns were coordinated by Geoscience Australia (GA) and the campaign data (1997 – 2008) 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. The processing of the APRGP data sets, from the years 1997 to 2006 inclusive, was undertaken by Geoscience Australia. Results from these campaigns have now been submitted to the IAG working group on regional dense velocity fields.

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 will be held in Bangkok, Thailand in October, 2009.
- 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 has commenced the AuScope Initiative, which includes the construction and operation of 3 new VLBI stations and 100 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 and 2009 were carried out in the austral summers 2008 and 2009. 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.

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).

Working Group SC 1.3 - WG 1: Regional Dense Velocity Fields

Chair: Carine Bruyninx

Objectives and Membership

Because of accuracy, ability to provide results in a global reference frame, and low cost of receivers and versatility, Global Navigation Satellite Systems (GNSS) are presently the main sensor of the Earth's surface deformation. Consequently, GNSS networks have been installed all over the world and repeated GNSS campaigns are conducted to monitor ground deformations. In addition, a large number of Continuous Operating GNSS Reference Stations (CORS) are operating today for multi-disciplinary applications ranging from surveying to numerical weather prediction.

The regional sub-commissions within IAG sub-commission 1 "Regional Reference Frames" have already made a first step in coordinating these activities in order maintain their regional reference systems.

This Working Group on "Regional Dense Velocity Fields" 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. For that purpose the WG has set up the following goals:

- define specifications and quality standards for the regional SINEX solutions and relevant meta-data;
- collect SINEX solutions and their meta-data ;
- study in-depth the individual strengths and shortcomings of local/regional and continuous/epoch GNSS solutions to determine site velocities;
- define optimal strategies for the combination of regional and global SINEX solutions;
- provide dense regional velocity fields;
- provide the densification of the ITRF2005 (or its successor);
- encourage participation in related symposia;
- implement a web site in order to provide information on the activities and access to the products of the WG
- and prepare recommendations and a comprehensive final report on the WG activities.

The Working Group brings together representatives of the regional sub-commissions and experts in the combination of SINEX files. Working Group members are Altamimi Z. (France), Becker M. (Germany), Bruyninx C. (Belgium), Craymer M. (Canada), Combrink A. (South Africa), Combrinck L. (South Africa), Dawson J. (Australia), Fernandes R. (Portugal), Dietrich R. (Germany), Govind R. (Australia), Herring T. (US), Kenyeres A. (Hungary), King B. (USA), Kreemer C. (USA), Lavallée D. (the Netherlands), Legrand J. (Belgium), Sánchez L. (Germany), Sella G. (US), and Woppelmann G. (France).

Activities

The goal of the WG is to provide regional dense GNSS-based velocity information in a common reference frame. The working group is linking its activities with the regional sub-commissions within IAG sub-commission 1 "Regional Reference Frames" (AFREF, Asia &

Pacific, Antarctica, NAREF, SIRGAS, and EUREF). Their expertise, coordination role for their region, and their capability to generate a unique cumulative solution for their region including velocity solutions from third parties (even campaigns) is essential for the WG.

The WG thus divided the world in different regions corresponding to the regions of the different sub-commissions and appointed for each region a region coordinator. The region coordinators are gathering velocity solutions for their region (in accordance with the WG requirements) and combine the submitted velocity solutions with GNSS solutions from the regional sub-commissions to produce one regional combined velocity solution. In addition to the individual regions, cumulative SINEX solutions from global networks as TIGA are also used. A first set of preliminary regional combined solutions is prepared for June 2009. Two working group members have agreed to combine the preliminary regional SINEX solutions with long-term solutions from global networks such as the IGS and tie the result to the ITRS anticipating a preliminary WG solution in time for the IAG 2009 meeting in Buenos Aires. This main goal of this preliminary solution will be to identify the problems that will arise and help to set strategic choices and guidelines for the future. These guidelines will be used to issue a new solution in 2010-2011.

The WG issued a call for participation at the end of 2008. Figure 1 shows on a map the solutions that have been proposed to the Working Group up to date. Not all of them have been received at this moment at it is expected that some of them will only be available end of 2009.

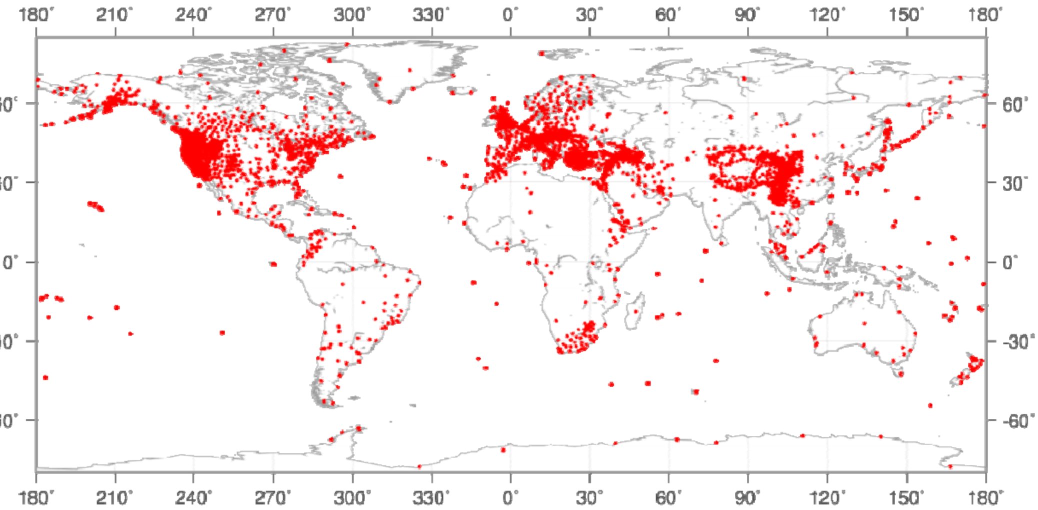


Figure 1 - Map of the velocity solutions proposed to the Working Group to date. In total about 6000 sites are included.

The following problems have been encountered up to now:

- *Domes numbers & station names:* Not all sites included in the contributing solutions have official domes numbers attributed by the IERS and this can make SINEX combination software fail. A coordinated approach for attributing virtual domes numbers will therefore be necessary. In the case of duplicates station names, a new station 4 char-ID and virtual DOMES number will also have to be assigned in a coordinates way avoiding overlaps duplicates and inconsistencies between the different regions.
- *Solutions with only precise velocity estimates and no precise coordinates:* The implication being that inter-site correlations (negligible in many cases, not so in others) are not included and some programs designed to merge SINEX files could fail.

- *Inconsistent solution numbers:* The WG recommended in the guidelines that: "For IGS sites the timing of offsets should be identical to those in use by the IGS". However, this does not help when solutions have already been produced. A dedicated approach for this problem will have to be investigated.

Working Group Meetings

- June 4, 2008, Miami Beach, US (during IGS Analysis Centres Workshop), the minutes are available from http://www.epncb.oma.be/IAG/documents/minutes/Minutes_20080604.pdf
- December 18, 2008, San Francisco, US (AGU 2008 Fall Meeting), the minutes are available from http://www.epncb.oma.be/IAG/documents/minutes/Minutes_20081218. pdf
- April 20, 2009, Vienna, Austria (EGU 2009), the minutes are available from http://www.epncb.oma.be/IAG/documents/minutes/Minutes_20090420.pdf

Outreach

A web site has been set up providing a gateway to the WG activities, including the submission guidelines, call for participation, list of contributors, etc... It is available from http://www.epncb.oma.be/IAG/.

Members of the Working Group have presented the activities of the WG at the following meetings:

- Sensitivity of the Reference Frame Definition in a Regional Network, C. Bruyninx, J. Legrand; *AGU Fall Meeting 2007, December 10-14, 2007, San Francisco, US*
- Sensitivity of the Reference Frame Definition in a Regional Network, Legrand J., Bruyninx C., Pottiaux E.; *EGU General Assembly 2008, April 14-18, 2008, Vienna, Austria*
- IAG Working Group "Regional Dense Velocity Fields": Objectives and Future Plans, C. Bruyninx, 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; *IGS Analysis Centres Workshop, June 2-6, 2008, Miami, US*
- IAG Working Group "Regional Dense Velocity Fields": Objectives and Future Plans, C. Bruyninx, 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; *AFREF Workshop, June 17-18, 2008, Johannesburg, South Africa*
- Objectives and Challenges of the IAG Working Group "Regional Dense Velocity Fields", C. Bruyninx, 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; *EUREF 2008 Symposium, June 18-21, 2008, Brussels, Belgium*
- EPN Reference Frame Alignment: Consistency of the Station Positions, Legrand J., Bruyninx C.; *EUREF 2008 Symposium, June 18-21, 2008, Brussels, Belgium*
- Objectives and Challenges of the IAG Working Group "Regional Dense Velocity Fields", 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. Sanchez, G. Sella; *EUREF 2008 Symposium, June 18-21, 2008, Brussels, Belgium*
- Towards the Provision of Regional Dense Velocity Fields in a Global Reference Frame, C. Bruyninx, Z. Altamimi, M. Becker, M. Craymer, L. Combrinck, A. Combrink, R. Fernandes, R. Govind, T. Herring, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, J. Legrand, M. Moore, L. Sánchez, G. Sella, G. Woppelmann; *WEGENER 2008 General Assembly, September 15-18, 2008, Darmstadt, Germany*

- IAG Working Group "Regional Dense Velocity Fields": Objectives and Future Plans, C. Bruyninx, Z. Altamimi, M. Becker, M. Craymer, L. Combrinck, A. Combrink, J. Dawson, R. Fernandes, R. Govind, T. Herring, A. Kenyeres, R. King, C. Kreemer, D. Lavallée, J. Legrand, L. Sánchez, G. Sella, G. Woppelmann; *AGU Fall Meeting, December 15-19, 2008, San Francisco, US*
- Influence of the Reference Frame Alignment on Station Positions and Velocities: Global or Regional?, Legrand J., N. Bergeot, C. Bruyninx, G. Wöppelmann, M.-N. Bouin, Z. Altamimi; A*GU Fall Meeting, December 15-19, 2008, San Francisco,*
- Progress of the IAG SC1.3 Working Group in Providing a Dense Global Velocity Field Based on GNSS Observations, C. Bruyninx, 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, Z. Shen, G. Sella, G. Woppelmann; *EGU General Assembly, April 19-24, 2009, Vienna, Austria*
- Reliability of Regional and Global GNSS Network Solutions Expressed in the Global Reference Frame, J. Legrand, N. Bergeot, C. Bruyninx, G. Wöppelmann, M.N. Bouin, Z. Altamimi; *EGU General Assembly, April 19-24, 2009, Vienna, Austria*
- Progress of IAG SC1.3 Working Group in Providing a Dense Global Velocity Field Based on GNSS Observations, C. Bruyninx, 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, Z. Shen, G. Sella, G. Woppelmann; *EUREF symposium, May 27-30, 2009, Florence, Italy*
- A Dense Global Velocity based on GNSS Observations: Preliminary Results, C. Bruyninx, 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; *IAG 2009 Scientific Assembly, 31 August – 4 September 2009, Buenos Aires, Argentina*
- Comparison of Regional and Global GNSS Position and Velocity Solutions, J. Legrand, N. Bergeot, C. Bruyninx, G. Wöppelmann, A. Santamaria-Gomez, M.N. Bouin, Z. Altamimi; *IAG 2009 Scientific Assembly, 31 August – 4 September 2009, Buenos Aires, Argentina*

and the following papers have been written:

- Bruyninx C., Z. Altamimi, M. Becker, M. Craymer, L. Crombrinck, A. Crombrink, R. Fernandes, R. Govind, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, J. Legrand, L. Sanchez, G. Sella, Objectives and Challenges of the IAG Working Group "Regional Dense Velocity Fields", Proc. EUREF symposium, July 2008, Brussels (in press)
- Legrand J., Bruyninx C., EPN Reference Frame Alignment: Consistency of the Station Positions, Submitted to Bulletin of Geodesy and Geomatics (in press)
- Legrand J., N. Bergeot, C. Bruyninx, G. Woppelmann, M.-N. Bouin, Z. Altamimi , Impact of the Reference Frame Definition on Geodynamic Interpretations, Submitted to Journal of Geodynamics (in press)
- Progress of IAG SC1.3 Working Group in Providing a Dense Global Velocity Field Based on GNSS Observations, C. Bruyninx, 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, Z. Shen, G. Sella, G. Woppelmann, Proc. EUREF symposium, Florence, Italy (in press)

and WG members have been co-chairing of session

- "Multi-GNSS & regional combined IGS products" at IGS Analysis Workshop, Miami Beach, June 2008

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

President: Harald Schuh (Austria)

The main objective of the 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, S. Klioner, D. MacMillan, J. Sokolova, O. Titov, V. Zharov, ex officio: H. Schuh, Chair 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 1.4.1 activity are the following:

1. Analysis of ICRS definition in view of the latest development in astrometry and space geodesy.
2. Effect of 2000, 2003, and 2006 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.

A part of the results outlined below and related to the construction of the next ICRF realization, ICRF2, will be included in detail in the IERS Technical Note 35 which is due for the IAU General Assembly 2009. This work is a result of joint activity with the dedicated IAU and IERS/IVS Working Groups and the IERS ICRS Product Center.

1. *Analysis of the 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 Report to the IAU 2006 General Assembly. No substantial progress has been achieved since that report. However, the ICRF definition becomes not well understood and consistent when moving to the modern observations e.g. VLBI and GAIA. To solve arisen problems a set of new considerations is needed on such issues as general relativity and acceleration of the solar system barycentre.

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

These issues are summarized in Capitaine (2007, 2008). Further analysis is planned.

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

To be investigated.

4. Alignment of ICRF to ICRS

A procedure for final aligning of the ICRF2 has been developed by the group at Paris Observatory. This procedure mainly follows the procedure used in the 1990s 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 the stability of the ICRF2 axes, in particular through a choice of the optimal set of core sources.

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 radio source position catalogues using various data sets, software and analysis options. Comparison of these catalogues allowed us to draw 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 investigate on),
- Atmosphere pressure loading (no 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 were conducted:

- Investigation of systematic and individual (peculiar) source motion,
- Analysis of the consistency of CRF realizations at different frequency bands,
- Methods of assessment of absolute accuracy and systematic errors of CRF catalogues.

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

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

7. Impact of the ICRS and ICRF problems on geodesy

Although geodesy mainly deals with measurements on and of the Earth, it is closely connected with and depends on measurements on the sky, at least in two aspects:

- Many geodetic measurements are made through observations of sky objects,
- Many applied and fundamental geodetic results are obtained from the common adjustment of the TRF, EOP, and CRF parameters.

For this reason an impact of the adopted ICRF on geodetic results is anticipated, and the consequences of moving from ICRF to ICRF2 should be investigated after completing and publishing the ICRF2.

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, 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 of the Working Group

Produce ICRF2 for IERS / IVS consideration and for submission to the corresponding IAU Working Group

2. Charter and purpose

The purpose of Working Group 1.4.2 (which is identical with the corresponding IERS/IVS Working Groups) is 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) will apply state-of-the-art astronomical and geophysical models in the analysis of the entire relevant S/X astrometric and geodetic VLBI data set. It will carefully consider the selection of defining sources and the mitigation of source position variations to improve the stability of the ICRF. The goal is 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.

3. Activities in the period 2007 to mid 2009

In the period 2007 to mid 2009 WG 1.4.2 undertook the analysis to generate the next realization of the ICRF at microwave frequencies using VLBI data. The WG concentrated on several main areas: time series of source positions to determine stable and unstable sources, compilation of source structure snapshots and evolution to supplement the time series, determining the effects of variations in modeling, data and analyst choices, generation of source catalogues using the best available geophysical and astronomical models, and orientation to the ICRS as realized by the current ICRF. The WG met a number of times: April 2007 in Vienna, September 2007 in Paris, March 2008 in St. Petersburg, September 2008 in Dresden, December 2008 in Washington and March 2009 in Bordeaux. The work for the catalogue to be proposed to the IAU is being compiled as IERS Technical Note No. 35.

WG 1.4.3 Interaction between Celestial and Terrestrial Reference Frames

Chair: Sébastien Lambert (since mid 2008)

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

This report summarizes research activities in link to IAG WG 1.4.3 between mid 2008 and mid 2009, i.e. since S. Lambert became Chair of the WG.

1. Effects of CRF realization on EOP and TRF

1.1. Influence of the CRF datum and analysis configuration

During a typical VLBI solution, station coordinates and velocities and radio source coordinates are estimated as global parameters, while EOP are estimated as arc parameters. The first version of the ICRF (Ma et al. 1998) proposed 212 sources to define the ICRS axes. Since then, other subsets have been investigated. Feissel-Vernier et al. (2006), MacMillan and Ma (2007), Titov (2007), Lambert et al. (2008), and Lambert and Gontier (2009) investigated the effects of the selection of reference radio sources and of the analysis configuration in geodetic products. In this context, analysis configuration deals with the split between global and arc radio source coordinates (e.g., downgrading very unstable sources as arc parameters, or keeping them as global but not using them in the no net rotation (NNR) condition). These studies showed that the choice of the defining sources mainly influences the bias of the nutation series. However, the analysis configuration can produce changes in estimates of long-period nutation spectral components at the level of 10 microarcseconds. This does not affect geophysical results like the Earth's outer core resonant frequency in a significant way.

1.2. Work w.r.t. the ICRF2

A number of IVS Analysis Centers are participating to the construction of the new realization of the ICRS. The ICRF2 is now in its final stage and should be delivered by mid-2009 for the IAU General Assembly. It will provide new coordinates for about 3800 sources, and a set of defining sources to replace the 212 ICRF defining sources. This work has been done within the IERS/IVS Working Group "Second Realization of the ICRF", chaired by C. Ma which as IAG WG 1.4.2 also reports to IAG. The consequences of using the ICRF2 in calculation of other geodetic products will have to be treated after its complete release. Besides, a number of scientific results including effects of the analysis configuration (station handling, models) in CRF realization will be reported in the IERS Technical Note 35.

2. Effects of the TRF realization on EOP and CRF

A study performed by Z. Malkin (2009) showed that the VLBI-derived EOP accuracy primarily depends on the VLBI network geometry and to a lesser extent on other factors, such as recording mode, data rate and scheduling parameters, whereas these factors have a stronger impact on the EOP precision. The study proposes a 'geometry index' for VLBI networks based on the network volume.

3. Geophysical or technique modeling issues

3.1. Atmosphere delay

Kouba (2009) and Steigenberger et al. (2009a) studied the impact of different mapping functions (GMF and VMF1) and hydrostatic a priori zenith delays (GPT and ECMWF) on GPS-derived station positions. Whereas Kouba (2009) used the Precise Point Positioning (PPP) approach, Steigenberger et al. (2009a) used homogeneously reprocessed double-differenced global network solutions. The station height differences between terrestrial reference frames computed from these reprocessed solutions with GMF/GPT and with VMF1/ECMWF are in general below 1 mm. Both authors found, that the application of GPT-derived a priori delays results in a partial compensation of atmosphere loading.

3.2 Antenna phase center variations

Steigenberger et al. (2009b) computed four TRF solutions with different GPS antenna phase centre models from 11 years of reprocessed GPS observations. The station coordinate changes due to different phase centre models can reach 5 mm for the horizontal and up to 16 mm for the vertical component. The velocity changes are 1 mm/yr and 2.5 mm/yr, respectively.

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Inter-Commission Project 1.2: Vertical Reference Frames

Chair: Johannes Ihde (Germany)

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

The IAG Inter-Commission Project 1.2 studied during the period 2003 – 2007 the possibilities of the definition and 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.

The results of the work of the Inter-commission Project 1.2 are documented in **Conventions for the Definition and Realization of a Conventional Vertical Reference System (CVRS)**. 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. Parts of the IERS 2003 conventions are the basis for the CVRS conventions.

Open topics are concepts for the

- Establishment of an information system describing the various regional vertical reference frames and their relation to a GVRS,
- Determination of transformation parameters between regional vertical reference frames and the unified global height system as well as
- Relationship between a GVRS and the International Terrestrial Reference System.

Objectives in the period 2007 - 2011

- 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

Program of Activities

- Study of information on regional vertical systems and their relations to a global vertical reference system for practical applications;
- Study of combination procedures of height data sets from different techniques;
- Development of the basic relationships between ITRS and IVRS conventions, parameters, realization, models
- Unification of regional (continental) height systems
- Preparation of a pilot project for the realization of a GVRS.

2. The Realization Concept

The realization of an IVRS is a typical item of the IAG project GGOS, mainly as a 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 and if possible of GNSS/levelling with a global gravity model (GGM); which is named as the geodetic boundary value problem (GBVP) approach. This approach is the combination of different components:

- A global permanent GNSS network of stations connected with levelling networks, optionally supplemented by permanent (SG) and/or periodical (AG) gravity observations at selected stations
- A global gravity model (GGM) with continental and regional densifications using the remove restore technique.

As result of this approach we have available physical heights or geopotential numbers related to a geoid/quasigeoid $\boldsymbol{T_{p\ RRT}}$ which is related to a conventional zero level of the potential of the Earth gravity field W_{0C}. W_{0C} is a parameter of the mean Earth ellipsoid which shall used for all realization procedures of the WHS.

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

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

A further approach which can be used for the unification of vertical reference frames bases 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.

In general the realization und unification is a combination of the different elements based on a set of consistent conventional numerical standards. The accuracy of WHS realization depends in the first order from the resolution of the gravity model. A service providing all relevant information would be useful.

3. WHS Pilot Project

The pilot project (WHS-PP) could start with a case study of combination of available elements:

(1) The global gravity model EGM07 with continental and national densifications

(2) For GNSS the IGS TIGA-PP, which monitors vertical movements of globally distributed tide gauge stations

(3) Continental and national levelling networks linked to IGS TIGA stations

(4) The tide gauge stations observations linked to IGS TIGA stations which are a product of the PSMSL

(5) Absolute and super conducting gravity meter measurement at selected IGS TIGA stations

(6) A global sea surface topography model

(7) The numerical standards of IERS conventions 2003

Partners for the WHS-PP are inside the IAG the IGFS for GGM, absolute and super conducting gravity meter measurements, IGS for TIGA, SC2.4 for continental and regional desification of a GGM and GLOSS for PSMSL and a global sea surface topography model.

4. Proposed continuation

The IAG 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.

Proposed items for continuation:

- Discussion of the results of ICP1.2 (GGOS action)
- Initiation of a pilot project for an IVRS realization on the basis of the IGS TIGA-PP, GGP and IGFS for AG and a CGGM (call for participation as an IGFS action)
- Further development of the CVRS conventions
- Decision about numerical standards as task of GGOS in cooperation with International Astronomical Union (IAU) and international hydrological and oceanographic organisations.

The project continuation shall be realized in cooperation with other organizations, especially the International Association of Hydrological Sciences (IAHS), the International Association for the Physical Sciences of the Oceans (IAPSO), Global Sea Level Observing System (GLOSS) the International Hydrographic Organisation (IHO), the International Federation of Surveyors (FIG), and the Inter-service Geospatial Working Group (IGeoWG) of NATO.

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.

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 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. 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 are also mandatory. 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 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 loading services currently available.

long-term biases in the reference frame -- Because environmental models do not yet conserve overall mass or properly account for exchange of fluids between states, 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. 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 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 field of corrections used must be reported in new SINEX blocks that will need to be documented. The availability of such information will permit only an approximate removal of the non-tidal corrections, though, if the applied sampling is finer than the geodetic integration interval.

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 bureau, 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.

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. 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") should also be reduced. 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. The result would be a long-term frame for each technique consisting of the usual reference positions and velocities. 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. 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 geocentre 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.

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.

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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Inter-Commission Working Group 1.2: Precise Orbit Determination and Reference Frame Definition

Chair: Frank Lemoine (USA)

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. In addition, we discuss in this report the work accomplished by members of the DORIS community with respect to radiation pressure modelling, the development and testing of improved radiation pressure models for Jason-1 and ENVISAT. Finally we report how we have successfully mitigated the effects of atmospheric drag on DORIS POD and determination of reference frame parameters. We note the work underway in the community to developed improved atmospheric drag models for satellite applications.

Historically the DORIS recoveries for geocentre have been characterized by reasonable recoveries in X and Y, but large signals in Z. For example *Feissel-Vernier et al.* (2006) for three sample series find annual signals of ± 5 mm in X and Y but ± 20 mm in Z. In the DORIS geocentre time series, the prime signals occur at the annual period, but also at the solar beta prime (draconitic) period for TOPEX/Poseidon. This was the key clue that indicated mis-modelling of radiation pressure was aliasing into geocentre recovery for DORIS. *Gobinddass et al.* (2009) showed that by tuning the solar radiation pressure reflectance coefficient (C_r) for each satellite (in effect scaling the macro-model), and fixing it in the orbit solutions, it was possible to mitigate the radiation pressure mis-modelling and recover a cleaner geocentre signal, particularly in the Z component. The problem is particularly acute for DORIS as many members of the satellite constellation are sun-synchronous, and so the radiation pressure mis-modelling will alias directly into an annual signal. In the new IGN solutions, the Z component in geocentre is more in line with the expected annual amplitude predicted by geophysical models. We are pleased to report that the time series of *Gobinddass et al.* (2009) has been incorporated into the IDS combination, however not all the DORIS analysis centres have completed the same level of radiation pressure model tuning. A spectral analysis was completed of the geocentre signals of all the IDS AC's, and strong Z amplitudes at the annual period (365 days) and TOPEX draconitic period (120 days) were present in several of the series. In future work, all the AC's will be encouraged to upgrade their models and data processing.

Drag modelling and parameterization of drag coefficients are also a key issue for DORIS satellite POD, particularly in solar storms and other overall periods of high solar activity (*Willis et al., 2005*). The drag mis-modelling effects can be mitigated by increasing the drag parameterization (i.e. adjusting an empirical drag coefficient more frequently for the low altitude satellites such as the SPOT's and ENVISAT). The habit had been to adjust such c_d's every four to six hrs, however more frequent adjustments improve the station repeatability and EOP recovery during high drag periods *(Gobinddass and Willis, 2008*). Of the DORIS analysis centres, for the IDS-1 Combination prepared for ITRF2008, only IGN and ESA parameterized drag at the higher levels (1-2.4 hrs) (*Valette and Yaya, 2009*). As a consequence, when the WRMS (weekly RMS repeatability w.r.t. a cumulative position velocity solution) was computed, a spike was observed in late 2001 to 2002. This was found to coincide nearly exactly with the increase in solar flux around the peak of the solar cycle, and the increase in the RMS of fit in the DORIS satellite arcs (*Yaya and Valette, 2009*). Thus, the analysis centres were asked to reprocess their data from the Autumn of 2001 to the Spring of 2002 with a higher drag parameterization. The GAU, GSC and LCA analysis centres complied with this recommendation, and the result is that in IDS-2 ITRF2008 test combination, the peak in the WRMS around the peak of the solar maximum has been much reduced from 26 mm with IDS-1 to 20 mm in IDS-2. We note that the GOP analysis centre is probably not as affected by atmospheric drag as they use the Bernese software and solve for frequent stochastic parameters as a routine part of their OD solutions (*Stepanek et al., 2006*). The more frequent c_d adjustment (in the ESA, IGN, GSC, GAU and LCA satellite orbits) is made possible by applying a weak constraint on the estimated c_d's and/or a time-correlation with exponential decay time constant and a process noise sigma between adjacent c_d parameters.

We note that work is underway in the community to upgrade atmosphere models. These include the group at the GRGS/CNES who are analyzing accelerometer data from GRACE and CHAMP for inclusion into new atmosphere models (cf. *Bruinsma and Forbes, 2007*; *2008*). In addition teams led by US. Naval Research Lab has developed improved drag models built upon the long history of MSIS models (*Picone et al., 2002*). The NRL is leading an experiment with the ANDE satellite, to study the Earth's thermosphere and gather further data to improve drag models (*ILRS/ANDE, 2009; Thomas, 2008*). The model developed by *Bowman et al.* (2008) is particularly interesting, as it relies on solar indices that track more closely how the Sun deposits energy into the thermosphere of the Earth. These indices are in the Far Ultraviolet and Extreme Ultraviolet, as opposed to the standard F10.7 proxy that has been used for years. The development of these models is very encouraging, however in any given orbit determination software it is easier to adjust new parameters than integrate a new orbit determination model, which requires manpower, testing and possibly adherence to standards of configuration control.

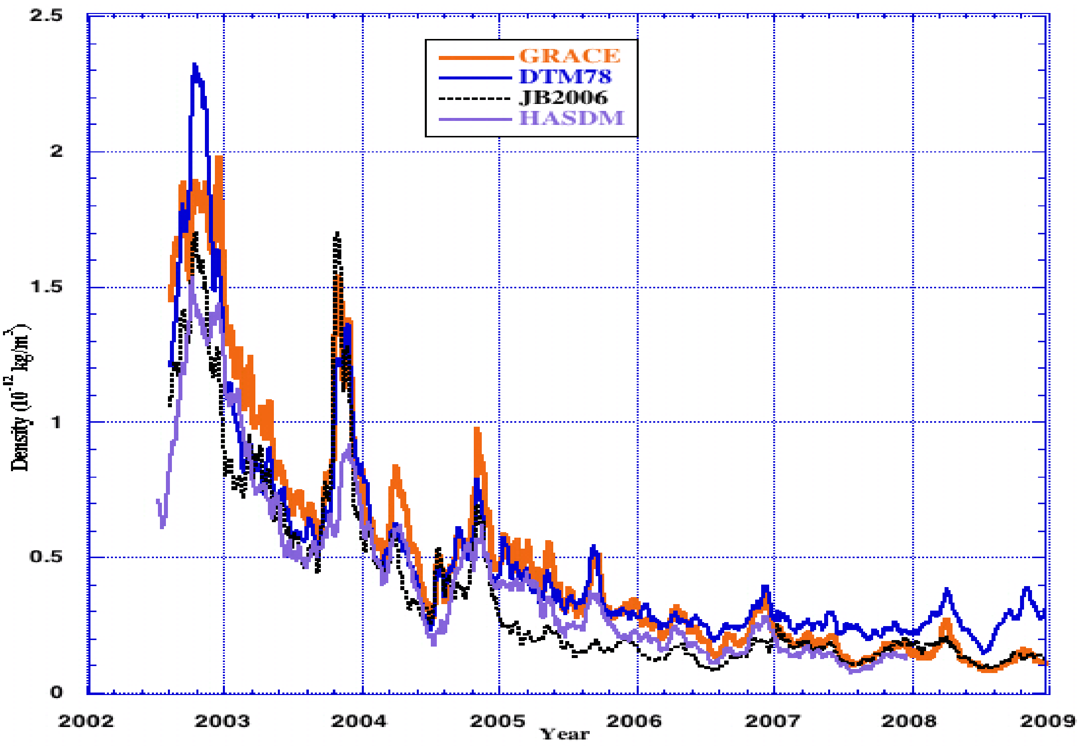

Figure 1: Density comparisons from 2002 to 2009 from atmosphere density models and from GRACE.

Atmosphere density estimates based on GRACE accelerometer data have been used to validate various density models, including the 1978 Density Temperature Model (DTM78), the Air Force Space Command's High Accuracy Satellite Density Model (HASDM) and the Jacchia-Bowman 2006 (JB2006) model (*Cheng et al., 2007, 2008; Tapley et al., 2007).* Figure

1 shows that the models tend to under-predict the density when solar activity is high (except for DTM78 over some periods) but agree better (especially for HASDM) with GRACE densities during low solar activity (starting from early 2006). The earlier empirical DTM78 model appears to over-predict the density as compared to the GRACE measurements after 2006 where the solar activity was decreasing. The extreme density values in during 2003 are due to the high solar activity and geomagnetic super-storm that occurred during the period of October-November 2003.

We also note that while at present the issue of drag modelling and parameterization affects primarily the IDS contribution to the reference frame, atmospheric drag is a strong signal on the Starlette and Stella satellites. These SLR cannonball targets are not typically used for reference frame work although some preliminary work has been done in this regard (*Govind et al., 2007*). The addition of further satellites, in particular targets with a tight SLR target signature (cf. see *Otsubo and Appleby, 2003* for a discussion of this issue) could benefit the SLR solutions. In particular prior to 1993, the addition of Starlette would strengthen the SLR reference solutions when Lageos was the only contributor. However many issues other than proper drag modelling and parameterization need to be resolved before these new satellites can be added to SLR reference frame solutions.

In this report period, working group members have tested improved radiation pressure models developed at the University College London (UCL) for the Jason-1 and ENVISAT satellites (*Ziebart et al., 2005; Sibthorpe, 2006*). ENVISAT is one of the members of the DORIS satellite constellation. Jason-1 does not presently contribute to the DORIS reference frame solutions as the data are omitted due to the instability of the DORIS Ultra-stable Oscillator and its radiation sensitivity (*Willis et al., 2004*). However, development of an improved radiation pressure model is important first of all for oceanographic and mean sea level applications, as analysis of the CNES/GDR-C orbits has revealed a draconitic signature (beta-prime, or Sun-related) in the altimeter data (*Leuilette et al., 2009*). The UCL models were tested at NASA GSFC. For Jason-1, they find a systematic improvement in the SLR residuals, and a reduction in the magnitude of the empirical accelerations (*Lemoine et al., 2009*). The NASA GSFC std0905 orbits to be released to the Jason-1/Jason-2 Science team will use this modelling (*Lemoine et al., 2009*). Although Jason-1 is not part of DORIS reference frame solutions at present there is always the possibility the USO DORIS problem may be mitigated in the future by more detailed modelling (eg. *Lemoine JM and H. Capdeville, 2006*). In addition the Jason-1 spacecraft carries an SLR retro-reflector and GPS receivers. While the prime and backup GPS receivers each in turn have failed, the long time span of SLR and GPS data available mean that Jason-1 could make an interesting satellite with which to attempt joint GPS/SLR reference frame solutions, should some group wish to make those experiments in the future. A prerequisite would be minimizing the errors due to the non-sconservative forces, including radiation pressure and in this context, the UCL radiation pressure model for Jason-1 would be particularly useful.

The NASA GSFC team also tested the application of the UCL model on ENVISAT. It was found that the amplitude of the daily empirical accelerations showed a notable improvement (a factor of two to five). *Doornbos et al.* (2002), who applied a proprietary model, ANGARA, to orbit determination for ENVISAT, found that during periods of intense solar activity, deficiencies in the drag model, in particular the atmosphere response function to high flux or geomagnetic indices was the dominant source of error. We note that Le Bail et al. (2009) saw in 2003 a 27 day, solar-rotation-related, periodicity in the recovered ENVISAT along-track empirical acceleration amplitudes. At low solar flux conditions, the drag and radiation pressure model errors were found to be at a comparable level. In the future it would be interesting to inter-compare the recovered 1opr accelerations from the different analysis centres that analyze ENVISAT data, as well as the *computed* drag and radiation pressure perturbations, in order to see what each orbit determination software is actually doing. The UCL model for ENVISAT has also been implemented in the GIPSY/OASIS software at JPL, and we expect that further tests with the IGN and/or INA DORIS analysis centres will be possible in the near future.

Advances in GPS orbit modelling have also been accomplished by members of our working group. An issue that has been present in GPS analyses is a putative bias in the SLR residuals to GPS satellites. In addition *Urschl et al.* (2007) found that the range residuals derived from the various GNSS orbits show similar periodic variations, which are correlated with eclipsing seasons and the sun's elevation above the orbital plane, indicating orbit or attitude modelling deficiencies. *Ziebart et al.* (2008) have made progress in this area. They observe that the bias can reach 4-5 cm around an arc on the dark side of the Earth (affecting primarily the satellites that experience eclipse). They find that modelling planetary radiation pressure can reduce this bias and that modelling antenna thrust further reduces the SLR residuals. The UCL team have experimented with different parameterizations of the albedo, and with detailed radiation pressure models for the GPS satellites (eg for the Block 2A and the Block 2R series of GPS satellites). These model developments are promising and offer the prospect of improving the GPS processing potentially for the next ITRF. Another avenue of radiation model improvement for the GPS satellites is suggested by *Herring* (2009). In his EGU paper, he showed the radiation signature in the GPS orbits, and demonstrated the correlation with the empirical terms used in orbit adjustment. As in Gobinddass et al. (2009) for the DORIS satellite orbits, he showed how the effect could be mitigated by a proper tuning of the parameterization. Taken together, these model and analysis developments are promising and offer the prospect of improving the GPS processing potentially for the next ITRF (i.e. ITRF2011 or ITRF2012). However, further testing is required and the working group will need to enlist the involvement of GPS analysis centres to carry out detailed tests (meaning processing a long time series of orbits and analyzing the daily station time series).

In the coming year, the working group will continue to focus on surface force model improvement for the ENVISAT and SPOT satellites, and we will also address modelling for Jason-2 (in orbit since June 2008) and Cryosat (scheduled for launch in late 2009) which will likely become strong contributors to the IDS reference frame in the future. Both satellites carry the DGXX DORIS receiver which can track up to seven DORIS beacons. Thus the quantity of DORIS data available will drastically increase in coming years.

Another possible activity would be to ascertain how we might improve the orbits of LEO satellites during periods of high solar activity through better forward modelling. If time and resources permit, we will evaluate the JB2006 atmosphere density model, and another atmosphere model upgrades that might be available.

We note that we have not addressed so far how the GPS reference frame might be affected by non-conservative force mis-modelling. A draconitic signature is evident in the GPS orbits, and is imputed to be due mis-modelling of the non-conservative forces.

We envisage a special session at the EGU General Assembly Meeting 2010 as a means to focus community attention on the precision determination and reference frame issues.

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Inter-Commission Working Group 1.3: Concepts and Terminology related to Geodetic Reference Systems

Chair: Claude Boucher (France)

Recommended nomenclature related to Geodetic Reference Systems

V06 feb 2009

Introduction

The recommended nomenclature is composed of a set of selected terms, associated with definitions, as listed in the lexicon given below in alphabetical order. In this introduction, we present in a narrative format all selected terms, as well as other terms currently used, but not or no more recommended. Recommended terms are written in bold .

The concept of *Geodetic Reference System (GRS)* is used here to designate any reference system of metrological quality specific to Geodesy. It must be distinguished from the specific use of this term traditionally adopted by the IAG and consisting of four fundamental constants (such as GRS80) and the derived models (ellipsoid, normal gravity…). Nevertheless, we do not consider it as part of the formal nomenclature, but as a background concept, in which we must adopt a common understanding of the term "reference system".

The general understanding of a reference system adopted here is the set of data necessary to unambiguously determine numerical quantities, in addition to measurable quantities. In other words, one can estimate unambiguously some quantities of interest, such as the coordinates of points, by a combined use of relevant measurements and the choice of a GRS. Several aspects can be considered related to a GRS:

- At the "ideal" level, a GRS is identified with objects of some physical model, such as a local coordinate system of the relativistic space-time, or an affine frame of Newtonian physics.
- The unique identification of a given GRS requires a set of rules, numerical constants and algorithms, designated as a *Conventional GRS*.
- At the so-called realization level, or the translation from the physical model to the estimation model, the GRS follows two main approaches:
    a) The application of a Conventional GRS, which permits a unique estimation of the relevant quantities. In other words, they are the necessary and sufficient data and rules which enable a proper estimation of parameters from measurements.
    b) A conventional selection of quantities estimated according to those rules.

The primary example of a GRS is the ***Terrestrial Reference System (TRS***) understood as a spatial reference frame co-moving with the Earth in space.

The physico-mathematical model of a TRS is the spatial part of a system of Earth-linked space-time coordinates within the framework of General Relativity, or alternatively an affine Euclidian reference frame in the framework of Newtonian Physics. The general purpose of such a system is to define coordinate systems in which points of the Earth are only slowly changing, and to describe the motion of any object of the Earth's environment (such as an artificial satellite). If needed, one can be more specific by using the expression "ideal TRS".

The conventional rules to identify a TRS or its realizations were traditionally designated by the expression *Conventional Terrestrial Reference System (CTRS)*. We no longer recommend the use of this expression, which is not clear enough for a wide community.

The main characteristics of a TRS are its origin, orientation and scale. These can be considered either at the physical level, or at the estimation level.

At the physical level, for a given TRS:

- The origin is modeled by the event (t,0,0,0) of the local coordinate system in relativistic physics, or by the origin point of the affine frame in Newtonian physics.
- The orientation can be represented by the unit vectors tangent to the spatial coordinate axes in relativistic physics, or by the ortho-normal basis of the affine frame in Newtonian physics.
- The scale is related to the way the metrology of lengths is handled. It is a choice not to allow any scalar factor with regard to the SI unit of length, or to allow a choice of unit of length depending on the TRS.

At the estimation level, we introduce the concept of ***Terrestrial Reference Frame (TRF)*** as a realization of a TRS, clearly identifying the origin, orientation and scale..

Usually, such a realization is done by a set of identifiers of physical points (geodetic markers, tracking instrument reference points, center of mass of artificial satellites…) with corresponding numerical coordinate information (values, derivatives, tabulation…) expressed in a selected coordinate system linked to a specific TRS. Such a set was designated by the expression *Conventional Terrestrial Reference Frame (CTRF*), which is no longer recommended either. TRF is the unique preferred term to designate the realization of a TRS.

Two major types of TRS are currently used in Geodesy:

- the local TRS well designed to map a small area of the topographic surface, as used by laboratory experiments or topographers
- the geocentric TRS, designed to map the whole Earth as well as its motion in space

For a local TRS, the origin is located on or near the topographic surface and the orientation is local (horizontal and vertical).

For a geocentric TRS, the origin is at or near the geocentre and the orientation is equatorial. If needed, one can distinguish between truly geocentric (see after) and quasi-geocentric, for the TRS underlying classical terrestrial networks using fundamental points and for which the origin may be displaced from the actual geocentre by several hundred meters.

For the astro-geodetic community, the ***Geocentric Terrestrial Reference System (GTRS)*** is the fundamental strictly geocentric Terrestrial Coordinate System, now formally recognized by the IAU and the IUGG.

The spatial part (3d) of the 4d GTRS is therefore a geocentric TRS.

Since 1988 a specific geocentric TRS has been selected and progressively formally adopted by the international scientific community, and beyond. It is the ***International Terrestrial Reference System (ITRS).***

ITRS is currently under the responsibility of the IERS which establishes its primary realization by producing a specific TRF designated as ***International Terrestrial Reference Frame (ITRF).***

Concerning vertical frameworks, the primary concept is the ***Vertical Reference System (VRS).***

Lexicon

Geocentric Terrestrial Reference System (GTRS)

Geocentric Terrestrial Reference System is defined jointly by IAU and IUGG as "a system of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth and related to Geocentric Celestial Reference System by a spatial rotation which takes into account the Earth orientation Parameters."

International Terrestrial Reference Frame (ITRF)

Primary realization of the ITRS developed and published by the IERS. ITRF is therefore the primary TRF related to the ITRS.

International Terrestrial Reference System (ITRS)

ITRS is the spatial tridimensional part of the specific GTRS for which the orientation is operationally maintained in continuity with past international agreements (so-called BIH orientation). Since 1988, this task has been assigned by the international scientific astro-geodetic community to the International Earth Rotation and Reference Systems Service (IERS).

Terrestrial Reference Frame (TRF)

Realization of a TRS through the numerical realization of its origin, orientation and scale, and their time evolution. This is currently obtained through a set of identifiers of physical points (geodetic markers, tracking instrument reference points, center of mass of artificial satellites…) with corresponding numerical coordinate information (values, derivatives, tabulation…) expressed in a selected coordinate system linked to a specific TRS

Terrestrial Reference System (TRS)

Spatial reference frame co-moving with the Earth in space. The physico-mathematical model of a TRS is the spatial part of a system of Earth-linked space-time coordinates within the framework of General Relativity or an affine Euclidian reference frame in the framework of Newtonian Physics.

Vertical Reference System

A specific height system, associated with a specific equipotential surface of the Earth's gravity field (geoid).

Inter-Commission Working Group 1.4: Site Survey and Co-locations

Chair: Gary Johnston (Australia), Pierguido Sarti (Italy)

Background

The IAG Sub-Commission 1.4 Site Survey and Co-locations operates jointly with the

IERS, Working Group on Site Survey and Co-location. The major goals and objectives of the WG are to:

Develop site survey and standards, including:

- Develop, test, compare and set standards on site survey methods, including observational techniques, network design, classical adjustment, geometrical modelling and/ or direct measurement techniques for invariant point determination, reference frame alignment, software implementation and SINEX generation. This will include the development of a standards document for undertaking site surveys;
- Undertake test campaigns to be used for the comparison of different approaches to local tie surveys addressing each of the technical elements;
- Develop standards for the documentation of site surveys, including survey report content and format; and
- Suggest a pool of expertise to provide advice to survey teams, as required, on standards for site surveys.

Assist in global local-tie coordination, including:

- Liaise with local and international survey teams undertaking site surveys at important co-location sites;
- Liaise with the technique combination groups to ensure WG site survey products meet user requirements;
- Coordinate as required and make recommendations to observatories as to survey scheduling and re-survey frequency;
- Develop and distribute software tools to the community to assist in the generation of site survey products, including SINEX generation software; and
- Provide a forum to raise the profile of site survey as a critically important independent geodetic technique.

Undertake site survey research, including:

- Investigate new site survey methodologies, including observational techniques, observational modelling, invariant point definition, geometrical modelling and/or direct measurement techniques for invariant point determination, reference frame alignment and structural deformation analysis.

Consider future planning issues, including:

- The WG makes recommendations for the future in respect to the ongoing site survey needs of the community and how these needs will be met in the long term (to address issues outside of the scope of this WG).

- Develop recommendations as to how the community can provide the IERS database with all information relevant to inter-technique combination and to the maintenance of the ITRF.

Meetings and Activity

A meeting was held in 2007, at EGU in Vienna, jointly with the GGOS Networks and communication working group. Copies of presentations from that meeting can be found at http://www.iers.org/MainDisp.csl?pid=68-40.

A meeting was held in 2008, at the AGU2008 meeting in San Francisco, US, jointly with the GGOS Networks and communication working group. The meeting was well attended and presentations from a number of speakers illustrated current topics of interest. A particular emphasis was placed on attempting to establish a new methodology for monitoring collocation vectors in near real time. The current survey methodology is episodic and as such will not pick up variations to the collocation vector between surveys. The need to continually refine accuracies was also discussed. With the GGOS aim of refining the accuracy of the ITRF below the 1mm level it becomes imperative that component accuracies are well below that level of accuracy. Current local tie accuracies are at the 1 – 5mm level and as such need to be refined further. As usual the meeting also stressed the need to continue to develop the concept of Local Ties as a key component of the technique combinations and reference frame definition and to ensure all collocated sites have up to date tie information.

Change of Working Group Chair

The chair of the Working Group on Site Survey and Co-locations was changed at the end of April 2009 from Gary Johnston (Geoscience Australia) to Pierguido Sarti (IRA-INAF, Italy). The new charter of the working group was prepared in April 2009. It was endorsed by the IERS Directing Board on the 19th April 2009 in Vienna and is reported below:

Introduction

Tie vectors are nowadays fundamental for the computation of global terrestrial reference frames: the combination of the individual techniques-specific reference frames relies on the accuracy of tie vectors as well as the number and distribution of co-location sites. In order to be useful, tie vectors must be provided with full variance covariance information and must be accurate to the 1 mm level. Variance covariance computation strictly attains to the data processing phase of the tie vector; it can be rather simply achieved and should be regarded as a mandatory task of any local tie. An accurate estimation of the tie vector is more difficult to obtain and many efforts must be taken during the whole local tie process. The accuracy of a tie vector is usually (and indirectly) assessed through a comparison with the space geodetic solutions in the combination phase: the residuals of the combination are analyzed and used to identify discrepancies between space geodetic and terrestrial measurements. If, on one hand, these discrepancies simply highlight a disagreement for a specific co-location site, on the other hand, they are the starting point for a rigorous investigation on the wide variety of causes that might originate from technique specific problems. It should be noticed that the whole process is characterized by the unavoidable complication of reliably coupling measurements of different nature (space geodetic and terrestrial) related to different reference points (electrical and conventional points, respectively).

Local tie surveys are usually performed combining terrestrial measurements of angles, distances and height differences and aim at computing differential coordinates (local ties) between space geodetic instruments expressed in a topocentric frame. In order to do so, terrestrial measurements are performed and combined according to a geometric model (whose complexity and flexibility can vary considerably) apt at realizing the *conventional* definition of the instrument's reference point. Regardless of the way the observations are acquired, processed and conditioned (all these aspects obviously impact the tie vector estimation) it should be noticed that it is impossible to directly observe the instrument's electrical reference point with terrestrial techniques (i.e. the antenna's phase centre for GPS, VLBI and DORIS and the photo-detector for SLR). Furthermore, the tie vector is naturally expressed with respect to a topocentric frame and, in order to be useful, it must be accurately transformed into a global frame.

Space geodetic observations are acquired at the electrical reference point and are commonly referred to the conventional reference point by means of specific corrections and models that are assumed to properly realize the connection. Many factors may influence the stability of the electrical point and any inconsistency related to this very delicate connection phase obviously reflects on the combination's residuals. Addressing, investigating and understanding electrical point instabilities has been a major concern for the whole geodetic community and it is a mandatory task when tie vectors and space geodetic measurements are combined.

The WG on site surveys and co-locations aims at enhancing the cooperation between the groups involved in local tie surveys and their adjustment, the combination centres, the users of tie vectors and the space geodetic techniques services (i.e. IGS, ILRS, IVS and IDS), with the purpose of bringing together all necessary capabilities apt to improve present day situation.

Cooperation with GGOS activities and its branches should be sought and established.

Goals and Objectives

The WG should spread the knowledge related to local surveys and their adjustment among the national agencies in charge of co-location sites maintenance.

1. Site surveys standards:
    a. Revise the local tie surveying activity developed so far. Identify open issues and promote research and discussion.
    b. Set guidelines related to in field operations.
    c. Spread the know how among the community and the national agencies in charge of co-located sites maintenance.
2. Tie vector estimation:
    a. Set guidelines on tie vectors computational standards and their transformation into global frame.
    b. Provide local tie vectors with full variance-covariance information in SINEX format.
    c. Develop a concrete action plan to improve local ties for future ITRF realizations.
3. Site surveys activities:
    a. Promote local tie surveying wherever needed.
    b. Remotely assist site surveying activities.
    c. Provide computational support.

4. Coordination and research:
    a. Liaise with technique combination centres.
    b. Liaise with technique services.
    c. Promote a joint effort aimed at focussing on the most recent combination residuals of the global frame for investigating local inconsistencies at co-location sites and identify actions to be taken to improve the performances of tie vectors within ITRF like combinations.

The list of WG members and the schedule is currently being finalized and will be ready soon.

Other Activities

Geoscience Australia continues to undertake monitoring surveys at the Australian sites. A new calibration pier at Mt Stromlo has been constructed in an attempt to refine the accuracy of the Minico near real time IVP monitoring system. The IVP was showing an apparent seasonal motion through the Minico system. It is believed that the tallest of the four calibration piers was actually moving seasonally and this was biasing the IVP results at the 0.5mm level.
Plans are also being developed for local tie infrastructure at the Yarragadee site which will have a 12m VLBI telescope installed in 2009. A methodology for surveying the relationship between the VLBI dish, Moblas 5 system, Proposed NGSLR system and the variety of GNSS sites is being developed.

IGN is now undertaking routine local tie surveys at numerous sites and offers this service to observatory operators who are unable to complete their own surveys.

Pierguido Sarti from the Italian Istituto di Radioastronomia (IRA) reports that in 2007 they have completely re-surveyed Medicina VLBI-GPS eccentricity and Noto elevation axis using terrestrial observations.

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 Middle of 2009. Commission 2 consists of five sub-commissions, six projects, two study group and several inter-commission projects, working groups, study groups. The sub-commissions cover following science themes; terrestrial, airborne, 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. It is clear that some entities of the Commission were significantly more active than others, but most if not all made progress in their stated objectives. Each of the chairs of the entities was asked to summarize their activities and here summarized the important highlights of these reports.

1. GGEO2008

One of the most important events of Commission 2 for the last 2 years was the International Symposium on Gravity, Geoid and Earth Observation 2008 (GGEO2008), which took place in Chania, a beautiful city in a Mediterranean island, Crete, 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 new IAG are pursuing. Studies of the gravity fields, in particular, temporal variations of the gravity fields, are closely related to the various phenomena which occur in Earth Systems. Gravity field studies or the geodesy in general today, should contribute to the Earth observation.

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 will be published in the IAG Symposia series by Springer Verlag.

2. Gravimetry and Gravity Networks

There are a great number of progresses in all the fields of activities of Sub-Commission 2.1, i.e., absolute gravimetry, relative gravimetry, superconducting gravimetry, airborne gravimetry, and regional gravity networks aiming at hydrological, tectonic, seismological, and other applications.

The Study Group 2.1 (SG 2.1) reported that the evaluation of the results of the 7th International Comparison of Absolute Gravimeters (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 is in the process of organization. The increasing number of participating absolute gravimeters (27 in 2009 relative to 15 in 2001) indicates the growing demand for confident and reliable absolute gravity measurements.

The cooperation of the Inter Commission Working Group (ICWG) 2.1 with the SG 2.1 is realized, in general, through the participation in the organization of ICAG at the BIPM. Therefore the organization of ICAG at the BIPM is strongly desired. However, since all BIPM programs are subject to review, the ICAGs could be terminated after ICAG-2009. A strong request from IAG, such as a resolution of the IAG Assembly would demonstrate the continuing interest and need of the user community.

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. 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”.

One of the most significant improvements over the Global Earth Gravity Models was the official release of EGM2008. The ICWK 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.

4. The gravity field satellite missions

Sub-commission 2.3 members are involved in the derivation of new releases of global static gravity field models based on GRACE and CHAMP mission data. Special emphasis has been given to the de-aliasing from short-term tidal and non-tidal gravity signal contributions. In addition to improved static gravity field models, monthly and even weekly GRACE solutions (CNES-GRGS, GFZ) have been derived. Currently, there are several studies on a GRACE follow-on mission. There is no doubt that GRACE allowed the continuous monitoring of mass transport within the Earth system and lead to a wealth of scientific results in a wide range of disciplines. However it has already been flying for more than 7 years and its remaining days are limited. To avoid/shorten the data gaps after GRACE mission, studies on future gravity missions should be emphasized. A workshop "The Future of Satellite Gravimetry" was conducted in April 2007 at ESTEC/Noordwijk, The Netherlands. As a follow-on activity, a joint GGOS/IGCP565 – IAG – GEO Workshop "Towards a Roadmap for Future Satellite Gravity Missions" will be held from September 30 to October 2, 2009, Graz University of Technology, Austria.

5. Regional Geoid Determination and Commission Projects

Under the coordination of Sub-Commission 2.4, the regional geoid and gravity projects on the continental scale are advancing well, especially in Europe, North-America, South-America and Antarctica. In these regions, the collaboration of National authorities works rather well.

For the African geoid project, a new result was presented in 2007, however a further improvement is difficult due to the lack of data (gravity, GPS/levelling and height). The great support of IAG is desired for collecting the required data sets and other activities of the project.

Mainly due to the missing collaboration of the countries and the problems in data exchange, Commission Project 2.6 (South Asia / Australia) has not been active in the period 2007 – 2009. However there is interest in the topic in the PCGIAP (UN Permanent Committee for GIS Infrastructure of the Asia Pacific). This body is expected to be best able to drive the program for the region.

6. Satellite Altimetry

Sub-commission 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. It was also decided, in the EC meeting, to establish the International Altimetry Service (IAS) and the SC-2.5 has been maintaining a close link with IAS. Mainly due to a lack of time, the sub-commission activities have not been significant. Nevertheless the SC2.5 has organized the scientific sessions on satellite altimetry in GGEO 2008 and IAG 2009 in Buenos Aires as well.

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 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 (BIPM)
Vice-President: Gerd Boedecker (Germany)

1. Terms of Reference and Objectives

Sub-commission 2.1 promotes scientific investigations of gravimetry, gravity measurements and gravity networks. It promotes the growth of the number of absolute gravity determination and of the number of the sites for such determinations. It provides the gravity community with the means to access the confidence in gravity measurements at the well-defined level of accuracy through organizing, in cooperation with metrology community, the international comparisons of absolute gravimeters. The sub-commission proceeds from such point-wise gravimetry to precise gravimetry/gradiometry which should cover, in particular, the land-sea border areas to resolve still existing problem of significant biases and errors in determination.

The Sub-commission promotes such research and development by stimulating airborne and shipboard gravimetry and gradiometry. It encourages and promotes special absolute/relative gravity campaigns, techniques and procedures for the adjustment of the results of gravity surveys on a regional scale. Sub-commission encourages development of the Global Gravity Reference Network for GGOS.

Through the inter-commission WG on Absolute Gravimetry the Sub-commission works on the standardization of absolute gravity data, software for absolute gravity measurement and appropriate information. The Sub-commission will encourage regional meetings or workshops dedicated to specific problems, where appropriate.

Program of Activities

To meet these goals, the Sub-commission sets up Study Group 2.1 on Comparisons of Absolute Gravimeters (Chaired by L. Vitushkin); inter SC 2.1 and IGFS Working Group on Absolute Gravimetry (chaired by H. Wilmes) and Commission Projects CP2.1-2.6.

Steering committee

Sub-commission vice-president: Gerd Boedecker <boe@bek.badw.de>
Rene Forsberg <rf@spacecenter.dk>: Gravity Networks in Polar Regions
Matthias Becker <becker@ipg.tu-darmstadt.de>: Relative Gravimetry
Herbert Wilmes <herbert.wilmes@bkg.bund.de>: Absolute Gravimetry
David Crossley <crossleydj@gmail.com>: Superconducting Gravimetry
Uwe Meyer <uwe.meyer@bgr.de>: Aerogravimetry and Gradiometry
Yoichi Fukuda <fukuda@kugi.kyoto-u.ac.jp>: East Asia and Western Pacific Gravity Networks
Maria Cristina Pacino <mpacino@fceia.unr.edu.ar>: Gravity in South America

2. Activities

There is a progress in the work of Study Group 2.1, inter SC2.1 and IGFS WGAG and in all the fields of activities of SC2.1. The reports are presented by the members of steering committee and the chairs of SC2.1.

The SG2.1 reports that the evaluation of the results of the 7th International Comparison of Absolute Gravimeters ICAG-2005 was completed and the 8th ICAG-2009 in September-October 2009 at the International Bureau of Weights and Measures (Bureau international des poids et mesures – BIPM) in Sèvres, France is in the process of organization. The increasing number of participating absolute gravimeters (27 in 2009 relative to 15 in 2001) indicates the growing demand for confident and reliable absolute gravity measurements. In some countries (Austria, Finland, Italy, Switzerland) the measurement capability in the gravimetry is officially presented in a database (Key Comparison Data Base) maintained by the BIPM (http://kcdb.bipm.org/AppendixC/country_list.asp?Sservice=M/ TVHG.8.1).

Further activity of SG2.1 in collaboration with Working Group on Gravimetry (WGG) of the Consultative Committee for Mass and Related Quantities (CCM) should be continued with the goal of the establishment of new sites suitable for Regional Comparisons of Absolute Gravimeters (not only in Europe as at present) and promoting the results of comparisons, i.e. Comparison Reference Values and the offsets of individual absolute gravimeters, into practical gravity measurements.

The organization of International Comparisons of Absolute Gravimeters at the BIPM should be continued after ICAG-2009 under the umbrella of IAG and Metre Convention. However, since all BIPM programs are subject to review, the ICAGs could be terminated by the BIPM as a result of the review process. A strong request from IAG, perhaps in the form of the resolution of the Assembly of IAG would demonstrate the continuing interest and need of the user community.

To improve communications between the IAG and the BIPM, the IAG could apply to the President of the CCM for institutional membership on the CCM WGG.

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 and 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 activity of Inter-Commission Working Group 2.1 "Absolute Gravimetry" is reported by H. Wilmes. The WGAG cooperates with SC2.1 Study Group "Comparison of Absolute Gravimeters", CCM Working Group on Gravimetry and SC2.1 in general. This cooperation is realized through the participation in the organization of international comparison at the BIPM and at the regional scale, the common work on the standardization of absolute gravity data, promotion of new techniques and procedures in absolute gravimetry and establishment of new stations of the global absolute gravity base net in the frame of GGOS.

It is reported on the establishment of a new absolute gravity data base, initiated by IGFS. This AGrav database was developed by Bundesamt für Kartographie und Geodäsie (BKG) and put into operation together with Bureau Gravimétrique International (BGI) at two mirrored servers http://bgi.dtp.obs-mip.fr/agrav-meta/ and http://agrav.bkg.bund.de/agrav-meta/. The database concept is described in the report of ICWG 2.1.

A WGAG meeting was held during the International Symposium on Gravity, Geoid and Earth Observation GGEO-2008 in Chania, Crete, June 24, 2008.

One direction in the future work is to enable the combination of absolute gravity data with e.g. geometric observations on the basis of the improved and complemented IAGBN data.

The activity in relative gravimetry (Appendix 1-1, M. Becker) is related to the extensive use of the relative gravimetry in local and regional projects for monitoring of temporal and spatial gravity variations. A specific task of relative measurements is also the support of International Comparisons of Absolute Gravimeters where the gravity field distributions above the gravity stations should be measured and the gravity differences between the stations measured by relative gravimeters provide the additional information for the adjustment of micro gravity networks used in the comparison and for the evaluation of the Comparison Reference Values

In relation to the watt-balance experiments for the redefinition of kilogram there is the growing interest to in-the-laboratory reconstruction of the gravity field realized using detailed relative gravity measurements with the reference to point where the absolute value of free-fall acceleration is determined.

A brief review of the history of the International Absolute Gravity Base Network (IAGBN) is presented in 2008 by G. Boedecker in his Aide Memoire.

The activity in the field of superconducting gravimetry (SG) moderated by David Crossley (chairman of Inter-Commission Project IC-P3.1 "Global Geodynamics Project - GGP" is well presented in the Report on GGP Activities in 2008-2009 and in GGP Newsletter #19 of 22 May 2009. The program of the establishment of the new GGP SG stations is developed and the update of the GGP data base is suggested. However, to give assurance in providing a continuous set of SG data to GGOS at the GGP Business Meeting in Vienna, Austria (22 April 2008), it was proposed to change the current status of GGP as Inter-Commission Project IC-P3.1 to IAG Service. That should secure a mechanism for permanent future operations of GGP. The Questionnaire on the proposed status of GGP was distributed.

The activity in airborne gravimetry including that in polar regions was presented by several talks at the workshop "Aerogravimetry: Technology and Applications" organized on 4-5 June 2009 by Dresden University of Technology and Institute for Planetary Geodesy (Germany) and chaired by M. Scheinert, U. Meyer and J. Schwabe. Further improvements in the gravity measurement procedures and techniques on various platforms (aircrafts, including new aircraft POLAR 5, helicopters, vehicles) as well as in the data processing were demonstrated. Some presentations in PDF format can be seen on the webpage http://tpg.geo.tu-dresden.de/antgp/workshops.htm.

In the course of discussions at the workshop on aerogravimetry the proposal to discuss a possible realization of the projects of airborne gravimetry on the airships is arose. Modern airships (Zeppelin NT, AU-30) can provide a good platform for the airborne gravimetry and that can significantly increase the resolution in the measurements with respect to the airborne gravimetry on the aircrafts.

French colleagues informed on the activity in the frame of the project GHYRAF (Gravity and Hydrology in Africa) coordinated by J. Hinderer (IPGS, Strasbourg University, France). This project planned for the period from 2008 to 2010 provides the applications of gravimetric methods to hydrology. It is planned to use in Algeria, Niger and Benin the combination of the repeated absolute (with the gravimeters FG5 and A10) and relative gravity measurements. The installation of superconducting gravimeter is planned at a site under construction in Djougou, Benin.

Sub-Commission 2.4 summarizes the reports of the Commission Projects.

The report on the SP "East Asia and Western Pacific Gravity Networks" is prepared by M. Honda <honda@gsi.go.jp> and W. Sun <sunw@eri.u-tokyo.ac.jp> and compiled by Y. Fukuda (Appendix 1-2).

It is reported on the establishing the Japanese Gravimetric Standardization Network (JGSN200X) by Geographical Survey Institute (GSI). Three absolute gravimeters and relative gravimeters were used for the measurements at 11 Fundamental Gravity Stations and 20 first order stations. Regular local comparisons of the absolute gravimeters are performed every year with up to 6 gravimeters.

The repeated absolute measurements for the detection of non-tidal gravity variations associated with tectonic activity are carried out by GSI and Earthquake Research Institute (ERI) of University of Tokyo every few months.

In China in the cooperation between ERI, the Institute of Seismology and Yunnan Seismological Bureau, China Earthquake Administrations a local gravity network of four absolute and 40 relative stations is established for the investigation of the tectonic structure at the edge area of Tibet plateau. The details of the network structure and the measurements are described in the report

For the improvement of geophysical interpretation of the land subsidence in each of three megacities of Indonesia about ten gravity stations are established to combine the results of monitoring of the groundwater levels, GPS monitoring and absolute and relative gravity measurements. The first measurement campaign has been carried out in 2008 and the measurements will be repeated once a year for next few years to detect the gravity changes associated with the land subsidence.

Jaakko Mäkinen (Finnish Geodetic Institute) reported on the activity in the frame of the Action ES0701 "Improved constraints on models of Glacial Isostatic Adjustment (GIA)" (see website http://www.cost-es0701.gcparks.com/) of European Cooperation in Science and Technology (COST). This action seeks to augment the accuracy of current GIA models by providing new and improved observational constraints. One of the main difficulties in interpreting changes in surface gravity in terms of GIA related to local effects, above all local hydrology in the observed gravity. Methods to correct for local hydrological effects at superconducting gravimeter (SG) sites are well-established, and require extensive local hydrological observation and modelling, calibrated or verified by the continuous SG record. For budgetary reasons, station owners can perform such detailed investigations only at very few of the much more numerous absolute-gravity (AG) sites. What to do at the rest of AG sites? To advance work on this question, the AG subgroup of the Working Group 1 of COST ES0701 organized at the Royal Observatory of Belgium, Brussels (March 16-17, 2009) a "Workshop on hydrological and other local effects in gravity measurements". The presentations are available at the website page: http://www.cost-es0701.gcparks.com/index.php/activities/conferencesworkshops.

For GIA studies, repeated AG measurements have during the recent years been performed at more than 50 stations in the Fennoscandian Postglacial Rebound area. At 20 stations the time span is now sufficient to derive a gravity change rate. The work is coordinated by the Nordic Geodetic Commission and reported in the Appendix 1-3 by J. Mäkinen.

The organization of Discussion Group on Planetary Absolute Gravimetry with the aim of analysis of the objectives for the absolute gravimetry on the Moon and Mars and the requirements to the uncertainty and technical characteristics of planetary absolute gravimeters is initiated. Currently the specialists from France, Germany, Italy, Japan Russia and USA expressed their interest to membership in this Discussion Group.

Currently the organization of the Second IAG Symposium "Terrestrial Gravimetry, Static and Mobile Measurements, TGSMM-2010", in St Petersburg, Russian Federation, is under discussion.

Appendix 1-1

Report on the activities in Relative Gravimetry

Reported by M. Becker

Relative gravimetry was used extensively in local and regional projects for monitoring of gravity variations [8]. Natural as well as man made changes, e.g. due to mining or construction works, were observed. The latest instrumental developments, like the Burris gravimeter and the Scintrex CG5M allow for almost 1 microgal accuracy in high precision applications [2], [3], [6].

The network of the International comparison of absolute gravimeters at the BIPM in Sèvres (France) was extensively studied and observed during the intercomparison campaigns. Results allow the assessment of the empirical uncertainties of relative gravimeters in such applications. Small ties and vertical gradients can be measured with an uncertainty of about 1 to 3 microgal [3], [4], [5].

Related research was undertaken by several groups with respect to the new Watt Balance projects at National Laboratories. Here an uncertainty of about 3 to 5 microgal was estimated for the interpolated gravity values at the center of the new Watt-Balance [1], [4], [7]. Further research in the derivation of reliable values for the uncertainty of relative gravimetry is required to allow a detailed assessment of the budget of uncertainty of those instruments and measurements.

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Appendix 1-2

Report on the activities in East Asia and Western Pacific Gravity Networks

Reported by M. Honda and W. Sun; compiled by Y. Fukuda

Absolute gravity measurements provide nationwide fundamental basis for local and regional gravity surveys and consequently a reference for the height system of the nation as well. Moreover the absolute gravity measurements contribute to the studies of crustal movements, sea level changes as well as secular gravity changes due to various phenomena in and on the Earth. Therefore the establishment of Gravity Networks regardless of size is essentially important for these studies.

For establishing Japanese Gravimetric Standardization Network 200X (JGSN200X), Geographical Survey Institute (GSI) has been conducting absolute gravity measurements using FG5 #104, 201 and 203 as well as relative measurements by means of LaCoste & Romberg gravimeters (G-type). Between Jan 2007 and Dec 2009, the absolute measurements have been conducted at 11 Fundamental Gravity Stations (FGS) including 4 new stations and the relative measurements at 10 FGS, 20 first order stations, 10 Bench marks and 3 GEONET (GPS Earth Observation Network System) stations.

Aiming at the detection of non-tidal gravity changes associated with tectonic activities, GSI and Earthquake Research Institute, the University of Tokyo (ERI) has repeatedly conducted absolute measurements at Omaezaki FGS which is located in the expected Tokai earthquake area. The measurements have been conducted every few months and the results have been regularly reported to the Coordinating Committee for Earthquake Prediction, Japan.

GSI also conducted absolute gravity measurements at Nagaoka FGS in 1997, 2004, 2005 and 2008. Nagaoka FGS is located within 50km from the epicentres of the 2004 Niigata-Chuetsu Earthquake (M6.8) and the 2007 Niigata Earthquake (M6.6). GSI reported that the gravity changes associated with these earthquakes have been detected by the absolute measurements.

In order to investigate the tectonic structure at the edge area of Tibet plateau through gravity changes caused by the movement of the large scale fault system, a local absolute gravity network is established in the Dali county of Yunnan province. This project is cooperated by ERI, the Institute of Seismology and Yunnan Seismological Bureau, China Earthquake Administrations.

The gravity network is composed of four absolute and 40 relative stations. The four absolute stations are Midu, Dali, Eryuan and Jianchuan located in Dali county of Yunnan province, China. The distance between any two neighbour stations is about 50-70 km. The four stations were measured by FG5 #212 absolute gravimeter in 2005, and repeat by FG5 #232 in 2007. Taking each absolute gravity station as a centre, four relative gravity profiles were designed and measured by 5 LaCoste & Romberg gravimeters G-581, 793, 854, 1003 and 1132. Each profile has 10 stations. The observed gravity values can serve as a reference for future measurement and can be used to compute gravity anomaly and so on.

In many of the urbanized cities, in particular in Asian coastal areas, one of the urgent problems is land subsidence due to excess pumping of groundwater. In Jakarta, Indonesia, for instance, there are more than several tens of observation wells and the monitoring of the groundwater levels have been conducted so far. However these observations are not sufficient to understand the mechanism of the subsidence. For the geophysical interpretation of the mechanism, precise gravity measurements combined with GPS measurements give us useful information about the density changes.

For these purposes, local gravity networks have been established in Jakarta, Semarang and Bandung, 3 megacities of Indonesia. In reference to InSAR images, about 10 gravity points have been selected from GPS observation points in each city. Employing A10 portable absolute gravimeter (#017) and a Schintrex gravimeter, the first campaign measurements have been conducted in Aug.-Sep. 2008 and the same measurements will be planed once a year for next few years. In maximum, more than 10 cm/yr land subsidence is expected at the points. Therefore the detection of the gravity changes associated with the land subsidence will be highly expected.

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Appendix 1-3

Absolute gravity measurements in the Fennoscandian Postglacial Rebound area

Reported by Jaakko Mäkinen, Finnish Geodetic Institute

Absolute gravity measurements in the Fennoscandian postglacial rebound area began in 1976 when a team from Istituto di Metrología "G. Colonnetti" (Torino) measured six stations with the rise-and-fall gravimeter IMGC (Cannizzo et al., 1978). In 1980 two stations were measured by the team of the Academy of the Sciences of the USSR from Novosibirsk, using the gravimeter GABL (Arnautov et al., 1982). From the beginning the goal was to establish reference values for future remeasurement in order to detect gravity change due to the post-glacial rebound. In 1988, regular repeat measurements were begun by the Finnish Geodetic Institute (FGI) with the JILAg-5. An important advance was the introduction of FG5 gravimeters into the work by the Federal Agency for Cartography and Geodesy (BKG, Frankfurt a.M. and National Oceanic and Atmospheric Administration (NOAA, Boulder, CO) in 1993.

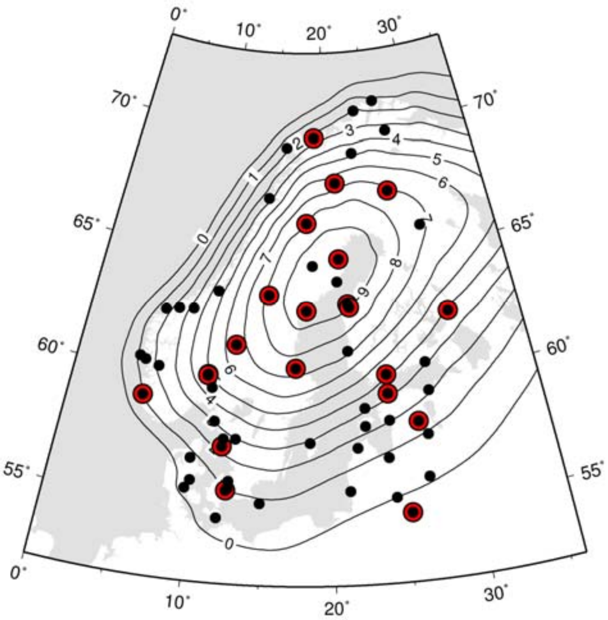

Figure 1. Absolute gravity stations in the Fennoscandian Postglacial Rebound area. Stations with a rim have repeats with a sufficient time span to determine a gravity trend. In addition to the stations depicted in the Nordic and Baltic countries, measured in the cooperation described here, stations in Russia exist. E.g. there are 4 sites measured by the Central Research Institute of Geodesy, Aerial Survey and Cartography (TsNIIGAiK, Moscow) with the FG5-110, partly in cooperation with the FGI. The isolines give the vertical velocity relative to the Earth's centre of mass in mm/yr, according to the empirical velocity model NKG2005LU (Ågren and Svensson, 2007).

In 2003 annual large-scale campaigns with FG5 gravimeters started, coordinated by the Working Group on Geodynamics of the Nordic Geodetic Commission. This was prompted by the launch of the GRACE gravity satellite mission, which made it important to collect a comprehensive set of ground-truth values of gravity change during the lifetime of the satellite pair. The work also forms a part of the Nordic Geodetic Observation System NGOS, embedded in the Global Geodetic Observing System GGOS.

The initial participation by the gravimeter teams of Leibniz Universität Hannover, FGI and BKG has since expanded to include the University of Life Sciences (Ås, Norway) and Lantmäteriet (Gävle, Sweden). In addition, ground support a.o. with the stations is provided by the Danish National Space Agency, the Norwegian Mapping Authority, the Estonian Land Board, the Latvian Geospatial Information Agency and the Vilnius Gediminas Technical University. At present some 50 sites have repeated absolute measurements (Figure 1) and most of them are co-located with continuous GPS. At 20 stations the time span is now sufficient to compute a gravity change rate with time (Figure 2).

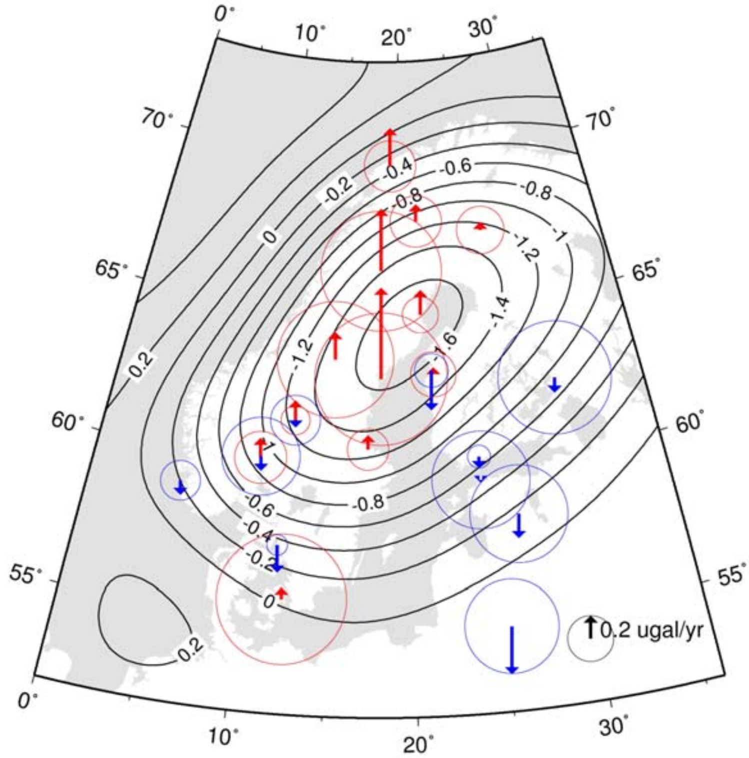

Figure 2. Comparison of observed gravity change rates with predictions from the model of Glacial Isostatic Adjustment by Milne et al. (2004). The isolines give the predicted gravity rates, obtained from predictions of vertical motion by multiplying them with –0.154 µgal/mm. The arrows give the residual of the observed rate with respect to the predicted rate, with sign. E.g., an observation –1.0 µgal/mm and a prediction –0.8 µgal/mm give a residual of –0.2 µgal and a downward arrow. The circle gives the 1-sigma uncertainty of the observed rate.

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

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
- 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.

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.

Sub-Commission 2.3: Dedicated Satellite Gravity Mapping Missions

President: Roland Pail (Austria)

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 mid 2009.

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-5S, GGM03S, ITG-Grace03, AIUB-GRACE01S). 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., [5], [7], [9]). In addition to improved static gravity field models, also monthly and even weekly GRACE solutions (CNES-GRGS, GFZ) have been derived (e.g., [3], [4], [11]). 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., [6], [16]), and are now extensively used by a wide geo-scientific community.

In preparation to the GOCE mission, the GOCE High-Level Processing Facility (HPF) has been developed, which is responsible for the generation of GOCE final orbit and gravity field products ([8]). This task has been performed by a consortium of 10 university and research facilities in Europe, where several members of the Sub-commission are very actively involved. In the frame of this project, innovative strategies for the solution of several specific problems of high-level gravity field modelling, precise orbit determination and the analysis and calibration of space-borne accelerometer, gradiometer, and star-tracker observations have been developed (e.g., [1], [2], [8], [12], [13], [14], [15], [17], [18]).

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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 ([21], [24]). 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 ([23]).

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 [19], [22]. The most recent high resolution European quasigeoid model EGG2008 was computed within the framework of the European Gravity and Geoid Project (EGGP; [20]).

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3. Future gravity field missions

Activities and results

Based on the success of the gravity mission CHAMP and GRACE, which brought an enormous improvement in the knowledge of the Earth's gravity field and particularly in its temporal evolution and thus led to a large amount of applied research in geosciences, a number of simulation studies for future gravity field mission concepts have been performed, investigating different observation types, candidate technology, formation flights, etc. The underlying challenges are the improvement of spatial and temporal resolution, reduction of temporal aliasing, as well as minimizing the effect of specific covariance characteristics of different observations types.

Currently, there are several studies on a GRACE follow-on mission, such as the research and development study "GRAF" (by GFZ and STI; [26]), the "Micromega" project which was selected by the CNES science committee to enter phase 0, or the ESA ITT "Assessment of a

Next Generation Gravity Mission to monitor the variations of Earth's gravity field". Further, national studies on future gravity field missions with the involvement of several Sub-commission members are carried out, e.g. in Germany in the framework of the Geotechnologien-Program of the BMBF.

Concerning temporal gravity and geophysical background models, within the ESA study "Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the Earth system by Means of Satellites" a complete multi year forward simulation of mass variations in the Earth system has been performed, potential mission scenarios have been identified, and their performance was investigated by numerical gravity field retrievals ([25]). Further, applications of future mission concepts have been studied together with main user groups, such as geophysicists, e.g. [28].

From the organizational point of view, a workshop "The Future of Satellite Gravimetry" was conducted in April 2007 at ESTEC/Noordwijk, The Netherlands, where future needs of gravity field observations from space have been identified ([27]). As a follow-on activity, a joint GGOS/IGCP565 – IAG – GEO Workshop "Towards a Roadmap for Future Satellite Gravity Missions" will be held from September 30 to October 2, 2009, Graz University of Technology, Austria ([29]). The workshop aims at bringing together stakeholders in satellite gravity missions in order to establish a roadmap for future satellite gravity missions that would outline the sensor developments, mission concept developments, and mission implementation, and that would be 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).

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4. Interfacing with user communities

Activities and results

The workshops discussed above ([27], [29]) 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 ([33]) or GOCE-ITALY. 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., [31]), glacioisostatic adjustment (e.g., [34]) or cryospheric modelling (e.g., [30]).

Online service access points for geoscientific data products, such as the Information System and Data Center (ISDC) portal maintained by the GFZ ([32], [35]) show a steadily growing number of users (status February 2009: almost 2000) from various user communities (climatology, oceanography, glaciology, geodesy, solid Earth physics, etc.).

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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 modelling 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, air-borne, satellite data specifically as applied to geoid modelling.

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

Website: http://www2.swisstopo.ch/um/sc24.htm (not updated since 2007).

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.

Two 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".

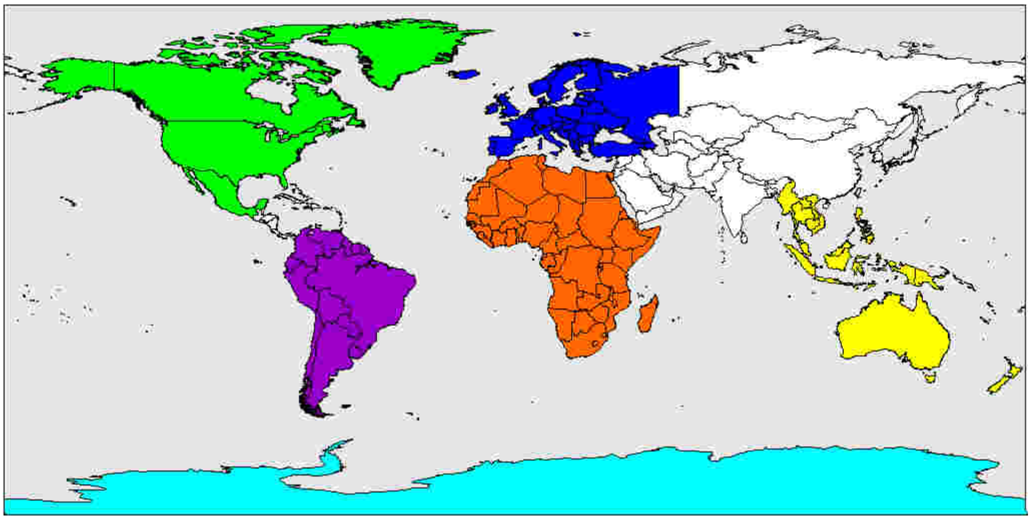

Figure 1: Coverage Areas of the Commission 2 geoid projects

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 first results are available. The collaboration of National authorities works rather well.

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) advance well on the national level.

Project 2.6 (South Asia/Australia) has big problems mainly due to the missing collaboration of the countries and the problems in data exchange. That's principal reason why this project has not been very active in the period 2007 - 2009 but "there is interest in the topic in the PCGIAP (UN Permanent Committee for GIS Infrastructure of the Asia Pacific) and I suspect this body is best able to drive the program for the region" (citation from B. Kearsley). The problems and possible ways to overcome them are described in the interesting report of the project.

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 gives 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)

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 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 established (http://space.cv.nctu.edu.tw /altimetryworkshop/ALT.html). Tools for satellite altimetry data processing and applications will be freely available at this webpage.

The current focus (2007-2009) is to promote applications of satellite altimetry over land and coastal zones. To this end, the "International Workshop on Gravity, GPS and Satellite Altimetry Observations of Tibet, Xinjiang and Siberia (TibXS)" will be held from August 20 to 22, 2009, in Urumqi, Xinjiang, China. (see http://space.cv.nctu.edu.tw/altimetryworkshop/ TibXS2009/TibXS2009.htm). Tibet, Xinjiang and Siberia (TibXS) are regions with active plate tectonics. This workshop will bring 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. IAG SC2.5 will again organize an altimetry workshop in 2010 to promote altimetric applications.

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 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 and evaluated by national and European GPS and levelling data sets (Denker et al., 2008 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 and shall be distributed soon to all data contributors.

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., 2008a – 2008d). 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 the situation is less transparent, as the differences exhibit wavy structures without a clear trend; further investigations with Italian colleagues are underway. In the end, the EUVN_DA GPS/levelling data shall also be combined with the gravimetric quasigeoid.

Other future steps include data improvements for selected areas, eventually using new airborne campaign results, the use of GOCE geopotential models, the testing of other modelling techniques, the refinement of the mathematical modelling, and the development of location-dependent error estimates.

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; 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 (US) – dan.roman@noaa.gov

Bottom Line Up Front

Collaboration continues and networks are expanding to include other nations in the region. Several meetings have been held specifically on this topic between national agencies responsible for datums and applications reliant upon them. Future activities will likely involve funded efforts to refine both the data and theoretical challenges – followed by a staggered implementation of a geoid height model as a vertical datum.

Meeting Activities

Meetings have been held concurrent with major IAG events including IUGG 2007 at Perugia, Italy (2007) and GGEO 2008 in Chania, Greece. Additional meetings and workshops have been held during the CGU 2008/Geoid Workshop in Calgary, Canada, at the GRAV-D session during the Fall 2008 AGU meeting San Francisco, USA and the Joint Assembly 2009 in Toronto, Canada. Additionally, specific collaborative meetings between USA agencies have been organized – specifically between the National Geodetic Survey (NGS) and the National Geospatial-Intelligence Agency (NGA). Additionally, NGS invited Lars Sjöberg for a one month visit to help improve the theoretical basis for modelling.

Future meetings are on track for IAG 2009 in Buenos Aires, Argentina, the meeting of the Americas in Iguassu Falls, Brazil and the Fall 2009 AGU meeting – where sessions are being convened that directly relate to the development of regional geoid models. Additionally, Heiner Denker will visit in August 2009 at the NGS to help implement improved theory and modelling techniques.

Data Improvement

The primary mechanism for improvement of data in the region will be by implementation of the Gravity for the Redefinition of the American Vertical Datum (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 centred 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.

From INEGI (Mexico), Antonio Hernandez Navarro has expressed interest in participating with the efforts of the North American Geoid Project. There, David Avalos has recently been added as a support for the improvements of their national gravity network and geoid model.

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 2018. 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 2009 Joint Assembly 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 W_0 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 modelling 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.)
Antonio Hernandez Navarro, INEGI (Mexico)
Laramie Potts, NJIT (U.S.A.)
Karim V. D. Hodge, L&SD (Anguilla)
Marc Veronneau, GSD (Canada)
Rene Forsberg, DNSC (Denmark)
Anthony Watts, L&SD (Cayman Islands)

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 modelling 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 is likely in place to start airborne data collections next year, surface data cleaning and the melding of these disparate data sets into a common seamless gravity field. 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)

1. 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.

2. Main activities (2007–2009)

This document presents the status report of IAG African Geoid Project (Commission Project 2.3) since 2007. During the period 2007–2009 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). Abd-Elmotaal (2008b, 2009) 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).

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).

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 wave-lengths in geoid computation using several approaches and modern techniques. Abd-Elmotaal and Kühtreiber (2008b) have implemented gravity interpolation in mountainous areas with high accuracy. Recently, Ulotu (2009) has computed a geoid model for Tanzania from sparse and varying gravity data density.

3. Future Activities

During the upcoming two-year period 2009–2011, the AGP intends to work on the main objectives of the commission project (see above). Special work on different local geoid models is going to take place. Work has started on the development of a new geoid model for South Africa, making use of a new set of precise GPS/levelling data to calibrate the model by Merry and his co-workers. A new GPS/levelling is recently available in Egypt. Abd-Elmotaal is going to incorporate this new set for a better geoid fitting in Egypt. Furthermore, meetings during the IAG Scientific Meeting at Buenos Aires, Argentina in 2009 and an IAG sponsored conference during 2010 are planned (if IAG supports the attendance of the African scientists during such meetings). Further direction of the AGP will be discussed during the future meetings (if applicable).

4. 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.

5. 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)

6. Publications

Abd-Elmotaal, H. (2007a) Reference Geopotential Models Tailored to the Egyptian Gravity Field. Bollettino di Geodesia e Scienze Affini, Vol. 66, No. 3, 129–144.

Abd-Elmotaal, H. (2007b) Tailored Reference Geopotential Model for Egypt. Presented at the 24th General Assembly of the IUGG, Perugia, Italy, July 2–13, 2007.

Abd-Elmotaal, H. (2007c) High-Degree Geopotential Model Tailored to Egypt. 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, 187–192.

Abd-Elmotaal, H. (2008a) Gravimetric Geoid for Egypt using High-Degree Tailored Reference Geopotential Model. Presented at the 1st Arab Conference on Astronomy and Geophysics "ACAG-1", Cairo, Egypt, October 20–22, 2008.

Abd-Elmotaal, H. (2008b) Evaluation of PGM2007A Geopotential Model in Egypt. Presented at the IAG International Symposium on Gravity, Geoid and Earth Observation "GGEO 2008", Chania, Greece, June 23–27, 2008.

Abd-Elmotaal, H. (2009) Evaluation of the EGM2008 geopotential model for Egypt. Newton's Bulletin, No. 4, 185–199.

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.

Abd-Elmotaal, H. and Kühtreiber, N. (2008a) An Attempt towards an Optimum Combination of Gravity Field Wavelengths in Geoid Computation. In Sideris, M., ed., Observing our Changing Earth, International Association of Geodesy Symposia, Vol. 133, 203–209.

Abd-Elmotaal, H. and Kühtreiber, N. (2008b) Gravity Interpolation in Mountainous Areas. Presented at the General Assembly of the EGU, Vienna, Austria, April 13-18, 2008.

Benahmed Daho S.A. (2009a) Evaluation of the Earth Gravity Model EGM2008 in Algeria. Newton's Bulletin N° 4, pp. 164-172, ISSN 1810-8547, January 2009.

Benahmed Daho, S.A. (2009b) Assessment of the EGM2008 Gravity Field in Algeria using gravity and GPS/levelling data. Accepted for publication in International Association of Geodesy (IAG) Symposia, Springer Verlag Editor.

Benahmed Daho, S.A. and Fairhead, J.D. (2007) Accuracy Assessment of the Available Geoid Models in Algeria. Computers & Geosciences Internat. Journal. Vol. 33, Issue 1, 78-82, Elsevier 2007.

Benahmed Daho, S.A. and Merry, C.L. (2007) Merging the African Geoid model with GPS/Levelling data in Algeria using the Collocation method. Bollettino di Geodesia e Scienze Affini, Vol. 66, N° 2, pp. 49-65.

Benahmed Daho, S.A., Fairhead, J.D., Zeggai, A., Ghezali, B., Derkaoui, A., Gourine, B. and Khelifa, S. (2008). A new investigation on the choice of the tailored geopotential model in Algeria. Journal of Geodynamics. Vol. 45, Issues 2-3, pp. 154-162.

Benahmed Daho, S.A., Mandes, A., Fairhead, J.D. and Derkaoui, A. (2009). Impact of the new GRACE Geopotential Model and SRTM data on the Geoid modelling in Algeria. Journal of Geodynamics, Vol. 47, Issues 2-3, pp. 63-71.

Kühtreiber, N. and Abd-Elmotaal, H. (2007) Ideal Combination of Deflection Components and Gravity Anomalies for Precise Geoid Computation. In Tregoning, P. and Rizos, C., eds., Dynamic Planet, International Association of Geodesy Symposia, Vol. 130, 259–265.

Merry, C.L. (2007). An updated geoid model for Africa. Presented, XXIV General Assembly of the IUGG, Perugia, July 2007.

Merry, C.L. (2009a). EGM2008 evaluation for Africa. Newton's Bulletin, No. 4.

Merry, C.L. (2009b). An evaluation of EGM2008 for southern Africa. Presented, International Geoscience & Remote Sensing Symposium, Cape Town, July 2009.

Ulotu, P.E. (2009) Geoid Model of Tanzania from Sparse and Varying Gravity Data Density by the KTH Method. Ph.D. Dissertation. Royal Institute of Technology (KTH), Department of Transport and Economics, Division of Geodesy.

Zeggai, A., Benahmed Daho, S.A., Kahlouche, S., Ghezali, B. and Nechniche, H. (2008) Transform Co-ordinates by Geodetic lines, GPS Levelling and Nord Sahara Datum. Revue Internationale des 'Technologies Avancées', pp 05-11, ISSN 1111- 0902 - N° 20, December 2008.

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 first four-year period of AntGP being a Commission Project of IAG (2003-2007), a great step forward has been made concerning the establishment of cooperation and close linkages between the different scientific disciplines working in Antarctica. At the IUGG General Assembly in Perugia, 2007, it was decided to continue the project.

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. The following IPY projects should be mentioned: Project 67 "Origin, evolution and setting of the Gamburtsev sub-glacial highlands (AGAP)", project 97 "Investigating the Cryospheric Evolution of the Central Antarctic Plate (ICECAP)", project 42 "Sub-glacial Antarctic Lake Environments (SALEUNITED)", project 152 "Trans-Antarctic Scientific Traverses Expeditions (TASTE-IDEA)", project 185 "Polar Earth Observing Network (POLENET)".

A milestone was the IUGG General Assembly, held in Perugia, July 2007. An overview poster on AntGP was presented and a presentation was given discussing the regional geoid determination in Antarctica (see List of Publications). Further presentations dealing with the goals of AntGP were given at the 10th International Symposium on Antarctic Earth Sciences (ISAES X), Santa Barbara, August 2007. Likewise, the linkage to the Scientific Committee on Antarctic Research (SCAR) was realized by M. Scheinert, chairing project 3 "Physical Geodesy" of the SCAR Standing Scientific Group on Geosciences, Expert Group on Geospatial Information and Geodesy (GIANT Geodetic Infrastructure in Antarctica).

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 aero-geophysical instrumentation. This aspect has been addressed by a workshop "Aerogravimetry: Techology and Applications", recently held in Dresden, June 4 and 5, 2009. A number of AntGP members actively took part in this workshop. This workshop provided an excellent opportunity for exchanging 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.

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:

- IAG General Assembly, August 31 – September 4, 2009, Buenos Aires.
- XXXI SCAR Meeting and Open Science Conference, September 2010, Buenos Aires.

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

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.
- Earth Tide Symposium 2008 "New Challenges in Earth's Dynamics", Jena, September 1-5, 2008.
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Commission Project 2.5: Gravity and Geoid in South America (GGSA)

Chair: Maria Cristina Pacino (Argentina)
Prepared by: Denizar Blitzkow[1]* and Maria Cristina Pacino[2]

Activities

1. Introduction

This report intends to cover most of the activities in South America related to Gravity and Geoid Project. It shows the many activities going on by different organizations like universities and research institutes. Between the many contributions, out of the organizations of the authors, it is important to mention IBGE (Brazilian Institute of Geography and Statistic), NGA (National Geo-Spatial Intelligence Agency), GETECH (Geophysical Exploration Technology), the many civil and military institutions in several countries of South America.

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 924,600 point gravity data in the continent, including Central America. Figure 1 shows new and old gravity data distribution.

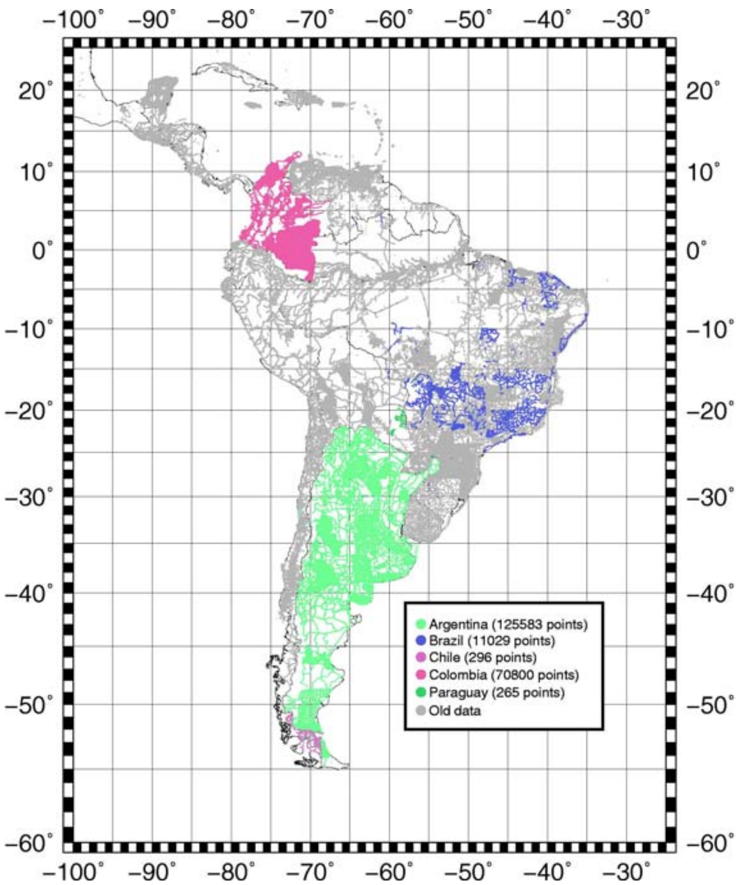
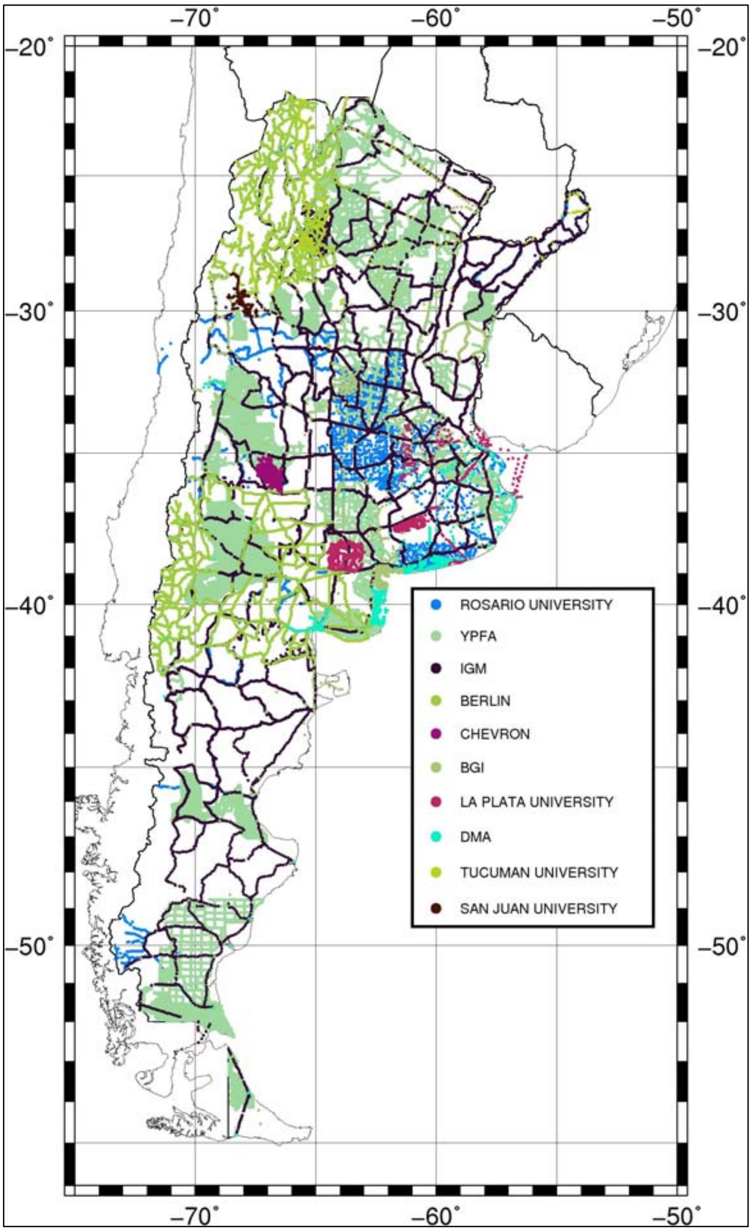


Figure 1 – South America gravity data

[1] Polytechnic School – University of São Paulo (EPUSP)

[2] University of Rosario (UNR)

1.1 Argentina



The complete gravity data base was validated, solving many inconsistencies. About 500 GPS/levelling points were established along the Argentinean territory to improve the geoid model.

A GPS station for continuous measuring at height was installed through the SIGMA program (GPS Mt. Aconcagua Research System) in 2005 at the summit of the Aconcagua, the highest pick in America. The station is named ACON. Important amount of data have been obtained, processed and analyzed during 2008. This yielded the 3D displacement velocities. Gravimetric studies were jointly performed to contribute to the study of the internal structure of Mt. Aconcagua for understanding its displacement. In the first field trip of 2009, gravity measurements have been carried out along the transect between the city of Mendoza (absolute gravity point) and the site called "Plaza de Mulas", at 4450 m above sea level within the Parque Provincial. The intention is to extend these determinations, reaching the summit of the Aconcagua during the next year.

1.2 Brazil

IBGE, through CGED (Geodesy Center), and EPUSP, supported by GETECH and NGA, carried out gravity surveys, with GPS measurements for station positioning, in Centre-West part of Brazil (677 stations).

IBGE worked also in Northeast, Southeast and Centre-West parts of Brazil with a total of 9335 stations surveyed from 2004 to 2008.

FAPESP (Foundation of the State of São Paulo) is supporting a thematic project, with the involvement of EPUSP/LTG (Laboratory of Surveying and Geodesy), FCT/UNESP (University of the State of São Paulo) - Presidente Prudente campus, CPTEC (INPE), ESALQ (USP). In this project a total of 482 points have been surveyed with an estimation of 1000 stations in the future.

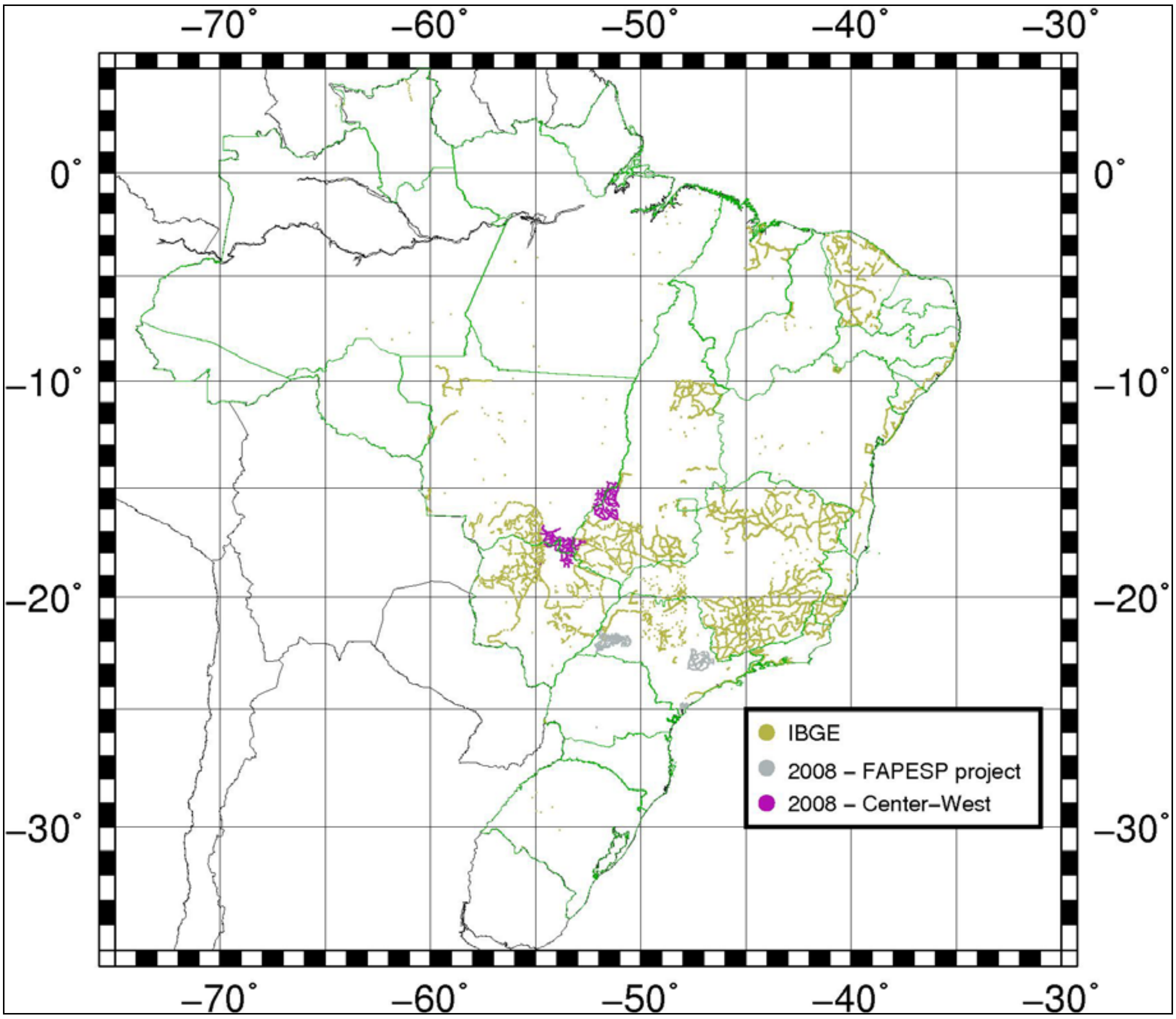


Figure 3 – Brazil new gravity data

1.3 Chile

New gravity data were surveyed in Punta Arenas region in Southern Chile (296 points). This region is geodynamically very active and the gravitymeters have been subjected to instabilities during the measurements. This fact resulted in some extra care in the processing.

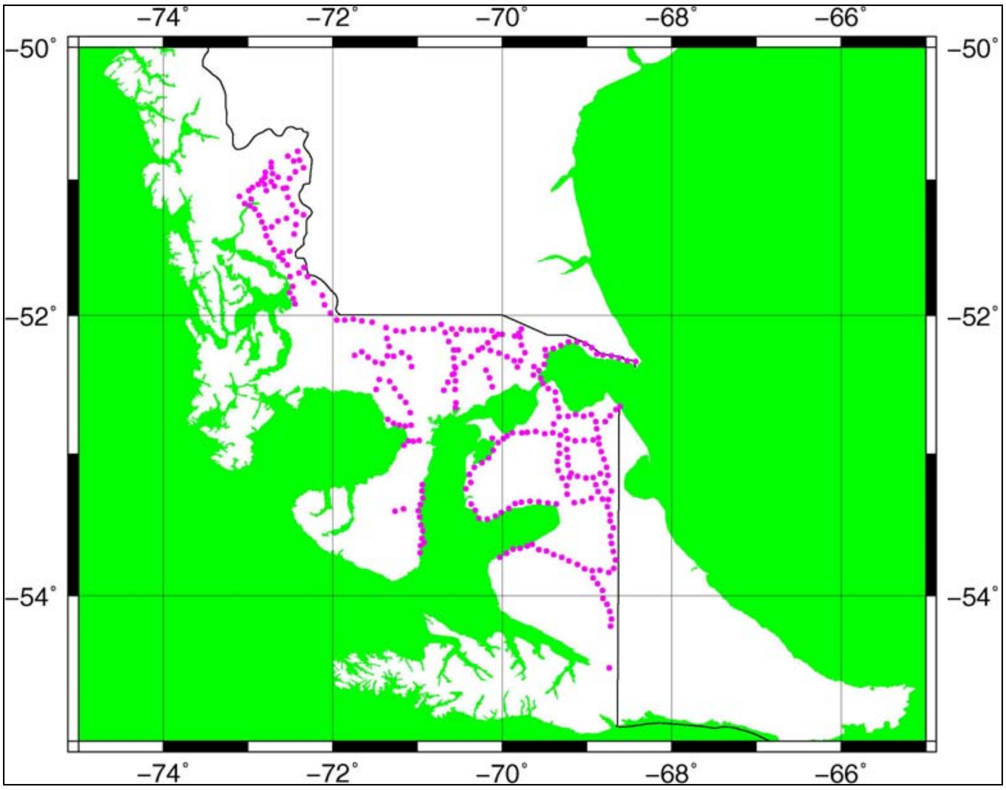


Figure 4 – Chile new gravity data

1.4 Colombia

At the SIRGAS 2008 General Meeting in May 2008, the IAG CP2.5 (GGSA) and the IAG Sub-commission 1.3b (SIRGAS) by means of its Working Group III (SIRGAS-WGIII: Vertical Datum) agreed to cooperate in the validation of the Colombian gravity data for inclusion in the continental geoid computation as well as in the unification of the continental vertical datum. The methodology applied by the SIRGAS-WGIII to identify the gravity datum to which the different data sets refer to, derived corrections to make the data compatible with the Colombian gravity reference system SIGNAR (Sanchez, 1996). The validation is showed in Validation of the IAG CP2.5 gravity data over Colombia report (Sanchez and Martinez, 2008).

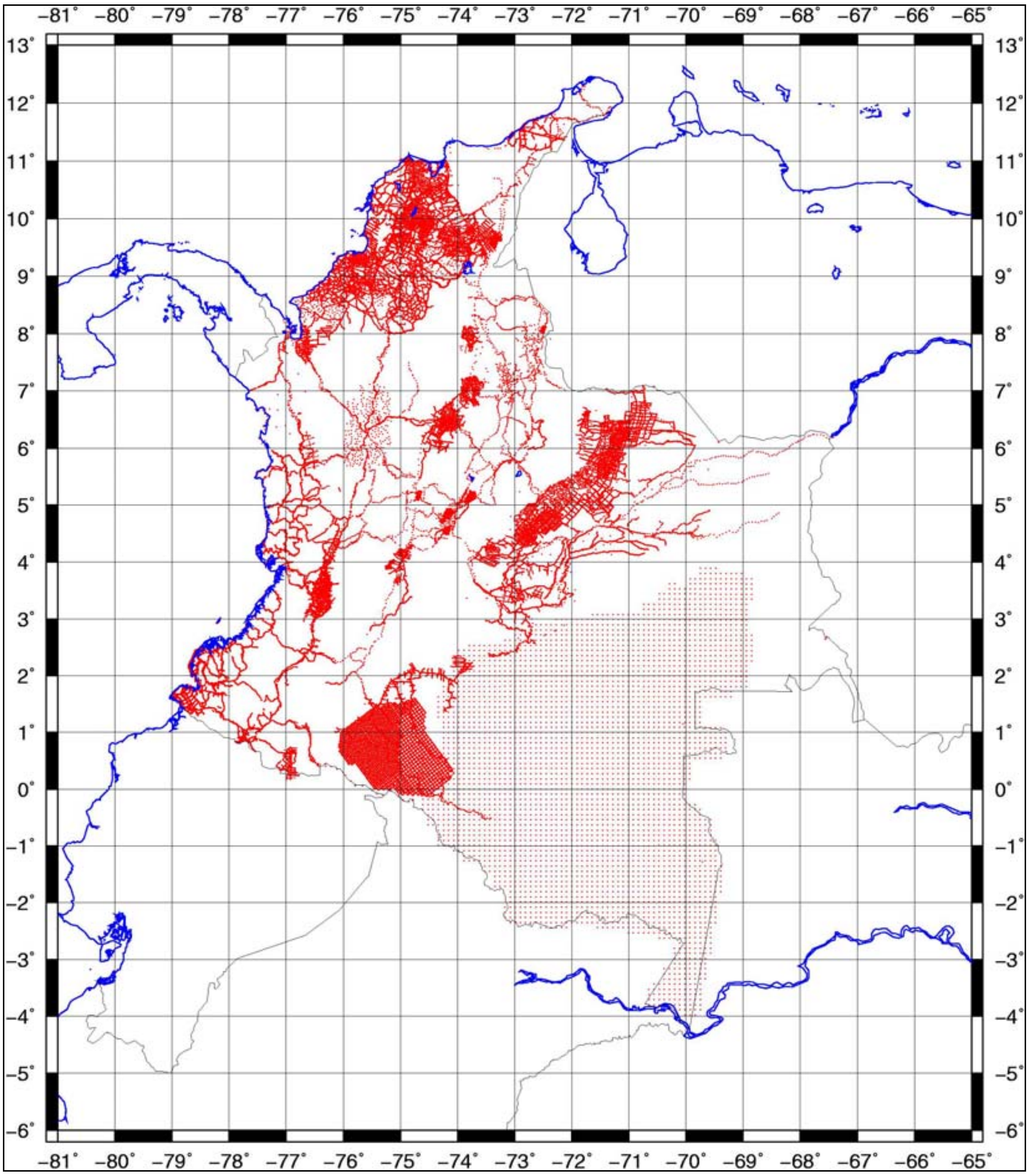


Figure 5 - Gravity data provided by IAG CP2.5 to SIRGAS-WGIII.

1.5 Paraguay

The efforts in Paraguay were concentrated in the Chaco area, northwest part of the country, with a total of 265 new stations surveyed. This is a remote region with difficult logistics.

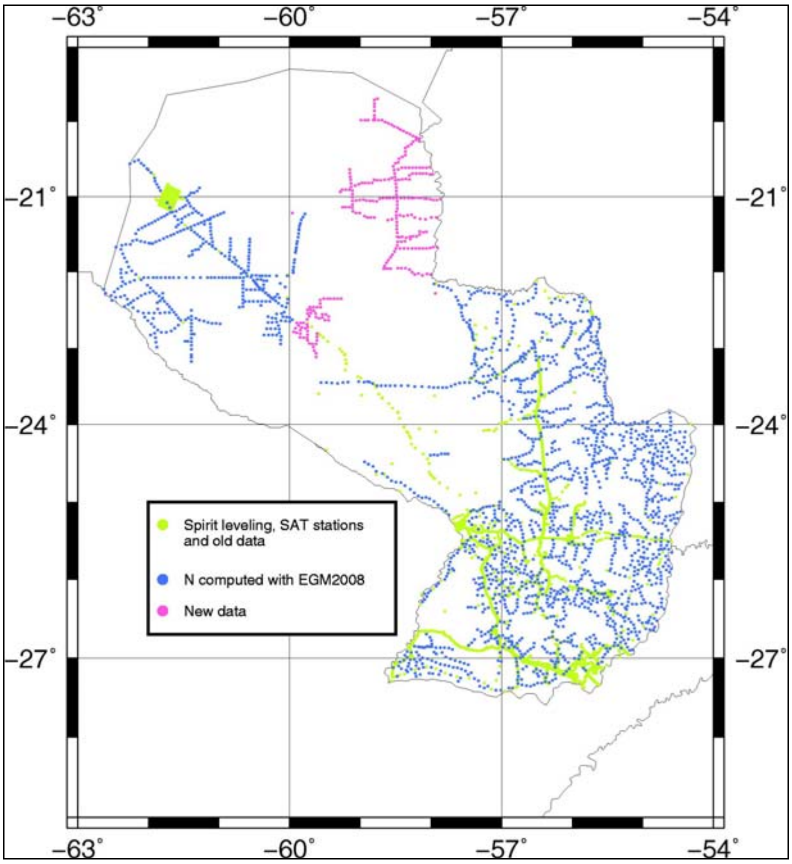


Figure 6 – Gravity data in Paraguay: new and old data.

2. Digital Terrain Model of 3" for South America

SRTM mission - Shuttle Radar Topography Mission - was a joint project of NASA - United States, the DLR - Germany and ASI – Italy, that derived a digital terrain model with 3" resolution, SRTM3, available globally (Hensley et al., 2001). An effort was undertaken by EPUSP/LTG in order to substitute the height anomaly derived from EGM96 by EGM08 in all the SRTM data. The model has several gaps due failures that occurred in data acquisition.

It has been derived the following two DTM:

1. SAM_3sv1: consist of SRTM3, with gaps substituted by DTM2002 (Saleh and Pavlis, 2002) .
2. SAM_3sv2: EGM96 used in the SRTM3 was substituted by EIGEN-GL04C in order to derive the orthometric height. Here the gaps were substituted by digitising maps and DTM2002.

Future efforts

At the moment the main attention is to derive a new version for the geoid model in South America with a resolution of 5´ using EGM2008 as a reference field.

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Commission Project 2.6: South Asian and Australian Geoid

Chair: Bill 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 catalogue 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 (2007–2009)

No specific meetings have been held at the recent IAG events (e.g. IUGG 2007 at Perugia, Italy, 2007) or GGEO 2008 in Chania, Crete. However a number of papers and presentations have been given which reflect the geoid-related research 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), Kearsley et al(2007), *Malaysia* (Forsberg, 2006; Forsberg and Olesen, 2006), and *Indonesia* (Kasenda, 2009; Kasenda and Kearsley (2007).

3. Future Activities

During the upcoming two-year period 2009–2011, the SE Asian Geoid Commission needs to establish stronger links with the Geodesy Sub-Committee of PCGIAP, (as this group is comprised 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 current economic decline is of course affecting much progress in areas of science, 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 caution which exists between nation states in the region to share their data and resources. The support from IAG 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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Study Group 2.1: Comparisons of Absolute Gravimeters

Chair: Leonid F. Vitushkin (BIPM)

SG 2.1 works in cooperation with the Working Group on Gravimetry of Consultative Committee for Mass and Related Quantities (CCM) of International Committee of Weights and Measures (CIPM).

1. After the International Comparison of Absolute Gravimeters ICAG-2005 at the Bureau International des Poids et Mesures (Sèvres, France) the main work of the IAG SG2.2.1 and CCM WGG was on the budgets of uncertainties of absolute gravity measurements using the absolute ballistic gravimeters (ABG) and the improvement of the strategy of absolute measurements in the comparison of absolute gravimeters. The results of ICAG-2005 show that currently the expanded uncertainty (that with a coverage probability of 95%) of absolute *g*-measurements using ABG is generally between 5 μGal and 15 μGal.

2. The BIPM in collaboration with CCM WGG and IAG SG 2.1.1 and with the help of the President of IAG Commission 2 Prof. Y. Fukuda who addressed his letter of support of the activity of BIPM in the field of absolute gravimetry to the Director of BIPM Prof. A. Wallard and to the President of International Committee of Weights and Measures (CIPM) Prof. Goebel, started the preparation of the 8th ICAG-2009 in September-October 2009 at the BIPM.

   The Steering Committee of ICAG-2009 has had two meetings (at BIPM, November 2008 and at the Research Institute of Geodesy, Topography and Cartography, Prague, Czech Republic, 11-12 May 2009).

   The Steering Committee and SG 2.1.1 Task Group on Budget of Uncertainties and Technical Protocol in the agreement with the Consultative Committee for Mass and Related Quantities have proposed that the ICAG-2009 will include CIPM Key Comparison CCM .G-K1. Organization of a Key Comparison makes it possible for the participating gravimeters to be officially recognized as the primary measurement standards in gravimetry in their countries. The goal and rules of Key Comparisons are described on the website: http://www.bipm.org/ en/cipm-mra/.

   The subset of absolute gravimeters declared by different institutes for their participation in ICAG-2009 consists of 15 gravimeters (from Austria, BIPM, Canada, China, Chinese Taipei, Czech Republic, Finland, France, Italy, Japan, Korea, Russian Federation, Spain, Switzerland and Turkey). The total number of the absolute gravimeters in the preliminary list of ICAG-2009 is 27.

   For the first time the participation of the cold atom gravimeter (LNE-SYRTE, France) is planned in ICAG-2009. Only five gravimeters (from China, Italy, France, Germany and Russia) are not fabricated at Micro-g LaCoste, Inc.

3. The objective for the ICAGs at the BIPM and Regional Comparisons of Absolute Gravimeters is the determination of the current level of uncertainty in the absolute gravity measurements, comparison reference values (CRV) with their uncertainties, which are the values of free-fall acceleration at the gravity stations of the BIPM obtained in the comparisons, and the offsets of each gravimeter from the CRV.

   The knowledge of the offsets of each absolute gravimeter from the CRV makes it possible to correct the results of the routine absolute measurements and that should contribute to reliability of the gravity measurements.

4. Besides the ICAGs at the BIPM the Regional Comparisons of Absolute Gravimeters should be organized at least in Asia and in North (and South) America. This should simplify the organization of the comparisons and, that is also of importance, this will reduce the expenses of comparisons.

   There is the site in Europe for RCAG (Walferdange, Luxembourg), where the international comparisons of gravimeters were already organized.

   A new site for RCAG is under construction in Chang Ping district of Beijing suburb in China.

   IAG SG 2.1.1 and CCM WGG also call up for the creation of the sites for RCAG in Americas.

5. One of the further directions of activity of IAG SG 2.1.1 in collaboration with CCM WGG should be the development of the linking of Comparison Reference Values obtained in Regional Comparisons of Absolute Gravimeters with the CRV obtained in the ICAGs at the BIPM.

6. The 2nd Joint Meeting of IAG SG 2.1.1 and CCM WGG recommended that its 3rd Joint Meeting will be organized in 2010 after the 8th ICAG-2009.

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Study Group 2.2: High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results

Chair: Michael Kuhn (Australia)

1. Primary Objectives

The IAG Study Group 2.2 (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. The SG will mostly focus 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 the introducing of 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 (2007-09)

This document presents the status report of IAG Study Group 2.2 (SG 2.2) since its creation in 2007. During the period 2007-09 the SG established its terms of references, organized its membership structure, created an internet site, held one official meeting and is currently working on a special focus topic for 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 activities within as well as outside the SG.

2.1 Meeting at GGEO2008

The first official meeting of the SG was held during the GGEO2008 conference at Chania, Crete, Greece and was open for both members and non-members (minutes are available form the SG's website, see link below). The meeting covered the following major topics:

- *Terms of Reference:* The proposed Terms of References have been discussed and accepted with minor changes including a change in the title form "High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results" to "High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results".
- *SG's special focus:* The SG agreed to focus first on the assessment of space domain forward gravity modelling techniques (see below for more details). 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 as possible future foci of the SG.
- *Further meetings:* At least once per year during an IAG sponsored conferences.

- *SG's Webpage:* It was recommended to set up a simple webpage as a portal for the SG to exchange information and data. The SG's webpage is available under: http://www.cage.curtin.edu.au/~218180B/IAG_SG22/2007-11/index.html.

2.2 SG's Special Focus

The SG agreed during its meeting at the GGEO2008 conference that 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 (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).

2.3 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) suggests modelling errors in the potential difference over a distance of 4 km is in the order of 10^{-3} mm expressed in terms of length unit.

Benedek (2009) studies 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 three applications of synthetic modelling of the gravitational potential. These studies include 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 planned 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-wide scales. A comprehensive study on the evaluation of precise terrain effects using high-resolution digital elevation models has been by Tsoulis et al. (2009). 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 (2009) implemented 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.

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, 2009, Abd-Elmotaal and Kühtreiber 2007, 2009), the determination and use of gravity reductions, gravity anomalies and gravity disturbances (Novák 2007, Tenzer et al. 2008, Vajda et al. 2008) and the evaluation of newly released global geopotential models (Abd-Elmotaal 2007a, 2007b, 2009). 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.

3. Future Activities

During the upcoming two-year period 2009-11 the SG intends to work on the special foci (see above) in particular and the SG's aim in general. Furthermore meetings during the IAG for Geodesy Scientific Assembly at Buenos Aires, Argentina in 2009 and an IAG sponsored conference during 2010 are planned. During the latter to SG intends to run a workshop or propose a conference session on the SG's topic. Further direction of the SG will be discussed during the future meetings.

4. Membership Structure

The SG's membership structure as of June 2009 is given below.

Michael Kuhn (Australia) (Chair), M.Kuhn@curtin.edu.au

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

5. Publications and Conference Presentations

5.1 Publications

Abd-Elmotaal H (2007a): Reference Geopotential Models Tailored to the Egyptian Gravity Field. *Bollettino di Geodesia e Scienze Affini*, **66(3)**, 129–144.

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Inter-Commission Working Group 2.1: Absoulte 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[3] and the IAG Sub-Commission 2.1 Gravimetry and Gravity Networks. This working group cooperates with the Study Group 2.1 "Comparisons of Absolute Gravimeters" and the "Consultative Committee on Mass and Related Quantities[4], Working Group on Gravimetry", which organize the four-yearly international absolute gravimeter comparisons. The International Gravity Field Service IGFS coordinates the servicing of the geodetic and geophysical community with gravity field-related data, software and information.

Motivation

Absolute gravity measurements have increased in significance because new questions and fields of application have arisen about time-varying geophysical processes. This is underlined by the continuously growing number of absolute gravimeters and observations worldwide. New applications are to monitor, for example, global change, mass transports and regional changes of the gravity field. Hence IAG's Global Geodetic Observing System[5] has asked for absolute gravity observations to be carried out in a global network in conjunction with selected reference stations using other geodetic observation techniques: GNSS[6], SLR[7], VLBI[8] or DORIS[9]. It is obvious that a combination of the different observation techniques requires agreed common standards for observations and data processing.

The WGAG strives to strengthen the importance of the gravity observations and to provide the means for a better presentation and coordination of activities together with a standardisation of procedures and outcomes. It works, in particular, on the following tasks discussed and agreed with IGFS and the Bureau Gravimétrique International (BGI):

- Implementation and promotion of a freely accessible common database for absolute gravity observations aiming at a better visibility of AG measurements and an improved cooperation with other disciplines,
- Encouragement of combined absolute gravity and superconducting gravity (SG) measurements for the determination of precise gravity time series. This is carried out in close cooperation with the Global Geodynamics Project, GGP[10],
- Establishment of a global network of absolute gravity sites in conjunction with other geodetic observation techniques. The absolute gravity observations need to be

[3] cf. IGFS – http://www.igfs.net/

[4] cf. CCM – http://www.bipm.org/en/committees/cc/ccm/

[5] cf. GGOS – http://www.ggos.org/

[6] cf. IGS – International GNSS Service http://igscb.jpl.nasa.gov/

[7] cf. ILRS – International Laser Ranging Service http://ilrs.gsfc.nasa.gov/

[8] cf. IVS – International VLBI Service for Geodesy and Astronomy http://ivscc.gsfc.nasa.gov/

[9] cf. IDS – International DORIS Service http://ids.cls.fr/

[10] cf. GGP – http://www.eas.slu.edu/GGP/ggphome.html

repeated at regular intervals. A first realisation has been achieved in the European Geodetic Network, ECGN[11],

– Standardisation of AG observation and evaluation to make the results compatible and to enable the combination with geometric observations or complementary information.

The absolute gravity database AGrav

The growing number of AG instruments together with the understanding that the absolute gravity measurements have a high importance in their timely and geographical distribution encourage the development of an international database for absolute gravity observations. This database initiated by the International Gravity Field Service (IGFS) (Forsberg et al. 2005) was developed at the Bundesamt für Kartographie und Geodäsie (BKG) and put into operation together with the Bureau Gravimétrique International (BGI). This new database improves the propagation and notice of the AG observations. Further, it enhances the use of gravity data, encourages cooperation in regional and global gravity projects, allows for synergy effects and improves the value of the existing networks.

The system was set into operation at two mirrored servers with web-based frontend located at BGI: http://bgi.dtp.obs-mip.fr/agrav-meta/ acting now as the official BGI AG database and at BKG: http://agrav.bkg.bund.de/agrav-meta/. Fig. 1 shows the AGrav database graphical web interface.

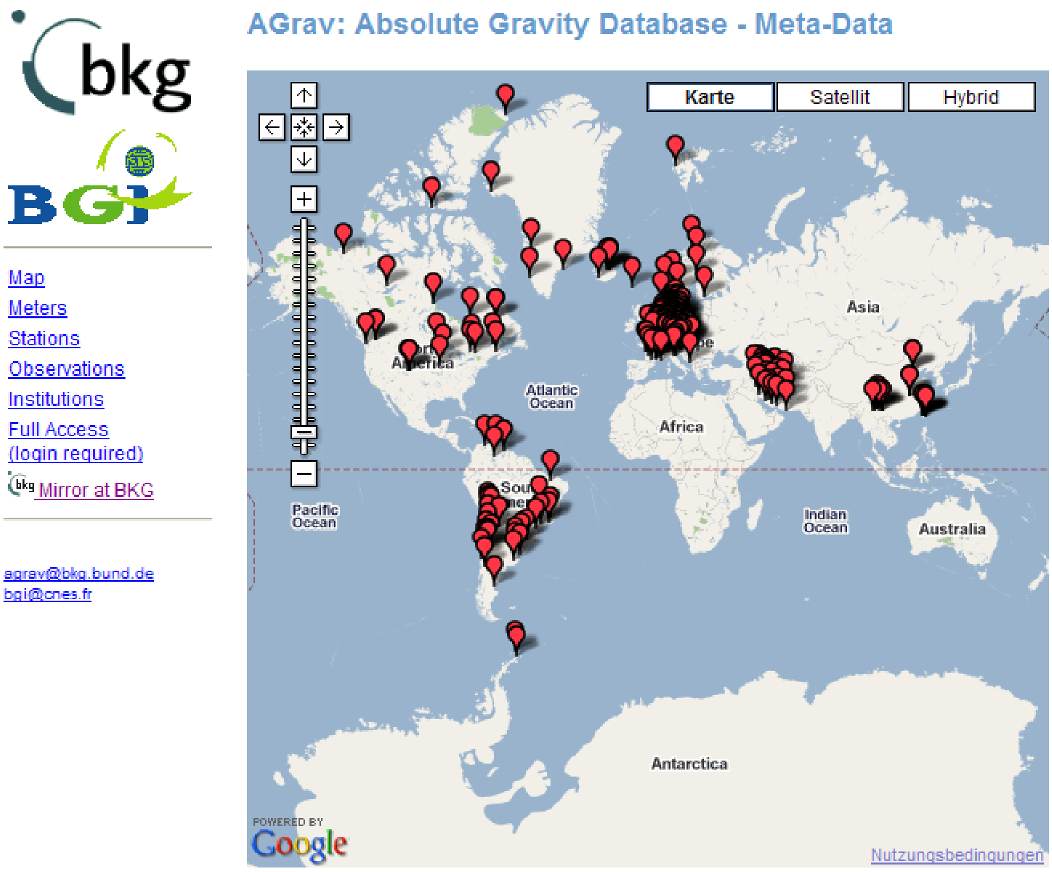

Figure 1: Layout of the AGrav database web interface (status 2009)

[11] cf. ECGN – http://gibs.bkg.bund.de/ecgn/

The AGrav database informs about station location, observation epoch, instrument type and serial number, instrument owner or user respectively 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 can be stored in supplemental tables. In this way, storage of redundant information is avoided and a flexible adaption to future needs is possible. Concerning observation epochs for instance, it is possible just to store time and date of the observation up to complete processing results, including single drop observations.

The database concept distinguishes two basic features:

- It 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 access restrictions.
- It can store the measurement results including all corrections and processing details. Here, restrictions are applied, access is granted only to users, who have contributed own data.

By this design, meta-data and detailed data share the same database. Dependent on task and authentication, meta-information only or complete datasets are provided. In this way it is possible just to inform other interested groups about the existence of the stations and observations or to store the data for projects, publications and cooperation. The latter case with the complete observation results would be very helpful for cooperation between groups or if the database is used as permanent repository. In any case, the user retains control over the data, which means, later editing of submitted data is possible at any time

The international community of absolute gravimeter users has been asked to contribute to this database. This process has started with contributions of e.g. Belgium, Canada, Czech Republic, France, Germany and Taiwan. The work with the database has shown that continuous support was necessary in the form of smaller database modifications and adaptations related to new requirements. Maintenance work was provided to support the international users with the upload of data. Contact with the groups to encourage cooperation and data upload will be continued. This service will be continued and the owners of absolute gravimeters will be requested for their support.

A working group meeting was held during the International Symposium on Gravity, Geoid and Earth Observation GGEO2008 in Chania, Crete, June 24, 2008.

Continuation of the work

As mentioned above, the standardisation of AG observation and evaluation are an important condition to make the results compatible and to enable the combination of absolute gravity data e.g. with geometric observations. The IABGN data processing features of 1992 still form an agreed basis for the observation and evaluation of absolute gravity data. Work has begun and will be continued to improve and complement these settings for AG measurements using consistent parameters and models.

The absolute gravity database and a standardisation of the data evaluation would make it much easier to create a new gravity reference system which could replace the IGSN71, the International Standardization Net 1971 after Morelli (1974). Its accuracy is estimated with ±1 $\mu m/s^2$ (±100 µGal!). 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.

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

Chair: Jianliang Huang (Canada)

Summary of Activities

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.

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.

We are grateful to all people who made the publication of this special issue possible. First of all, we would like to express our deep appreciation to all contributing authors of the evaluation papers for their interest and dedication to the project. The success of this project is primarily attributed to their continuous participation and close cooperation. Secondly, we would like to thank the development team of EGM2008 for their support and continuous collaboration towards the successful completion of this international project. Last but not least, the IGFS and the Commission 2 of the IAG are acknowledged for their effective international leadership, guidance and coordination.

Special thanks are due to the International Geoid Service (IGeS) and the Bureau Gravimétrique International (BGI) for the publication of this special issue of Newton's Bulletin.

Appendix

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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)

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.

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 become 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-organization 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 some papers collected for the Bulletin d'Information Marées Terrestres; the first volume no. 144 was already published in December 2008, and at least another one will follow. The *second part* of the proceedings will contain papers suitable for the Journal of Geodynamics; a special volume containing about 40 papers is under preparation. The papers and all the material are now under discussion with the publisher. We expect that the special volume will be published before the end of the year.

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 will be the responsible scientist.

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 answer.

We hope to receive at least some information before the IAG will start – to be reported during the splinter meeting of Sub-Commission 3.1.

The resolutions 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.

2. Working groups of SC3.1

The SC3.1 has three working groups which continued during the period 2005-2009:

- 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

3. Future work

The future work will have two foci:

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 access like Brussels was.
2. The second focus is the next symposium: It will be the first symposium in Afrika, and a small but quite active group in Cairo will be responsible (of course 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 involved up to now.

Sub-Commission 3.2: Tectonic Deformation

President: Markku Poutanen (Finland)
Vice-President: Jeffrey Freymueller (USA)

Home page: http://iagsc32.fgi.fi/

Terms of Reference

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 millimeters 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 during the period 2007-2009

The Commision 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. There will be a special issue in Journal of Geodynamics, to be published in 2009. A non-reviewed publication will appear in the series of Bulletin d’Information Marées Terrestres.

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 will be 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. The proceedings will be published in the Physics and Chemistry of the Earth, in 2010. For more details see http://DynaQlim.fgi.fi.

Related Working Groups and Associates

During the period 2003-2007, there existed a sub-group Geodynamics of the Central Europe, chaired by Janusz Sledzinski (Poland). Co-operation with this group will be continued. Till 2008 the programme of activities of the IAG Permanent Working Group „GEODYNAMICS OF CENTRAL EUROPE" was coincided and overlapped with very active actions performed by the Section C „Geodesy" of the WG „Science and Technology" of the Central European Initiative (CEI). In 2008 CEI has abolished all the working groups and the IAG WG has to work without any support of CEI. The formal membership list of the IAG WG includes 27 scientists from 12 European countries. The activities of the IAG WG concentrated on the following subjects:

Geodetic and geodynamic programmes

European programmes:

CERGOP = Central Europe Regional Geodynamics Project;

CEGRN = (Central European GPS Reference Network) Consortium,

Local geodynamic projects (projects realised by the subgroups of the CERGOP Study Group CSG.5 "Geotectonic Analysis of the Region of Central Europe") they concern 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 CEI Section C "Geodesy"– European Geophysical Society (EGS) / European Geosciences Union (EGU).

A more detailed report will be posted on the SC3.2 web page.

Close contacts with the "Working group of European Geoscientists for the Establishment of Networks for Earth science Research" (WEGENER) will be continued.

An ILP (International Lithosphere Program) Regional Co-ordination Committee CC 1/5 DynaQlim (Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas, chaired by Markku Poutanen) established in 2007 will link SC3.2 geodetic studies in other disciplines like geology, geophysics and seismology. The ILP is charged with promoting multidisciplinary research projects of interest to both the geological (IUGS) and geophysical (IUGG) communities. Joint GGOS/DynaQlim workshop (June 2009) is described above.

Sub-Commission 3.3: Geophysical Fluids

President: Aleksander Brzezinski (Poland)
Vice-President: Mike Thomas (Germany)

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 eight Special Bureaus: for the Atmosphere SBA, Oceans SBO, Tides SBT, Hydrology SBH, Mantle SBM, Core SBC, Gravity/Geocenter SBGG, Loading SBL. Due to the overlapping of the tasks, SC 3.3 should also have close contacts to the GGOS activities.

Report on Activities 2007-2009

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 occurred at the IERS Workshop in Sevres, France, at the conferences of the series Journées Systèmes de Référence Spatio-Temporels, 2007 in Meudon, France, and 2008 in Dresden, Germany, 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), "Geophysical models for the analysis of space-geodetic techniques" (2008) and "Geodetic observations: model advances and time series effects" (2009).

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., 2007). The IERS 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 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 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 www.ecgs.lu/ggfc/ and the remaining special bureaus SBT, SBM, SBC, SBGG, and SBL. It should be noted here that the GGFC will be reconstituted soon. The IERS Directing Board released in May 2009 a Call for Proposal emphasizing the renewal of existing operational products and inclusion of new operational products.

One important problem in estimation of the influence of external fluid components, 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: related research projects in Germany (Mike Thomas), 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, Earth rotation parameters, and gravity field variations in near real time.

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 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 2007-2009, 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., 2007) 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). 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). The potential importance of sea level observations for determining the oceanic mass fields was studied in detail by 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 Davis (USA)
Vice-President: Detlef Wolf

Introduction

The creation of Subcommission 3.4 (Cryospheric Change and Earth Deformation) is new for 2007–2009, 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 host of geodetic methods and techniques, including ground-based space geodetic observations for local and regional deformational studies, InSAR, and others.

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) soli-Earth response to cryospheric changes. (See also the Terms of Reference, below.) Members of the subcommission 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 Subcommission 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 2007–9

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] 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; 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].

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. Several studies use combinations of observations [e.g., Dietrich et al., 2008; Sasgen. et al, 2008] to approach this issue. 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].

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 Anet (Antarctic network), the network consists of 25 GNSS sites in Antarctica. Its "antipodal sister" is Gnet, consisting of 45 GNSS sites.

Relevant publications and talks by subcommittee members

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

D. Crossley and J. Hinderer

Recent Reports

GGP recently submitted a report (12 June 2009) to Leonid Vitushkin for inclusion in his Report of Subcommission 2.1 (Gravimetry and Gravity Networks). There have been no significant developments over the summer, so that report is also the basis for this document, with some new details.

GGP Newsletter #19.

The scientific status of the GGP network was thoroughly reviewed in GGP Newsletter #19, attached to this report, and available online at: http://www.eas.slu.edu/GGP/ggpnews19.pdf. Also distributed was a separate Newsletter (#19a) to Station Managers concerning the upgrading of information regarding stations and instruments http://www.eas.slu.edu/GGP/ggpnews19a.pdf. This upgrading of GGP information is timely considering the possibility that GGP may become a more formal IAG service.

Key Points

1. Of particular relevance to IAG (through Commissions 2 and 3) was the distribution of a Questionnaire in May to all GGP members asking their opinion of a plan to recast GGP as an IAG service. The outcome of the survey was positive – there were no objections from GGP members concerning the proposed change.

2. We, together with Corinna Kroner (GFZ, Potsdam; FSU Jena), are therefore pursuing a formal request to IAG for consideration at the upcoming IAG General Assembly in Buenos Aires. We are sending a short proposal to selected IAG representatives for consideration at the appropriate meeting, asking advice for how to proceed with the transition.

3. GGP was happy to learn from Herbert Wilmes about the merger of the Agrav database with the pre-existing BGI absolute gravity service. Because of the strong connections within BKG (the home of Agrav) between GGP and absolute gravimetry, the merger is consistent with the proposed move of GGP towards an IAG Service. Ultimately both directions should support the goals of GGOS.

4. GGP is very concerned in the apparent hiatus at GFZ Potsdam over making decisions that are necessary to support Bernd Ritschel and colleagues at the ISDC. Note, however, we have not been updated in this respect since May, 2009. Ritschel has done an outstanding job in the last decade of providing the functionality for the GGP database, as a service to ICET, and we hope that he will receive the necessary high-level support from GFZ management. Any influence within IAG to resolve the problem is welcome.

5. Progress in realizing a new online ICET database at Tahiti has been slow, but we are assured by Jean-Pierre Barriot (University of French Polynesia) that by later this year he will have reinstated the important aspects of the previous ICET operations at ROB (Brussels, under B. Ducarme). The physical remoteness of the ICET operation is obvious, but the lack of communication with Jean-Pierre is in contrast with the style of the previous Director of ICET.

6. The flow of GGP data to the ICET/ISDC database has slowed significantly in the last year or two. Many new sites have been started, particularly in Asia, but frequently they have not sent data. Consequently, as some stations have been retired the overall volume of GGP has decreased. This we believe to be partially a question of the inexperience on the part of the new SG groups in gravimetry, as well as other factors such internal restrictions on data release (e.g. in India). GGP is working to resolve these problems.

7. One new station in Europe (Pecny, Czech Republic) has recently come under threat of government closure due to economic hardship. This is one of our best new stations and has been very well managed by our colleague Vojtech Palinkas. GGP has sent a letter of support of this station to the Czech authorities.

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), T., Mourabit (Morocco), J.M. Nocquet (France), M. Pearlman (USA), R. Reilinger (USA), F. Rocca (Italy), W. Spakman (Netherlands), S. Stein (USA), 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 millimeter 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 GEO Data and Analysis Center (GEODAC) has been established at the University of Porto (http://geodac.fc.up.pt). The main objective of GEODAC is to provide a platform to the whole interested scientific community for European GPS and geo-data data archiving/linking, reprocessing of old data series in a unique reference frame, and an open data bank which will include, when available, environmental parameter series. Examples of some specific GEODAC functionalities are the computation of atmospheric loading corrections for stations that are not provided by the IERS Special Bureau for Loading, and realistic error bars for the trends in continuous GPS data analysis.
- In fall 2008, a large proposal entitled PLEGG (Platform for European GNSS Geo-products) was submitted to the EU to respond to the call FP7-INFRASTRUCTURES-2007-1. This project aimed at the integration of existing European initiatives, experiences and know-how by implementing a coordinated single e-infrastructure for an easy access of a wide user community of European researchers to high quality GNSS data, products and services. The proposal was submitted by a team of 13 European groups, 11 of which are actively involved in WEGENER since many years. The proposal coordinator is the University of Porto (Portugal). The project was recommended for funding although, due to limited budget, was not supported. A new submission is being prepared.

- Standards for GPS networks establishment, data acquisition and guidelines for data processing and reliability checks have been defined;
- Strategies for a full exploitation of different geodata (GPS, gravimetry, seismic, etc.) have been defined;
- 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, Morocco, Egypt, Cape Verde, S. Tomé e Príncipe, Malawi, Tanzania, Mozambique, Mauritius). In addition, WEGENER members are collaborating with AFREF Scientific Committee in the definition and implementation of procedures to compute the first AFREF solution.
- 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. The last two conferences were hosted by Géosciences Azur, CNRS-University of Nice on September 4-7, 2006, in Nice (France) and by the Institute of Physical Geodesy at the Conference Center of the Technische Universitaet Darmstadt on September 15-18, 2008 (http://www.ipg.tu-darmstadt.de/projekte/wegener2008/home/index.de.jsp). The next Assembly will be held in Istanbul, Turkey, in September 2010 and will be hosted by the Istanbul Technical University.

To keep close contacts among the Directing Board members and to coordinate the activities, teleconferences are being held regularly. Directory board meetings are held in association with the annual EGU meetings.

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.

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
- 5th IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 14th FIG Deformation Measurement Conference, 2010, most likely in Hong Kong, P.R. China

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"

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 Committee
- 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

Highlight: publications

Commission 4 will publish 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

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 pseudoliltes), 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)

Ongoing Research Activities

1. Particle filtering based modules for non linear INS/GPS integration (Dr. Kornberg and Dr. Noureldin).
2. Spectral analysis modules for both GPS and inertial sensor signals using fast orthogonal search (FOS) algorithms to enhance system accuracy and improve INS/GPS integration. (Dr. Noureldin, Dr. McGaughey and Capt. Armstrong).
3. AI modules to fuse data from mobile multi-sensor systems for indoor navigation applications and in denied GPS environments (Dr. Chiang and Dr. Noureldin).
4. Exploring the enhancement of multi-sensor system integration using spectral estimation techniques employing robust orthogonal search methods (Dr. Kornberg and Dr. Noureldin).
5. Augmented KF / NN modules for reliable INS/GPS integration for airborne navigation (Dr. Noureldin and Capt. Armstrong).
6. Parallel cascade identification for INS/GPS integration and for modelling inertial sensor errors (Dr. Kornberg and Dr. Noureldin).

Publications (April 08 – April 09):

1. Iqbal U., Karamat T., Okou A., Noureldin A. "Experimental Results on an Integrated GPS and Multi Sensor System for Land Vehicle Positioning" International Journal of Navigation and Observation, Hindawi. (Online) (In Print)
2. 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.
3. 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.
4. Chiang K-W, Noureldin A., and El-Sheimy N: "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.
5. Georgy J., Noureldin A. and Bayoumi M.: "Mixture Particle Filter for Low Cost INS/Odometer/GPS Integration in Land Vehicles" In Proc. IEEE Vehicular Technology Conference, Barcelona, April 27 – 30, 2009. (Peer Reviewed – Full Paper)
6. Georgy J., Iqbal U. and Noureldin A.: "Quantitative Comparison between Kalman Filter and Particle Filter for Low Cost INS/GPS Integration" In Proc. Of the 6th International

WG 4.1.2: Indoor Navigation Systems

Chair: Günther Retscher (Austria)

The IAG WG 4.1.2 on Indoor Navigation Systems has currently 13 members from 8 different countries.

In 2007 the WG has jointly organized with the ICA Commission on Ubiquitous Cartography and ISPRS WG V TC2 the 4th symposium on Location Based Services and Telecartograpy which was held in Hong Kong, P.R. China, in end of November. In one oral session on 'Indoor Positioning' and one session on 'Positioning in LBS' 8 papers were presented also from some of the members of WG 4.1.2. In addition, 5 papers on Positioning were presented as posters. The conference proceedings have been published as CD Rom.

Several WG members met again and presented their research work at the ION GNSS conference, which was held in Savannah, Georgia, USA, in September 2008. In the same year the working group was also actively involved in the organization of the 5th symposium on Location Based Services and Telecartograpy held in Salzburg, Austria, in end of November 2008. At this conference two sessions on 'Positioning' within total 9 presentations were held with participation of WG members. The participating WG members also discussed the future work and collaboration in the working group at this meeting.

In 2009 the working group WG 4.1.2 is involved in the organization of the 6th International Symposium on Mobile Mapping Technology (MMT'09) which will take place in Presidente Prudente, São Paulo, Brazil, from 21-24 July 2009 (see http://www4.fct.unesp.br/simposios/mmt09/ingles/). The WG 4.1.2 is also one of the organizers of the 6th International Symposium on Location Based Services and TeleCartography to be held at the University of Nottingham, UK, from September 2-4, 2009. The co-organizers of the conference are the ICA Commission on Maps and Internet and Ubiquitous Cartography and our working group together with the Center of Geospatial Science of the University of Nottingham, UK, and the Research Groups of Cartography and Engineering Geodesy of the Vienna University of Technology, Austria. The call for contributions can be found at http://www.lbs2009.org/.

Another opportunity for a meeting and exchange of ideas of WG members is the upcoming ION GNSS conference which will be held in Savannah, Georgia, USA, from 22-25 September 2009 (see http://www.ion.org/meetings/#gnss). WG members are strongly involved in the organization of the conference; e.g. Dr. Allison Kealy is representing the WG as technical chair of Track B and Dr. Guenther Retscher is co-chairing a session on 'Multi-sensor Navigation'. Other relevant sessions in track B include 'Algorithms for Multi-sensor Fusion', 'Alternatives and Backups to GNSS' and 'GNSS – Inertial Navigation Systems'.

For the future work of WG 4.1.2 co-organization of upcoming conferences in the field of GNSS and LBS is planned. In addition, networking and knowledge exchange between members of the WG will be continued.

WG 4.1.3: Multi-sensors systems for environmental monitoring applications

No report submitted.

Sub-Commission 4.2: Applications of Geodesy in Engineering

President: Günther Retscher (Austria)
Vice-president: Gethin Roberts (UK)
Secretary: Michaela Haberler-Weber (Austria)
Member-at-large: Wolfgang Niemeier

Terms of reference

The main tasks of the SC 4.2 are to study and enhance technologies for applications of engineering geodesy in order to address the objectives set in the Terms of References. To start with, a website has been set up to provide information on SC4.2 activities, a professional meeting calendar, contact information of the WG members, etc. The address of the website is http://info.tuwien.ac.at/ingeo/sc4/sc42.html.

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 Behavior of Landslides and System Analysis".

WG 4.2.1 and WG 4.2.2, however, are still in the process of establishment. We have received a proposal of Dr. Jose Bittencourt for the establishment of a new WG on Pavement Mapping. This proposed WG will be merged with the WG 4.2.1 under a new chair. Jose Bittencourt has started recently to invite people to join the new working group. He is planning to have a first meeting of WG members at the upcoming 6th International Symposium on Mobile Mapping Technology (MMT'09) which will take place in Presidente Prudente, São Paulo, Brazil, from 21-24 July 2009 (see http://www4.fct.unesp.br/simposios/mmt09/ingles/).

Dr. Gethin Roberts is very active in FIG and will take over as a chair of FIG Commission 6 in 2010. He found it to be difficult to work actively in IAG as well. Therefore he has asked use these days to be replaced by someone else in his role of Vice-Chair of SC4.2 and Chair of WG 4.2.2.

The secretary of SC 4.2 Dr. Michaela Haberler-Weber has left Vienna University of Technology recently and does not want to continue her work in our commission. Hopefully a new Secretary can overtake her role soon.

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, http://www.photogrammetry.ethz.ch/optical3d/

2. **4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 13th FIG Deformation Measurement Conference**

   May 12-15, 2008 in Lisbon, Portugal, http://measuringchanges.lnec.pt/

The established WG's have supported these two 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. **9th Conference on Optical 3-D Measurement Techniques**

   July 1-3, 2009 in Vienna, Austria; http://info.tuwien.ac.at/ingeo/optical3d/o3d.htm

2. **6th International Symposium on Mobile Mapping Technology (MMT'09)** July 21-24, 2009 in Presidente Prudente, São Paulo, Brazil; http://www4.fct.unesp.br/simposios/mmt09/ingles/

3. **5th IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 14th FIG Deformation Measurement Conference**

   2010, most likely in Hong Kong, P.R. China

The sub-commission will continue its work in the next two years and will encourage the active members to participate in the upcoming meetings to present and discuss their research.

WG 4.2.3: Application of Artificial Intelligence in Engineering Geodesy

Chair: Alexander Reiterer

In the last years, Artificial Intelligence (AI) has become an essential technique for solving complex problems in Engineering Geodesy. AI is an extremely broad field – the topics range from the understanding of the nature of intelligence to the understanding of knowledge representation and deduction processes, eventually resulting in the construction of computer programs which act intelligently. Especially the latter topic plays a central role in applications.

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 in 2008 can be summarized as follows

- networking and knowledge exchange between members of the WG,
- organisation of a first meeting (in form of an international workshop),

- public relation in form of an website
  (http://info.tuwien.ac.at/ingeo/sc4/wg423/wg_423.html).

In 2009 the WG is organizing a special session at the 9th Conference on "Optical 3-D Measurement Techniques" in Vienna. The session "Applications of Artificial Intelligence in Optical 3D-Systems" will present research work of different origin and content, e.g. basic research, application oriented research, etc.

Furthermore, WG has begun to plan the "Second International Workshop on Application of Artificial Intelligence in Engineering Geodesy – AIEG" which will be organized at the end of 2009 / begin of 2010.

For an easy communication within the WG a central data exchange unit (ftp-server) and a mailing list have been installed. The existing website will be extended to a WIKI.

Publications

Reiterer, Egly (Eds.): Application of Artificial Intelligence in Engineering Geodesy. Proceedings for the First Worksop on AIEG, 2008.

WG 4.2.4: Investigation of Kinematic and Dynamic Behaviour of Landslides and System Analysis

Chair: Gyula Mentes

In the frame of the working group the participants laid a great stress on multi-scale monitoring landslide prone areas [1]. For the investigations several test site were used in China (Baota test site), in Hungary (High Danube banks at Dunaföldvár and Dunaszekcső), in Greek (Touzla overpass, Kristallopigi landslide, Basilikos landslide, Gkrika Cuts, Prinotopa site, Anthohori entrance, the Big Cut), in Italy (Corvara test site). The different types of landslide areas make it possible to investigate the influence of geological, geomorphological, hydrological, meteorological, etc. factors and their role in triggering landslides. All the participants collect all data in GIS [e.g. 3, 4, 5] and use these data to develop Spatial Decision Support Systems (SDSS) [e.g. 2] and Early warning systems. Such systems consist of the following main modules

- Extended multi-sensor deformation measurement system based on geodetic, geophysical, geotechnical, hydrological, meteorological instrumentation.
- A knowledge-based system that analysis all data and makes a rough risk assessment, triggering the alarm for possible immediate failures.
- An alarm system to ensure the instant/direct authority action.
- The overall assessment of the results and the final decision level due to geo-informatics solutions.

The extended multi-sensor deformation measurement system consists of terrestrial geodetic and geotechnical measurements completed by InSAR technique. This latter is used for large-scale detection of landslide prone areas as well as for deformation measurements of the investigated landslide area. This complete measurement system is very suitable for the investigation of the kinematic behaviour of landslides and together with other (e.g. hydrological, meteorological, etc.) parameters for study the dynamics of landslides [4] In the frame of a close cooperation between the Wuhan University of Technology (China) and the University of Braunschweig (Germany) the Baota test site [8, 9], and in a co-operation between University of Braunschweig and the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences in Hungary the Dunaföldvár test site is monitored by terrestrial and InSAR measurement techniques. Berlin University of Technology, Institute of Applied Geosciences, Department of Hydrogeology and Bureau of Applied Geoscientific Remote Sensing takes also intensively part in the investigation of the Dunaföldvár test site using remote sensing data. In the frame of the latter cooperation the role of tectonic movements in triggering of slope failures was also revealed [7].

In this period of the activity of the working group the most characteristic test site was the high loess bank of the Danube at Dunaszekcső in Hungary. The high bank on this area was sliding slowly with increasing velocity since September of 2007 till 12 of February 2008. On this day there was an abrupt sliding. About 500.000 m^3 loess was sliding toward to the Danube. The whole sliding process was monitored. The study of the movement is a good possibility to understand the kinematics and dynamics of the slope. The monitoring will be continued in the future to study the after-sliding processes [10, 11].

The University of Thessaloniki developed very intensively Spatial Decision Support Systems and applied it on several test sites [2, 3].

The Institute of Geodesy and Geophysics of the Vienna University of Technology works on development of multi-sensor measurement systems [1] and in co-operation 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 [5, 6].

The working group participants are in connection with each other via internet and if it is necessary a workshop will be organised in spring of 2010 to discuss the problems and results.

Publications

1. Kahmen, H., Eichhorn, A. and Haberler-Weber, M.: A Multi-Scale Monitoring Concept for Landslide Disaster Mitigation. In: Tregoning, P. and Rizos, C. (Eds.): Dynamic Planet Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools. IAG Symposium, Cairns, Australia, 22-26 August, 2005 Series, International Association of Geodesy Symposia. 2007, Vol. 130, 769-775.
2. Lakakis, K., Charalampakis, M., Savaidis, P.: A Spatial Decision Support System for Highway Infrastructure. Fifth International Conference on Construction in the 21st Century (CITC-V), "Collaboration and Integration in Engineering, Management and Technology. May 20-22, 2009, Istanbul Turkey. pp. 1-8.
3. Lakakis, K., Charalampakis, M., Savaidis, P.: A Landslide Definition by an Integrated Monitoring System. Fifth International Conference on Construction in the 21st Century (CITC-V), "Collaboration and Integration in Engineering, Management and Technology. May 20-22, 2009, Istanbul Turkey. pp. 1-8.
4. Mentes G.: Investigation of different possible agencies causing landslides on the high loess bank of the river Danube at Dunaföldvár, Hungary. Proceedings of the Measuring the Changes, 13th FIG International Symposium on Deformation Measurements and Analysis, 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, LNEC, Lisbon, Portugal, CD, May 12-15, 2008, pp. 1-10.
5. Mentes G.: Investigation of Micro-Movements by Borehole Tiltmeters on the High Loess Bank of the River Danube at Dunaföldvár in Hungary. Proceedings of the INGEO 2008 – 4th International Conference on Engineering Surveying, Slovak University of Technology, ISBN 978-80-227-2971-0, Bratislava 2008, p. 11.

6. Mentes G.: A new method for dynamic testing of accelerometers. INGEO 2008 – 4th International Conference on Engineering Surveying, Slovak University of Technology, ISBN 978-80-227-2971-0, Bratislava 2008, p. 10.

7. Mentes, G., Theilen-Willige, B., Papp, G., Síkhegyi, F., Újvári, G.: Investigation of the relationship between subsurface structures and mass movements of the high loess bank along the River Danube in Hungary. J. Geodyn. (2008), doi:10.1016/j.jog.2008.07.0005.

8. Riedel, B., Heinert, M.: An adapted support vector machine for velocity field interpolation at the Baota landslide. AIEG 2008 – First Workshop on Application of Artificial Intelligence in Engineering Geodesy. pp. 1-13.

9. Riedel, B., Walther, A.: InSAR Processing for the recognition of landslides. Advances in Geosciences. 2008, 14, 189-194.

10. Újvári, G., Mentes, G., Bányai L., Kraft, J., Gyimóthy, A. Kovács, J.: Evolution of a bank failure along the River Danube at Dunaszekcső, Hungary. Geomorphology, 2009, 109, 197-209. (doi:10.1016/ j.geomorph.2009.03.002).

11. Újvári, G., Mentes, G., Theilen-Willige, B.: Detection of landslide prone areas on the basis of geological, geomorphological investigations, a case study. Proceedings of the Measuring the Changes, 13th FIG International Symposium on Deformation Measurements and Analysis, 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, LNEC, Lisbon, Portugal, CD, May 12-15, 2008, pp. 1-9.

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.

Study Group 4.3.1 - Ionosphere Modelling and Analysis

Chair: Michael Schmidt (Deutsches Geodätisches Forschungsinstitut, Munich, Germany)
Co-Chair: Mahmut O. Karslioglu (Middle East Technical University, Ankara, Turkey)

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 modelled 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 Center (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.

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)

List of 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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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.

Papers/posters presentation

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 Attemp. 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.

M. Negusini, P. Sarti, Precipitable Water Vapour at VLNDEF GPS Network Sites: An Example of Multidisciplinary Investigation. Poster at the *SCAR Open Science Conference (St. Petersburg, July 2008)*. The work presents the potentialities of geodetic GPS Antarctic data for multidisciplinary applications.

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 vapor content computed with GPS at Terra Nova Bay and its relation with long wave radiation.

A. W. Wernik, A. Lucilla, M. Aquino, G. De Franceschi, A. Dodson, C. N. Mitchell, V. Romano, GPS Ionospheric Scintillations Monitoring and Studying: Bipolar Capabilities During Ipy. *Poster at XXIXth URSI General Assembly, Chicago, USA, 9-16 August 2008*. The state of art of GPS network is presented over Arctic and Antarctica for scintillation studies.

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.

Vincenzo Romano, Silvia Pau, Michael Pezzopane, Enrico Zuccheretti, Stefano Locatelli, Liudmila Kurylovich, Luca Spogli, The Electronic Space Weather Upper Atmosphere (ESWUA) System. *Poster at V European Space Weather Week (Brussels, 17-21 November, 2008)*. The state of the art is presented of a proper data base designed and developed to manage high latitude GPS high rate experimental observations from Antarctica and Arctic (http://eswua.ingv.it).

G. De Franceschi, 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.

Publications

GPS Imaging of the Antarctic Ionosphere: a First Attempt, by L. Alfonsi, Y. Ping, C.N. Mitchell, G. De Franceschi, V. Romano, P. Sarti, M. Negusini, A. Capra, submitted to *Journal of Atmospheric and Solar-Terrestrial Physics, 2008*.

Improving the GNSS Positioning Stochastic Model in the Presence of Ionospheric Scintillation, M Aquino, JFG Monico, AH Dodson, H Marques, G De Franceschi, L Alfonsi, V Romano and M Andreotti, submitted to *Journal of Geodesy, 2008*. The work focuses on the introduction of a novel technique to mitigate the effects of corruption on GNSS signals due to scintillations and it is based on the cooperation between the ionospheric and the geodetic communities in UK, Brazil and Italy.

Probing the High Latitude Ionosphere from Ground-Based Observations: The State of Current Knowledge and Capabilities during IPY (2007–2009), L. Alfonsi, A. Kavanagh, Amata E., P. Cilliers, E. Correia, Freeman M., Kauristie, K., Liu R., Luntama J-P, Mitchell, C.N, Zherebtsov, G.A, *Journal of Atmospheric and Solar-Terrestrial Physics*, 70, 18, December, 2008. The review includes also information on the international cooperation, in progress and planned, among the different communities handling GPS data at polar latitudes.

Validation of the Atmospheric Water Vapour Content from NCEP Using GPS Observations over Antarctica, Vey, S. and Dietrich, R. (2008). In Capra, A. and Dietrich, R., Geodetic and Geophysical Observations in Antarctica, An Overview in the IPY Perspective p. 125-135., Springer Berlin Heidelberg, ISBN: 978-3-540-74881-6, DOI10.1007/978-3-540-74882-3.

Working Group 4.3.3 – Numerical Weather Predictions for Positioning

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 vapor pressure, other groups prefer to interpolate water vapor pressure levels using an exponential scheme. Nevertheless, all submitted solutions 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.

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

Boehm, 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 download.

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Boehm, 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 JoGeod

Nievinski F.G., Ray-tracing Options to Mitigate the Neutral Atmosphere Delay in GPS (MSc. thesis), download .

Sub-Commission 4.4: Applications of Satellite and Airborne Imaging Systems

President: Xiaoli Ding (Hong Kong)
Vice-President: Dr. Linlin Ge (Japan)
Secretary: Dr. Makoto Omura (Australia)

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 mine site and city area deformation monitoring and earthquake studies. Prof. Makoto Omura has been leading a research project that focuses on studying ground deformations associated with mining activities and urban subsidence in many parts of the world. The work involves collaborations between researchers from a number of countries.

Dr. Linlin Ge and some other members of the SC have been working on ground deformations associated with the devastating Wenchuan earthquake in Sichuan, China that occurred on 12 May 2008. The work supported by ERSDAC (Earth Remote Sensing Data Analysis Center) of Japan has contributed significantly to the efforts of emergency response in the affected area by providing rapid D-InSAR results from the ALOS/PALSAR L-band SAR data.

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 Geosciences 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 Oceana 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 Geosciences 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.
- A conference on Satellite and Airborne Imaging Systems for Geodetic Studies in Beijing, China in 2010.
- IEEE International Geoscience and Remote Sensing Symposium (IGARSS) in Sendai, Japan, 1-5 August 2011.

Special Issue in Journal of Geodesy

The SC is currently working on a special issue on InSAR and LiDAR in Journal of Geodesy.

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 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)
- WG4.5.4 "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
- 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 nine papers journals and seven conference papers.

Conference, Workshop, Technical Session

- 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.
- WG4.5.1 plans to organise a dedicated NRTK QC workshop in 2010.

Publications

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Cai, C. and Gao, Y. (2008). "Estimation of GPS/GLONASS System Time Difference with Application to PPP", Proceedings of ION GNSS 2008, September 16-19, 2008, Savannah, Georgia, USA.

Tao, W. and Y. Gao (2008). "Real-time Water Vapor Distribution Surface Rendering Using Ordinary Kriging". CGU Annual Scientific Meeting, May 11-14, 2008, Banff, Canada.

Wang, M. and Y. Gao (2008). "A Controlled Experiment of Real-Time Precise Point Positioning for Deformation Monitoring". Proceedings of ION NTM'08, San Diego, California, January 28-30, 2008.

Study Group 4.2: GNSS Remote Sensing and Applications

Chair: Shuanggen Jin (South Korea)

Introduction

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.

Website:

http://www.gnss.googlepages.com/iag-sg4.1

Activities

2009

- 31 August-4 September 2009, Shuanggen Jin attended the International Association of Geodesy (IAG) Scientific Assembly, Buenos Aires, Argentina and Chaired one subsession "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.
- 10 October 2007, Dr. Y. T. Song of SG4.1 member published the recent result “Detecting tsunami genesis and scales directly from coastal GPS stations” at Geophys. Res. Lett., 34, L19602, doi: 10.1029/2007GL031681.
- **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 with SG4.2 members

Cardellach E, A. Rius (2008) A new technique to sense non-Gaussian features of the sea surface from L-band bi-static 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.

Jin S.G., and O.F. Luo (2009), Variability and climatology in PWV from global 13-year GPS observations, *IEEE Trans. Geosci. Remote Sens*., 47, doi: 10.1109/TGRS.2008.2010401.

Jin, S.G., W. Zhu, and E. Afraimovich (2009), Insights on the 2008 M_w 8.0 Wenchuan earthquake from dense GPS network observations, *Int. J. Remote Sens*., 30.

Jin S.G., O.F. Luo, and S. Gleason (2009), Characterization of diurnal cycles in ZTD from a decade of global GPS observations, *J. Geodesy*, 83(6), 537-545, doi: 10.1007/s00190-008-0264-3.

Jin S.G., O.F. Luo, and J. Cho (2009), Systematic errors in VLBI precipitable water vapor estimations from 5-year GPS measurements, *J. Atmos. Sol.-Terr. Phys.*, 71(2), 264-272, doi: 10.1016/j.jastp.2008.

Jin S.G., O.F. Luo, and P. Park (2008), GPS observations of the ionospheric F2-layer behaviour during the 20th November 2003 geomagnetic storm over South Korea, *J. Geodesy*, 82(12), 883-892, doi: 10.1007/s00190-008-0217-x.

Jin S.G., Z. Li, and J. Cho (2008), Integrated water vapor field and multi-scale variations over China from GPS measurements, *J. Appl. Meteorol. Clim.*, 47(11), 3008-3015, doi: 10.1175/2008JAMC1920.1.

Jin S.G., Y. Wu, R. Heinkelmann, and J. Park (2008), Diurnal and semidiurnal atmospheric tides observed by co-located GPS and VLBI measurements, *J. Atmos. Sol.-Terr. Phys.*, 70(10), 1366-1372, doi: 10.1016/ j.jastp.2008.04.005.

Jin S.G., J.H. Cho and J.U. Park (2007) Ionospheric slab thickness and its seasonal variations observed by GPS, *Journal of Atmospheric and Solar-Terrestrial Physics,* 69(15), 1864-1870, doi: 10.1016/j.jastp.2007.07.008.

Jin S.G., J.U. Park, J.H. Cho, and P. H. Park (2007) Seasonal variability of GPS-derived Zenith Tropospheric Delay (1994-2006) and climate implications, *Journal of Geophysical Research*, 112, D09110, doi: 10.1029/ 2006JD007772.

Jin S.G., and J.U. Park (2007) GPS ionospheric tomography: A comparison with the IRI-2001 model over South Korea, *Earth Planets and Space*, 59(4), 287-292.

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.

Larson, K.M., E.E. Small, E. Gutmann, A. Bilich, J. Braun, V. Zavorotny (2008), Use of GPS receivers as a soil moisture network for water cycle studies, *Geophys. Res. Lett.*, 35, L24405, doi: 10.1029/2008GL036013.

Nogués, O., Cardellach, E., Sanz Campderros, J., Rius, A.(2007) A GPS-Reflections Receiver That Computes Doppler/Delay Maps in Real Time, *IEEE Transactions on Geoscience and Remote Sensing*, 45, 1, pp. 156-174, doi: 10.1109/TGRS.2006.882257.

Song Y. (2007) Detecting tsunami genesis and scales directly from coastal GPS stations, Geophys. Res. Lett., 34, L19602, doi: 10.1029/2007GL031681.

Study Group 4.3: IGS Products for Network RTK and Atmosphere Monitoring

Chair: Robert Weber (Austria)

The IAG Study Group 4.2 on the 'Use of IGS Products for Network RTK and Atmosphere Monitoring' has been established end of 2007

Study Groups Web-site:
http://www.hg.tuwien.ac.at/Research/SatelliteTechniques/IAG_Study_Group_42/iag_study_group_42.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 shall identify the needs of near real-time atmospheric monitoring in terms of orbit and clock-correction quality and investigate 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).

According to work program proposed at the set up phase of this study-group the topics to be studied in 2008/09 can be summarized as

2008 – Investigate deficiencies of current IGS products for Near Real-time atmosphere Monitoring

2008/2009 – Use of IGS Real-Time products for regional RTK-networks

Accomplished and upcoming tasks

Over the past year 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 the Austrian Meteorological Office 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. Several publications and presentations were issued (see list of publications below). Close to Real-Time Ionospheric Models have not been handled in 2008 but will be investigated in 2009.

In spring 2009 modified professional RTK software offered by the Geo++ company will be installed at TU-Vienna to study in more detail the use of IGU products for ambiguity resolution and the effect on the issued corrections at different scales within two different RTK networks. Of special interest will be to merge IGS tropospheric and ionospheric quasi-realtime products as well as clock-corrections with regional models obtained by data of the RTK Reference Station Network (Steady State Representation merging global and regional Models).

Publications and Presentations of SG members related to the goals of the Study Group (time frame end 2007/2008, selection)

V. Bröderbauer, M. Opitz, R. Weber: "*Automated quasi-realtime prediction of GNSS clock corrections*"; Österreichische Zeitschrift für Vermessung und Geoinformation (VGI), begutachteter Spezialband, Heft 2 (2007), 95. Jahrgang; S. 53 -58.

T. Hobiger, T. Kondo, Y. Koyama, R. Ichikawa, R. Weber: *Effect of the Earth's oblateness on the estimation of global vertical total electron content maps*; Geophysical Research Letters, **34** (2007), 11.

A. Karabatic, R. Weber: "*Near real-time zenith wet delay estimation*"; Analysis Center Workshop 2008, Miami; 02.06.2008 - 06.06.2008.

A. Karabatic, R. Weber: "*Potential contribution of GNSS data based tropospheric zenith delay to weather forecasts in alpine areas*"; Poster: AGU Fall Meeting San Francisco, San Francisco; 10.12.2007 - 14.12.2007.

A. Karabatic, R. Weber, S. Leroch, Th. Haiden: "*GNSSMET - Contribution of tropospheric zenith delays derived from GNSS data for weather forecast in alpine areas*"; EGU 2008, Vienna; 13.04.2008 - 18.04.2008.

M. Opitz, R. Weber: "*Real Time Monitoring of IGS Products within the RTIGS Network*"; in: "*Proceedings of the IGS Analysis Center Workshop, Darmstadt*", Proceedings of the IGS Analysis Center Workshop, 2008, S. 5 - 13

R. Weber, M. Opitz, G. Thaler: "*Real-Time quality control of IGS clocks and orbits*"; Analysis Center Workshop 2008, Miami; 02.06.2008 - 06.06.2008.

R. Weber, S. Englich: "*Scientific Applications in Geodesy and Geodynamics - Innovations offered by the new Galileo signals*"; 1st Colloquium Scientific and Fundamental Aspects of the Galileo Program, Toulouse, France; 01.10.2007 - 04.10.2007; Proceedings of Colloquium.

R. Weber, A. Karabatic, S. Leroch, Th. Haiden: "*GNSSMET – Quasi Real tropospheric zenith delays derived from GNSS data for weather forecast*"; Final Report, 120 pages, University of Technology, Vienna.

Scientific sessions in close relation to the goals of the Study Group chaired/co-chaired by R. Weber

AGU 2007; Session G11A on 'Future of Global Navigation Satellite Systems and Their Impact on Geodetic and Geophysical Applications'

EGU 2008:, Session G7 on 'GNSS new capabilities for geosciences'

AGU 2008: Session G41C on 'The Future of Global Navigation Satellite Systems (GNSS) and Their Impact on Geodetic, Geophysical, and Environmental Applications'

According to the published work program the group will focus in the period 2009-2010 on the topics

2009/2010 – Investigate formulation of IGS Real-Time Products as State Space Representation

2009/2010 – Investigate formulation of IGS Products as Real-Time RTCM and/or RTCA Corrections

Inter-Commission Committee on Theory (ICCT)

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

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). 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.

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).

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.

The Hotine-Marussi Symposium was not the only scientific meeting with the visible presence of the ICCT. At the last two EGU General Assemblies in Vienna (2008, 2009), sessions on recent developments in geodetic theory were co-organized and co-convened by the ICCT President. The ICCT Vice-President is a member of the Scientific Committee of the next IAG Scientific Meeting held in Buenos Aires, September 2009. The ICCT was also present through its Working Groups at other meetings, see their respective reports below. The Study Group 1 will organize the IAG School on Reference Systems that will be held for the period May 31 - June 6, 2010 at the facilities of the Aegean University at Mytilene, Island of Lesvos, Greece.

The activities of the ICCT are related namely to the research carried out by members of its Study Groups. Their mid-term 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 on "Theory, implementation and quality assessment of geodetic reference frames" since its creation in 2007 after the IUGG General Assembly in Perugia. It is a joint Study Group of the ICCT, the IAG Commission 1 (Reference Frames) and the IERS (International Earth Rotation and Reference Systems Service).

Primary Objectives of the Study Group

The primary objectives of this SG are:

- 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

Full members:

A. Dermanis (Chair, Greece)
Z. Altamimi (France)
G. Blewitt (USA)
C. Boucher (France)
X. Collilieux (France)
H. Drewes (Germany)
F. Lemoine (USA)
A. Nothnagel (Germany)
E. Pavlis (USA)
G. Petit (France)
J. Ray (USA)
F. Sansò (Italy)

Activities of the Study Group

The main activity of the Study Group has been the research carried out by its members which is documented in the list of publications below. No meetings of the Study Group took place, due to lack of sufficient overlapping of member presence at the various meetings. The Study Group Web page has been established at: http://der.topo.auth.gr/sgrf/. A conference session on the Study Group topic will take place at the VII Hotine-Marussi Symposium, Rome 6-10 July 2009 (Session 7: Theory, implementation and quality assessment of geodetic reference frames, Conveners: A. Dermanis, Z. Altamimi).

Future Activities

As an initiative of the Study Group an IAG School on Reference Systems will be held for the period May 31 - June 6, 2010, at the facilities of the Aegean University at Mytilene, Island of Lesvos, Greece. The School will cover theoretical aspects, data assessment and analysis for each particular technique (VLBI, SLR, GPS, Doris), their implementation in the derivation of the International Terrestrial Reference Frame (including computational aspects and training in the use of relevant software) as well as the geophysical interpretation and use of the ITRF results. We have asked the IAG to sponsor the School and official approval will be (hopefully) given at the next meeting of the IAG Executive Board.

Publications

Abbondanza C, Altamimi Z, Sarti P, Negusini M, Vittuari L (2009) Local effects of redundant terrestrial and GPS-based tie vectors in ITRF-like combinations. *Journal of Geodesy* (online).

Altamimi Z, Collilieux X (2008) IGS contribution to the ITRF. *Journal of Geodesy* 83: 375-383

Altamimi Z, Gambis D, Bizouard C (2007) Rigorous combination to ensure ITRF and EOP consistency. *Proc. Journees* 2007: 151-154

Altamimi Z, Collilieux C, Boucher C (2008) Accuracy assessment of the ITRF datum definition. In: Xu P, Liu J, Dermanis A (eds), VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy. IAG Symposia 132: 101-110, Springer Berlin.

Altamimi Z, Dermanis A (2009) Theoretical foundations of ITRF determination. The algebraic and the kinematic approach. Hotine-Marussi Symposium, Rome, 6-10 July 2009.

Altamimi Z, Collilieux X, Boucher C (2007) Preliminary analysis in view of the ITRF2005. In: *Dynamic Planet – Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools*, Tregoning P, Rizos C (eds.), Springer, ISBN-103-540-49349-5, IAG Symposia 130: 685-691

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: 9401

Barache C, Berio P, Bizouard C, Bouquillon S, Collilieux X, Coulot D, Deleflie F, Féraudy Exertier P, Gontier A, Lambert S, Vanderschueren Y (2007) A first step for the French geodetic VO. In: *Proceedings of SF2A'06*, Paris, France, June 2006.

Böckmann S, Artz T, König R, Müller H, Nothnagel A, Panafidina N, Steigenberger P, Thaller D, Tesmer V (2007) Consistent VLBI, GPS and SLR Time Series of Station Positions and Troposphere Parameters. Geotechnologien Science Report 11: *Observations of the System Earth from Space*. ISSN 1619-7399: 60-63

Böckmann S, Artz T, Nothnagel A, Tesmer V (2007) Comparison and combination of consistent VLBI solutions. Geowissenschaftliche Mitteilungen, Schriftenreihe Vermessung und Geoinformation der TU Wien, Heft 79: 82-87

Collilieux X, Altamimi Z, Coulot D, Ray J, Sillard P (2007) Comparison of very long baseline interferometry, GPS, and satellite laser ranging height residuals from ITRF2005 using spectral and correlation methods. *Journal of Geophysical Research* 112: B12403, doi:10.1029/2007JB004933

Collilieux X, Altamimi Z, Ray J, van Dam T, Wu X (2009) Effect of the satellite laser ranging network distribution on geocenter motion estimation. *Journal of Geophysical Research* 114, B04402, doi:10.1029/2008JB005727.

Collilieux X, Altamimi Z, van Dam T, Coulot D, Ray J (2008) Impact of loading effects on the terrestrial reference frame determination (abstract). 37th COSPAR Scientific Assembly, held in Montreal, Canada, 13-20 July 2008.

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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 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 two years.

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. Neumann et al. (2008) and Alkhatib et al. (2009a, b) 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. Imprecision is modeled using fuzzy theory which allows a more flexible concept of uncertainty propagation. Presently, a linear propagation is considered which is more meaningful in case of the uncertainty about systematic errors. However, depending on the particular definition of a fuzzy vector other types of propagation are possible such as, e. g., a quadratic propagation. Note that Koch (2008a, b) studied the same topic in a Bayesian framework. The analysis of fuzzy data is described, e.g., in Viertl (1996); see Neumann (2009) for some recent developments in Geodesy.

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 2^{nd} 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; a dedicated publication is in preparation. Vennegeerts and Kutterer (2009) consider efficiency issues of the algorithmic variance-covariance propagation of geometric mass data (3D point clouds) which are observed using a kinematic multi-sensor system (GPS, INS, terrestrial laser scanner).

Neumann and Kutterer (2007) and Kutterer and Neumann (2009) develop a Kalman filter extension 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 rough estimates (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.

Future Activities

In the second phase of the SG, the work on uncertainty modeling and propagation will be continued with more emphasis on uncertainty-based quality measures such as sensitivity and integrity. It is still necessary to look into the total uncertainty budget in detail regarding meaningful original and independent influence quantities to better describe dependencies and to suggest adequate uncertainty propagation techniques. Data pre-processing methods such as differencing and averaging are of further interest. The extensions of recursive state-space filters, mainly the particle filter, will be studied regarding efficiency and the interpretation of the results. Although there are already some meaningful results the fuzzy extension of the Kalman filter has not yet been completely understood; this needs to be improved. In addition, issues of terminology will be addressed. For these purposes the performance of the SG has to be improved. A number of colleagues working in related fields will be invited to join the SG.

Publications

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IC-SG3: Configuration Analysis of Earth Oriented Space Techniques

Chair: F. Seitz (Germany)

Introduction and Primary Objectives of the Study Group

This document presents a status report of the work undertaken in the framework of the ICCT Study Group SG3 since its creation in 2007. Activities of the study group are focussed on modern methods of Earth observation from space. Today, a multitude of simultaneously operating satellite systems with different objectives is available. They offer a broad spectrum of information on global and regional-scale processes within and/or between individual components of the Earth system in different temporal resolutions.

The primary objective of this study group is the development of strategies for multi-mission approaches for Earth sciences which combine complementary and redundant information from heterogeneous space-based, air-borne and terrestrial sensors. The study group provides a forum for researchers from various fields of space geodesy and geophysics in order to discuss theoretical and computationan aspects of sensor combination. Special attention of the research is turned to methodology and data analyses with view to physical processes in the Earth system.

Since many observation techniques are restricted to the measurement of integral effects, i.e. a combined signal of a multitude of underlying geophysical processes, it shall be investigated in which way the combination of heterogeneous data sets allows for the separation of processes and the identification of individual contributors. 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.

Current Membership Structure

Full members:

F. Seitz (Chair, Germany)
J. Dickey (USA)
F. Meyer (USA)
M. Motagh (Germany)
M. Schmidt (Germany)
M. Seitz (Germany)
X. Wang (Germany)

Activities of the Study Group

Conference Contributions of SG Members

Anderssohn J, Motagh M, Walter T (2008) Magma source modeling derived from ScanSAR and InSAR time series analysis. *IAVCEI General Assembly*, Reykjavik, 2008.

Albertella A, Wang X, Rummel R (2007) Filtering of Altimetric Sea Surface Heights with local and global approaches. *Joint International GSTM and DFG SPP Symposium*, Potsdam, 2007.

Dickey J, Marcus S, Seitz F (2006) Freshening of the Arctic Ocean and melting effects in Siberia and Northern Canada: Motivation and Initial GRACE Results. *AGU Fall Meeting*, San Francisco, 2006.

Dickey J et al. (2007) Constraints of Global Time Variable Gravity Measurements on Global Continental Hydrology Models. *NASA Modeling, Analysis and Prediction Meeting*, College Park, USA, 2007.

Dickey J, de Viron O, Marcus S (2007) Global and Regional Modes of Mass Variability in the GRACE Data. *GRACE Science Team Meeting*, Potsdam, Germany, 2007.

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Dickey J, Marcus S (2008) The Changing Cryosphere in Alaska: Results and Implications. *Western Pacific Geophysical Meeting,* 2008.

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Motagh M, Hooper A, Walter T (2009) The value of InSAR time-series analysis to investigate natural and anthropogenic processes. *AGU Spring Meeting*, Toronto, 2009.

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Seitz F, Schmidt M, Shum CK, Chen Y (2007) Hydrological mass variations due to extreme weather conditions in Central Europe from regional GRACE 4-D expansions, *ESA Hydrology Workshop* Surface Water Storage and Runoff: Modeling, In-Situ Data and Remote Sensing, Geneva, 2007.

Seitz F, Güntner A, Schmidt M, Bosch W (2008) Mass variations in continental water storages from a combination of heterogeneous space and in-situ observations. 2nd Colloquium of the DFG-Priority Programme SPP1257 'Mass transport in the Earth System', Munich, 2008.

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Wang X, Peters T (2008) Determination of mass transport in the Earth system from satellite constellation flights. *IAG International Symposium on Gravity, Geoid and Earth Observation 2008*, Chania, 2008.

Conference Sessions:

German Geodetic Week, Bremen, 2 October 2008:

Session 5: GGOS – Global Geodetic Observing System (Convenor: F. Seitz): 5 oral presentations.

VII Hotine-Marussi Symposium, Rome 6-10 July 2009:

Session 6: Earth oriented space techniques and their benefit for Earth system studies (Convenors: F. Seitz, R. Gross): 6 oral & 6 poster presentations.

German Geodetic Week, Karlsruhe, 24 September 2009:

Session 5: GGOS – Global Geodetic Observing System (Convenor: F. Seitz)

Publications

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Seitz F, Schmidt M, Shum CK (2008) Signals of extreme weather conditions in Central Europe from GRACE 4-D hydrological mass variations. *Earth and Planetary Science Letters,* 268/1-2, 165-170, doi:10.1016/j.epsl. 2008.01.001.

IC-SG4: Inverse Problems and Global Optimization

Chair: Christopher Kotsakis (Greece)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group IC-SG4 on "Inverse Problems and Global Optimization" since its creation in 2007 after the IUGG General Assembly in Perugia. It is a joint Study Group of the ICCT and the IAG Commission 2 (Gravity Field).

Primary Objectives of the Study Group

The primary objectives of this SG are:

- Identification and theoretical understanding of the nature of inverse and/or ill-posed problems in geodesy, with emphasis on problems related to gravity field modeling at various spatial and temporal scales.
- Development and comparison of mathematical and statistical methods for the proper treatment of inverse problems, particularly in geodetic applications with certain characteristics such as coloured noise, heterogeneous data, partial over- and/or under-determination in the parameter space, and existence of data gaps.
- Theoretical study and practical implementation of optimal estimation and filtering techniques for cases with cross-correlated signal and noise.
- Study and improvement of current inversion and parameter estimation procedures for data sets with completely unknown noise structure.
- Investigation of formal measures for the quality analysis and error assessment in regularized or constrained solutions of inverse geodetic problems.
- Recommendation and communication of new inversion strategies within the IAG and to the broader scientific community.

Current Membership Structure

Christopher Kotsakis (Greece)
A.R. Amiri-Simkooei (The Netherlands/Iran)
F. Bauer (Germany)
S. Pereverzev (Austria)
M. Reguzzoni (Italy)
B. Schaffrin (USA)
Y. Shen (China)
W. van der Wal (Canada/The Netherlands)
M. Vennebusch (Germany)
Z. Wisniewski (Poland)

Activities of the Study Group

The main activity of the Study Group has been the research carried out by its members which is documented in the list of publications that is given in the study group's webpage. No meetings of the Study Group took place, due to the delay in launching the SG activity and the lack of sufficient overlapping of member presence at the various meetings. A Study Group Web page has been established at: http://users.auth.gr/kotsaki/. A conference session on the Study Group topic took place at the VII Hotine-Marussi Symposium, Rome 6-10 July 2009 (Session 2: Estimation and filtering theory, inverse problems, Conveners: H. Kutterer and J. Kusche).

Future Activities

There are plans to hold a SG meeting within 2010, most probably during the EGU General Assembly or in coincidence with a gravity field/new satellite missions meeting at a larger event. Future activities will concentrate on producing (theoretical and practical) results for the scientific geodetic community motivated from internal communications and discussions among the group members, or even if not definite results, at least a clear identification of current challenging problems and key issues in inverse problems and optimization theory that need to be the topic of further investigations within future research which might well exceed the lifetime of this study group.

Publications

See SG's webpage.

IC-SG5: Satellite Gravity Theory

Chair: T. Mayer-Gürr (Germany)

Introduction

At the present there is the unique situation in satellite geodesy. The satellite mission GOCE was successfully launched from Plesetzk on March, 17, 2009 exactly seven years after the launch of GRACE. Together with CHAMP this means three dedicated gravity field satellite missions being in orbit at the same time. Besides the data processing and interpretation of the results, the theoretical background of satellite gravity requires special attention. This study group focuses on the following research activities:

Primary objectives and Activities of the Study Group

Members of the study group are involved in the development and implementation of different methods for the estimation of gravity field models from satellite data. The different strategies include the analysis of short arcs of the satellites orbit, the acceleration approach, the energy balance approach, and the use of invariants in satellite gradiometry. Furthermore, algorithms have been developed to deal with the large amount of data occurring especially in case of the GOCE mission.

Noise and error treatment, aliasing problem

Especially when dealing with GRACE data it has been identified that one of the key problems in gravity field processing is the understanding of the behaviour of the gravity field in space and time and the resulting aliasing problem due to insufficient data coverage. Special effort has been carried out by members of the study group to deal with the aliasing effect caused by ocean tides on the GRACE and GOCE processing. Another approach to deal with the aliasing problem is the adaption of the temporal and spatial gravity field parametrization, see next section.

Gravity field modelling

Concerning different gravity field modelling techniques there is currently a large variety of research activities taking place with a strong participation of member of the study group. One major focus in this context is the use of regional parametrizations, such as Wavelets, radial basis functions, or Slepian functions. In the time domain, some approaches have been developed to model the gravity field variations by temporal splines or by use of a Kalman filter.

Post processing, filtering

Due to the noise level present in the GRACE solutions, these gravity field solutions have to be post-processed by filtering techniques. In the recent years there have been several publications by members of the study group dealing with the development of sophisticated filters tailored to the non-isotropic error structure of the GRACE gravity field solutions.

Future satellite missions

Currently there are several simulation studies for future gravity field mission concepts have been performed, investigating different observation types, formation flights, etc. The underlying challenges are the improvement of spatial and temporal resolution, reduction of temporal aliasing, as well as minimizing the effect of specific covariance characteristics of different observations types. There exists a strong connection to IAG Sub-Commission 2.3 (Dedicated Satellite Gravity Mapping Missions).

Current Membership Structure

Full members:

T. Mayer-Gürr (Chair, Germany)
O. Baur (Germany)
W. Bosch (Germany)
P. Ditmar (Netherlands)
T. Gruber (Germany)
S.-C. Han (USA)
J. Kusche (Germany)
P. Moore (Great Britain)
M. Schmidt (Germany)

Corresponding members:

R. Pail (Austria)
M. Kern (Netherlands)
F. Wild-Pfeiffer (Germany)

Selected References

Baur O (2008) Tailored least-squares solvers implementation for high-performance gravity field research. *Computers and Geosciences*, doi:10.1016/j.cageo.2008.09.004.

Baur O, Austen G, Kusche J (2008) Efficient GOCE satellite gravity field recovery based on LSQR. *Journal of Geodesy*, doi:10.1007/s00190-007-0171-z.

Baur O, Sneeuw N, Grafarend EW (2008) Methodology and use of tensor invariants for satellite gravity recovery. *Journal of Geodesy*, doi:10.1007/s00190-007-0178-5.

Ditmar P, Klees R, Liu X (2007) Frequency-dependent data weighting in global gravity field modeling from satellite data contaminated by non-stationary noise. *Journal of Geodesy*, 81:81–96, doi:10.1007/s00190-006-0074-4.

Eicker A, Mayer-Gürr T, Ilk KH (2009) Improved resolution of a GRACE gravity field model by regional refinements. In: Proceedings IUGG General Assembly, Perugia.

Han S-C, Ditmar P (2007) Localized spectral analysis of global satellite gravity fields for recovering time-variable mass redistributions. *Journal of Geodesy*.

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IC-SG6: InSAR for Tectonophysics

Chair: M. Furuya (Japan)

Introduction

This document is a status 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. Centinel-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

M. Furuya (Chair, Japan)
F. Amelung (USA)
A. Donnellan (USA)
Y. Fukushima (Japan)
R. Hanssen (Netherlands)
B. Heck (Germany)
S. Jónsson (Switzerland)
Z. Li (UK)
D. Sandwell (USA)
T. Wright (UK)

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 FRINGE2007 workshop, ALOS-PI meeting and the IAG's 2008 GGEO meeting.

Conference Sessions

We are planning to organize a relevant session at any international meetings during the up-coming two years.

Future Activities

Each of the group members will conduct her/his own research around the research areas mentioned above. During the next two years, we plan to organize a conference session to present the cutting-edge status on "InSAR for Tectonphysics".

Publications

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Li Z, Fielding EJ, Cross P, Preusker R (2009) Advanced InSAR atmospheric correction: MERIS/MODIS combination and stacked water vapour models. *International Journal of Remote Sensing*, in press.

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IC-SG7: Temporal Variations of Deformation and Gravity

Chair: D. Wolf (Germany)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group 7 since its foundation in 2007.

Primary Objectives of the Study Group

The topic of the study group is based on recent advances in ground-, satellite- and space-geodetic techniques, which monitor temporal variations of deformation and gravity with unprecedented accuracy over a wide period range. These variations are related to a variety of surficial and internal earth processes. The new types of observational data require the development of 2-D/3-D earth models and novel interpretational techniques. The primary objectives are: (i) Development of 2-D/3-D elastic/viscoelastic earth models for simulating the individual processes responsible for deformation and gravity variations. (ii) Forward modelling of deformation and gravity variations caused by atmospheric, cryospheric, hydrospheric or internal forcing functions. (iii) Inverse modelling of observed deformation and gravity variations in terms of forcing functions or in terms of elastic/viscoelasic earth parameters.

Current Membership Structure

Full members:

D. Wolf (Chair, Germany)
H. Abd-Elmotaal (Egypt)
M. Bevis (USA)
A. Braun (Canada)
L. Brimich (Slovak Republic)
D. Carbone (Italy)
B. Chao (Taiwan)
J. Fernández (Spain)
L. Fleitout (France)
P. Gonzáles (Spain)
E. Ivins (USA)
V. Klemann (Germany)
Z. Martinec (Ireland)
G.A. Milne (Canada)
J. Müller (Germany)
Y. Rogister (France)
H.-G. Scherneck (Sweden)
G. Spada (Italy)
W. Sun (Japan)
Y. Tanaka (Japan)
P. Vajda (Slovak Republic)
P. Varga (Hungary)
L.L.A. Vermeersen (Netherlands)
P. Wu (Canada)

Corresponding members:

J. Davis (USA)
E.W. Grafarend (Germany)
J. Hinderer (France)
L.E. Sjöberg (Sweden)

Activities of the Study Group

The major activity of the study group has been the organization of the 3rd Workshop on 'Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change'. The Workshop took place on Lanzarote, Spain, during February 23-26, 2009. Responsible for the scientific organization were D. Wolf (Germany), J. Fernández (Spain) and P. Gonzáles (Spain). The workshop was attended by 14 participants presenting 16 talks or posters. Details of the workshop are documented in a 'Program and Abstracts' booklet.

Publications

The main publication activity of the study group has been the preparation of a Pageoph topical volume entitled 'Deformation and Gravity Change: Indicators of Isostasy, Tectonics and Climate Change, Volume 2' edited by D. Wolf, J. Fernández and P. Gonzáles. The volume (in print) has approximately 400 pages with 16 contributions. Many of the publications in it were presented at the 2nd Workshop on 'Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change' that took place on Lanzarote, Spain, during March 27-30, 2007. Volume 1 was published in 2007 and documents the 1st Workshop held in 2005. Together, the two volumes reflect the activities of the ICCT Working Group 2 on 'Dynamic Theories of Deformation and Gravity Fields' that existed during 2003-2007.

Future Activities

It is intended to document the 3rd Workshop in a further topical volume. The details are presently discussed by the organizers of the workshop.

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. Its accuracy depends on a precise theory and quality data. Computation methods are important as well. Decimeter differences have been reported purely due to the use of different computation methods. The cm-geoid is a challenge not only to theoreticians, but also to practitioners.

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 effect, refinement of the topographic and gravity reductions.
- Studies on harmonic downward continuations.
- Non-linear effect of the geodetic boundary value problems on geoid determinations.
- The effect of topographic density variations on the Earth's gravity field, especially the geoid.

The geoid has applications in other disciplines, such as in oceanography. Joint efforts between different disciplines have produced useful results.

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)
W. Freeden (Germany)
E. Grafarend (Germany)
J. H. Kwon (South Korea)

L. Sjöberg (Sweden)
D. Roman (USA)
J. Saleh (USA)
D. Smith (USA)

Main Activities of the Study Group

This document presents the status report of IC-SG 8 since its creation in 2007. During the period 2007-09 the SG established its terms of references, organized its membership structure, adopted an Internet site, and proposed focus items. We also proposed to have a group meeting at IAG 2009 Science Meeting. This report can only cover the main activities of SG members and that there are more activities within as well as outside the SG. 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.

Sjöberg (2008, 2009) continues research in the topographic bias. Since the downward continuation is always associated with instability and may be divergent, his simple formula for the bias has been under stringent scrutiny. The relationship between the height anomaly and geoid height in Heiskanen and Moritz (1967) is an approximation. Flury and Rummel (2009) find the separation between the two surfaces is much smaller. In the Alps, it is only 30 cm at the highest summit—while results based on approximations are often larger by several decimeters. 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. Abd-Elmotaal and Kühtreiber (2007a, b) compared the method of Stokes kernel modification and the Window Technique used in geoid computation. They (2008) also attempted on the optimal combination surface gravity data with a global coefficient model. The method of optimal combination of the deflections of the vertical and the surface gravity anomaly is also proposed by Kühtreiber and Abd-Elmotaal H (2007). Ellmann (2009) showed a large difference (9 cm standard deviation) between the geoids computed by using different kernel modifications. The difference is 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 method properly. Traditionally, the gravimetric geoid is fitted to GPS/levelling data. Featherstone and Lichit (2009) fitted the deflections of the vertical to a geoid model. Wang et al (2008) computed the direct and indirect effects on a global scale in 30” resolution. Different ways of downward continuation are proposed and tested in a rugged high mountain region.

Future Activities

During the upcoming two-year period 2009-11 the SG aims to work on the special subjects listed above. Because the differences between the geoid computed from different methods are almost one order larger than cm–geoid requirement, the SG intents to set up a special sub-study group investigate this issue. Strategy of the investigation and structure of the sub-group will be discussed at SG group meeting at IAG 2009. Since the geoid computation is the prime task of the physical geodesy, cooperation between study groups is proposed.

Publications and Conference Presentations

Publications

Abd-Elmotaal H (2007a) Reference Geopotential Models Tailored to the Egyptian Gravity Field. *Bollettino di Geodesia e Scienze Affini* 66(3): 129–144

Abd-Elmotaal H (2007b) High-Degree Geopotential Model Tailored to Egypt. Proc. 1st Int. Symp. of the IGFS, Harita Dergisi, Özel Sayı 18: 187–192

Abd-Elmotaal H (2009) Evaluation of the EGM2008 geopotential model for Egypt. *Newton's Bull.* 4: 185–199

Abd-Elmotaal H, Kühtreiber N (2007a) Comparison between Window Technique and Modified Stokes' Kernel in Geoid Determination for Austria. *Österreichische ZfV & Geoinformation* 95(4): 267–274

Abd-Elmotaal H, Kühtreiber N (2007b) Modified Stokes' Kernel versus Window Technique: Comparison of Optimum Combination of Gravity Field Wavelengths in Geoid Computation. Proc. 1st Int. Symp. of the IGFS, Harita Dergisi, Özel Sayı 18: 102–107

Abd-Elmotaal H, Kühtreiber N (2008a) An Attempt towards an Optimum Combination of Gravity Field Wavelengths in Geoid Computation. In: Sideris MG (ed.), *Observing our Changing Earth*, IAG Symposium 133: 203–209

Abd-Elmotaal H (2008b) Gravimetric Geoid for Egypt using High-Degree Tailored Reference Geopotential Model. Presented at the 1st Arab Conference on Astronomy and Geophysics "ACAG-1", Cairo, Egypt, October 20–22, 2008.

Abd-Elmotaal H (2009) Evaluation of the EGM2008 geopotential model for Egypt. *Newton's Bulletin* 4: 185–199

Amos MJ, Featherstone WE (2009) Unification of New Zealand's local vertical datums: iterative gravimetric quasigeoid computations. *J Geod* 83: 57-68

Darbeheshti N, Featherstone WE (2009a) Non-stationary covariance function modelling in 2D least-squares collocation. *J Geod* 83: 495-508

Darbeheshti N, Featherstone WE (2009b) Non-stationary covariance function modelling in 2D least-squares collocation. *J Geod*. 83: 495-508

Featherstone WE, Lichti DD (2009) Fitting gravimetric geoid models to vertical deflections. *J Geod*. 83: 583-589

Flury J, Rummel R (2009) On the geoid-qusigeoid separation in mountain areas, *J Geod*.

Huang J, Véronneau M (2009) Evaluation of the GRACE-based Global Gravity Models in Canada. In: External quality evaluation reports of EGM08, *Newton's Bulletin* 4: 66-72

Huang J, Veronneau M, Mainville A (2008) Assessment of systematic errors in the surface gravity anomalies over North America using the GRACE gravity model. *Geophys. J. Int*.175: 46-54, doi: 10.1111/j.1365-246X.2008.03924.x.

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Kühtreiber N, Abd-Elmotaal H (2009) The Geoid as a Transformation Surface. Presented at the General Assembly of the European Geosciences Union (EGU), Vienna, Austria, April 19 24, 2009.

Kuhn M, Featherstone WE, Kirby JF (2009) Complete spherical Bouguer gravity anomalies over Australia. *Australian Journal of Earth Science* 56: 209-219

Novák P (2007) Gravity reduction using a general method of Helmert's condensation. *Acta Geodaetica et Geophysica Hungarica* 42: 83-105

Rangelova E, Fotopoulos G, Sideris MG (2009) On the use of iterative re-weighting least-squares and outlier detection for empirically modelling rates of vertical displacement. *J Geod* 83: 523-535

Thompson KR, Huang J, Veronneau M, Wright DG, Lu Y (2009), Mean surface topography of the northwest Atlantic: Comparison of estimates based on satellite, terrestrial gravity, and oceanographic observations. *J. Geophys. Res*., doi:10.1029/2008JC004859, in press.

Conference Presentations

Abd-Elmotaal H (2007) Tailored Reference Geopotential Model for Egypt. 24th General Assembly of the International Union of Geodesy and Geophysics IUGG, Perugia, July 2007.

Abd-Elmotaal H (2008) Gravimetric Geoid for Egypt using High-Degree Tailored Reference Geopotential Model. 1st Arab Conference on Astronomy and Geophysics "ACAG-1", Cairo, Egypt, October 2008.

Abd-Elmotaal H (2008) Evaluation of PGM2007A Geopotential Model in Egypt. IAG International Symposium on Gravity, Geoid and Earth Observation "GGEO 2008", Chania, June 2008.

Abd-Elmotaal H, Kühtreiber N (2008) Gravity Interpolation in Mountainous Areas. General Assembly of the European Geosciences Union (EGU), Vienna, April 2008.

Ellmann A (2009) Deterministic and stochastic modifications of the Stokes formula. General Assembly of the European Geosciences Union (EGU), Vienna, April 2008.

Featherstone WE (2007) Quassie-Geoid: The anticipated new Australian geoid-type model. International Union of Geophysics and Geodesy, XXIV 2007, Perugia, Report of the International Association of Geodesy 2007-2009 ─ Travaux de l'Association Internationale de Géodésie 2007-2009.

Huang J, Novák P (2008) One- and Two-Step Integral Solutions for Gravimetric Geoid – Revisited. American Geophysical Union Fall Meeting, 15-19 December 2008, San Francisco.

Huang J, Véronneau M (2008) Will ESA's gravity mission GOCE improve the Canadian geoid model? In: Canadian Geophysical Union annual scientific meeting.

Kotsakis C, Gruber T (2007) Review of Evaluation Methods and Test Results for the Quality Assessment of Earth Gravity Models, International Union of Geophysics and Geodesy, XXIV 2007, Perugia.

Kadlec M, Novák P, Tsoulis D (2008) Comparison of two modeling strategies for evaluation of the terrain correction using high resolution digital elevation models. IAG International Symposium "*Gravity, Geoid and Earth Observation*", Chania, June, 2008.

Kühtreiber N, Abd-Elmotaal H (2009) The Geoid as a Transformation Surface. Presented at the General Assembly of the European Geosciences Union (EGU), Vienna, April 2009.

Li X, Roman D, Saleh J Wang YM (2008) High Resolution DEM over Alaska and Its Application to Geoid Modeling. *Eos Trans. AGU,89*(53), Fall Meet.

Moritz H (2008) Great Mathematicians and the Geosciences: From Leibniz and Newton to Einstein and Hilbert. Presented to the Leibniz Society of Sciences at Berlin November 14, 2008.

Roman D (2007) The impact of littoral aerogravity on coastal geoid heights. International Union of Geophysics and Geodesy, XXIV 2007, Perugia, Italy

Saleh J, Wang YM, Roman D, Li X, Smith D (2008) USGG08 – A new gravimetric geoid for the US. *Eos Trans. AGU,89*(53), Fall Meet.

Santos M (2007) Insights into the Mexican Gravimetric Geoid (GGM05). International Union of Geophysics and Geodesy, XXIV 2007, Perugia, Italy.

Wang YM (2007) Accurate Account of the Topographic Effect on the Geoid Computations. International Union of Geophysics and Geodesy, XXIV 2007, Perugia, Italy.

Wang YM, Saleh J (2008) On the Use of the EGM08 Geopotential Model for Local Geoid Computations, *Eos Trans. AGU,89*(53), Fall Meet.

IC-SG9: Application of Time-Series Analysis in Geodesy

Chair: W. Kosek (Poland)

Introduction

The IC-SG9 "Application of time-series in geodesy" was created in July 2008.

Observations of the new space geodetic techniques (geometric and gravimetric) deliver a global picture of dynamics of the Earth usually represented in the form of time series which describe 1) changes of the surface geometry of the Earth due to horizontal and vertical deformations of the land surface, variations of the ocean surface and ice covers, 2) the fluctuations in the orientation of the Earth divided into precession, nutation, polar motion and spin rate, and, 3) the variations of the Earth's gravitational field as well as the variations of the centre of mass of the Earth. Geometry, Earth rotation and the gravity field are the three components of the Global Geodetic Observing System (GGOS). The vision of GGOS is to integrate all observations and elements of the Earth's system into one unique physical and mathematical model. However, the temporal variations of Earth rotation and gravity/geoid represent the total, integral effect of all mass exchange between all elements of Earth's system including atmosphere, ocean and hydrology.

Different time series analysis methods are applied to analyze all these geodetic time series for better understanding of the relation between all elements of the Earth's system as well as their geophysical causes. The interactions between different components of the Earth's system are very complex so the nature of considered signals in the geodetic time series is mostly wideband, irregular and non-stationary. Thus, it is necessary to apply time frequency analysis methods in order to analyze these time series in different frequency bands as well as to explain their relations to geophysical processes e.g. by computing time frequency coherence between Earth's rotation or the gravity field data and data representing the mass exchange between the atmosphere, ocean and hydrology. The techniques of time frequency spectrum and coherence may be developed further to display reliably the features of the temporal or spatial variability of signals existing in various geodetic data, as well as in other data sources.

Geodetic time series may include for example variations of site positions, tropospheric delay, ionospheric total electron content, temporal variations of estimated orbit parameters. Time series analysis methods can be also applied to analyze data on the surface including maps of the gravity field, sea level and ionosphere as well as temporal variations of such surface data. The main problems to deal with concern the estimation of deterministic (including trend and periodic variations) and stochastic (non-periodic variations and random changes) components of the geodetic time series as well as the application of digital filters for extracting specific components with a chosen frequency bandwidth.

The multiple methods of time series analysis may be encouraged to be applied to the preprocessing of raw data from various geodetic measurements in order to promote the quality level of enhancement of signals existing in the raw data. The topic on the improvement of the edge effects in time series analysis may also be considered, since they may affect the reliability of long-range tendency (trends) estimated from data series as well as the real-time data processing and prediction.

For coping with small geodetic samples one can apply simulation-based methods and if the data are sparse, Monte-Carlo simulation or bootstrap technique may be useful.

Understanding the nature of geodetic time series is very important from the point of view of appropriate spectral analysis as well as application of filtering and prediction methods.

Primary Objectives of the Study Group

- 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

Full members:

W. Kosek (Chair, Poland)
M. Schmidt (Germany)
J. Vondrák (Czech Republic)
W. Popinski (Poland)
T. Niedzielski (Poland)
J. Boehm (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).

Corresponding members:

M. Schmidt (Germany)

Activities of the Study Group

Conference Contributions of SG Members

Boehm J, Salstein D, MacMillan D, Steigenberger P, Schindelegger M, Englich S, Schuh H (2009) Hourly Earth rotation parameters and atmospheric angular momentum functions for CONT08. EGU General Assembly, Vienna, 19-24 April 2009.

Fang M, Zhou YH, Salstein D, Hager BH (2009) The equivalence of gravitational and centrifugal torques in the equatorial plane in a shallow atmosphere. EGU General Assembly, Vienna, 19-24 April 2009.

Gross RS (2009) Ocean tidal effects on length-of-day. *Geophys. Res. Abs*. 11, Abstract EGU2009-1558.

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Kosek W, Rzeszotko A, Popinski A (2008) Contribution of wideband oscillations of the EOP data excited by the fluid excitation functions to their prediction errors. EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008, abstract: EGU2008-A-05133.

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Kosek W, Popinski W, Rzeszótko A, Niedzielski T (2008) The causes of the prediction errors of the x, y pole coordinates data. AGU Fall Meeting, 15-19 December 2008, San Francisco.

Kosek W (2009) Causes of prediction errors of pole coordinates data. 6th Orlov Conference, "*The study of the Earth as a planet by methods of geophysics, geodesy and astronomy*", June 22-24, 2009, MAO NAS of Ukraine, Kiev.

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Schmidt M (2008) Spatio-temporal multi-resolution representation of the gravity field from satellite data. Goddard Space Flight Centre, Seminar, Greenbelt.

Schmidt M (2008) Spatio-temporal multi-resolution representation of the gravity field from satellite data. Ohio State University, Columbus.

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Sen A, Niedzielski T, Kosek W (2008) Probability models of the x, y pole coordinates data. AGU Fall Meeting, 15-19 December 2008, San Francisco.

Schuh H, Kosek W, Kalarus M, Akyilmaz O, Gambis D, Gross R, Jovanovic B, Kumakshev S, Kutterer H, Mendes Cerveira PJ, Pasynok S, Zotov L (2008) Earth Orientation Parameters Prediction Comparison Campaign - first summary. EGU General Assembly 2008, Vienna, 13 – 18 April 2008.

Study Group Webpage

The webpage of the group is http://www.cbk.waw.pl/~kosek/ICSG9/.

Conference Sessions

- Michael Schmidt - EGU General Assembly 2008, Vienna, Austria
- Michael Schmidt - EGU General Assembly 2009, Vienna, Austria

Future Activities of the Group

The IERS Workshop on EOP Combination and Prediction will be held in Warsaw on October 19-21 2009. The Session 3 of this Workshop "EOP prediction techniques and algorithms" will be convened by W. Kosek and W.H. Wooden. This session present different EOP prediction techniques as well as results of EOP predictions provided by them and will cover three of the aspects given in primary objectives of the Study Group (1, 4, 5 and 6). Among all the topics concerning time sere analysis methods (e.g., filtration, spectral analysis and prediction), prediction is the most difficult because good approximation does not guarantee good forecast due to irregular variations of the EOP.

Publications

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Natali MP, Müller M, Fernández L, Brunini C (2009) CPLat: first operational Experimental Processing Center for SIRGAS in Argentina. *Journal of Geodesy* 83: 219-226, doi: 10.1007/s00190-008-0270-5.

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Popiński W (2009**)** Insight into the Fourier transform band pass filtering technique. Accepted to *Artificial Satellites*.

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Communication and Outreach Branch (COB)

http://www.iag-aig.org

President: József Ádám (Hungary)
Secretary: Szabolcs Rózsa (Hungary)
Gyula Tóth (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 HAS-BME Research Group for Physical Geodesy and Geodynamics of the Hungarian Academy of Sciences (HAS), Budapest, Hungary.

The Communication and Outreach Branch is one of the components of the Association. According to the new Statutes (§5) of the IAG, the COB is the office responsible for the promotional activities of the IAG and the communication with its members.

The Terms of Reference and program of activities of the COB, and a short report on the IAG website („IAG on the Internet"), were published in The Geodesist's Handbook 2008 (pp.830-831, pp. 836-838), respectively).

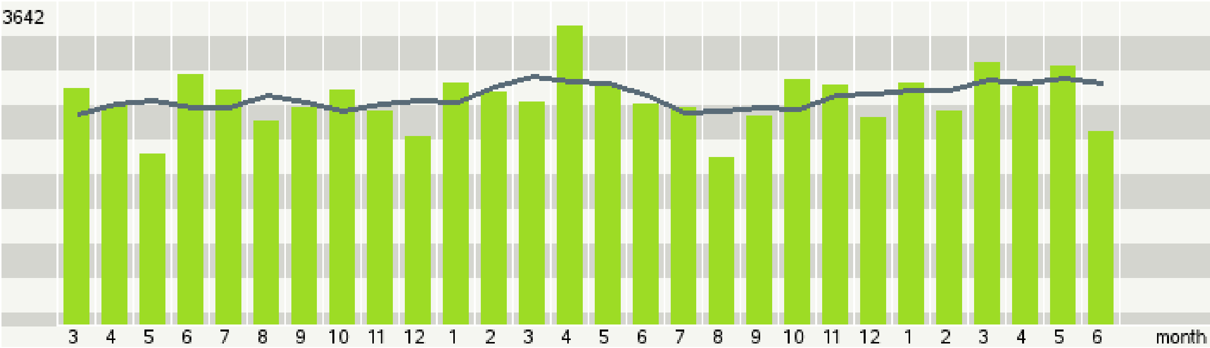
In the past period of the second term (since the 2007 IUGG General Assembly in Perugia till July, 2009) the COB's Steering Committee held a meeting in Vienna, Austria, 18 April, 2008. Helmut Hornik IAG Assistant Secretary General visited us at the COB office in Budapest in 25-26 February, 2009 in order to update and synchronize the database of the IAG Individual Members.

2. Status of the IAG Website

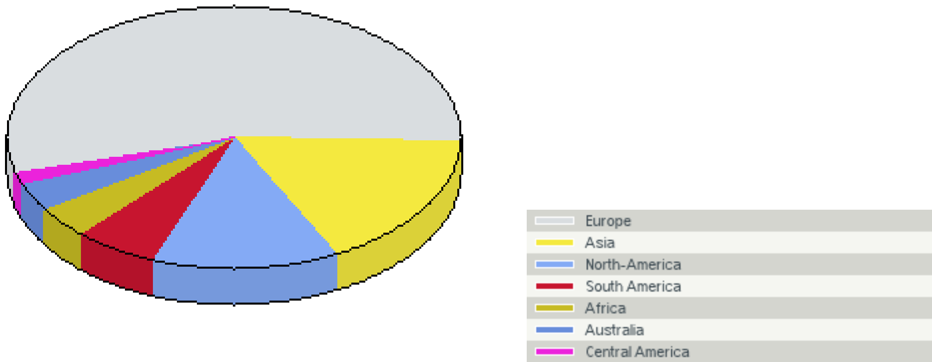
After the final version of the Handbook has been approved, the update process of the IAG website started in October 2008. Until December 10 the process was finished, now all the documents should contain only relevant information on the structure of IAG. However all the previous documents have also been saved to archive folders and are still available on the website. We believe that this is a good idea, if one intends to trace back previous entities, officers, etc. of IAG.

Some modifications have been made on the layout as well – although it is not visible to the public. The proposed layout is available under the link: http://www.iag-aig.org/index.php?tpl=newindex . The new layout contains an intro to IAG based on the current draft of the IAG brochure. In the new layout the problem with the resizing of windows has also been corrected.

The IAG Forum has also been restructured. All the IAG members have received their personal password to be able to log in to the IAG Forum. With this personal password the members can open discussions in any field related to the activity of the Association. The discussion topics can be seen only by IAG members.



Monthly number of visits since March, 2007



Geographical Distribution of visitors

3. The IAG Newsletters

Altogether 28 IAG Newsletters have been published from March 2007 till June 2009 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 as well as interested persons mainly in developing countries received it each month 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 21 issues of the Journal of Geodesy (Vol 81/5 – 83/8). 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. We try to publish only new and/or relevant material here as well.

4. Outreach Activities

The Membership Application Form (MAF) has been updated in collaboration with IAG Office and placed to the IAG Website. It contains all the information for payments by credit card and by bank transfer, and it can be filled using Adobe Acrobat Reader.

In 2008 the COB made a campaign to gather new e-mail addresses and check the existing e-mail addresses of individuals, who are interested in the field of Geodesy. In this campaign some 200 new e-mail addresses have been collected, and it was possible to check the existing e-mail database as well. Currently the data are being processed, and the updated and controlled e-mail database will be ready in next year.

A new version of the IAG Leaflet was prepared in order to promote the IAG to the geo-scientific community and to encourage individuals to become members of the Association. 4000 copies of this leaflet were printed for distribution for different IAG Symposia in the future. The leaflet was available at the AGU, EGU Assemblies and at different IAG Meetings (e.g. GGOS workshop).

In the frame of the COB a more detailed IAG Brochure for the wider public was prepared, which is written in non-technical language. The Brochure is finalized after a long review process. It highlights the projects, applications and in general the usefulness of geodesy to society, as well as gives an overview of its historical development. Information on the IAG Commissions, Services, GGOS are also included very briefly. The length of the Brochure is 20 pages. Our intention is to distribute the first print of the IAG Brochure at the IAG Scientific Assembly in Buenos Aires, Argentina in 2009.

The COB took part in the preparation and work finalizing The Geodesist's Handbook 2008. An article on the recent history of IAG ("Update of the History of the International Association of Geodesy") has been written in The Geodesist's Handbook 2008 (pp. 662-674).

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 reduced parts of them were prepared to publish in the Journal of Geodesy;
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) some works were made in preparation and for finalizing The Geodesist's Handbook 2008, and
f) many e-mail correspondences to the community as part of the outreach activities.

Global Geodetic Observing System (GGOS)

http://www.ggos.org

Chair: Markus Rothacher (Switzerland)
Vice Chairs: Ruth Neilan (USA), Hans-Peter Plag (USA)

No report available – the volume will be updated as soon as possible (2009-08-26)

Bureau International des Poids et Mesures (BIPM) – Time, Frequency and Gravimetry Section –

http://www.bipm.org/en/scientific/tfg/

Head of Section: 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, and in the updates of the key comparison CCTF-K001.UTC. The frequency stability of TAI, expressed in terms of an Allan deviation, is estimated to be at or below 0.4×10^{-15} for averaging times of one month.

Twelve primary frequency standards contributed during the period to improve the accuracy of TAI, including eight caesium fountains developed and maintained in metrology institutes in France, Germany, Italy, Japan and the USA. The scale unit of TAI has been estimated to match the SI second to about 1×10^{-15}.

Routine clock comparison for TAI is undertaken using GPS C/A observations from time and geodetic-type receivers operated in laboratories. Some laboratories are equipped of two-way satellite time and frequency transfer (TWSTFT) devices allowing time comparisons independent from GPS through geostationary communication satellites. The uncertainty of time comparison by GPS is limited by the hardware to 5 ns for the best dual-frequency links whilst in the case of TWSTFT it is at the nanosecond order.

Studies on the use of phase measurements along with the code measurements of geodetic-type GPS receivers were performed in 2007 by using the Precise Point Positioning method (PPP). In April 2008, a pilot experiment started with the participation of 25 laboratories for studying the introduction of PPP links in TAI. The successful results of the pilot experiment were presented to the Consultative Committee for Time and Frequency (CCTF) in June 2009, which approved the inclusion of this method in clock comparison for TAI. The solutions based on this method (TAI PPP) will be used in the routine computation of Circular T starting from October 2009.

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 GPS receiver round trips with the aim of characterizing the relative delays of time transfer equipment in contributing laboratories. In 2009 the first measurements of relative delays of GLONASS equipment have been made, and more are under organization. A pilot experiment to study the possibility of including GLONASS time transfer in the calculation of TAI is planned to start by the end of 2009.

Improvements to the algorithm for calculation of TAI and UTC are on the way; a new model for the hydrogen maser clock frequency prediction has been tested, providing a partial justification to the drift observed between the industrial clocks and the caesium primary standards.

Radiations other than the caesium 133 have been recommended by the International Committee of Weights and Measures (CIPM) as secondary representations of the second. One is in the microwave frequencies (Rubidium) and the other in the optical frequencies (ytterbium, strontium, mercury, aluminium). These frequency standards are at least one order of magnitude more accurate than the caesium, but by the moment their use for time metrology is limited due to the state of the art of frequency transfer, still unable to compare these standards at the level of their performances.

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 Workshop on the IERS Conventions took place at the BIPM in September 2007. Updates to the Conventions (2003) have been posted on the website. Concerning the realization of reference frames for astro-geodynamics, section staff has participated to the construction of the new international celestial reference frame in the scope of IAU and IVS activities.

The work on the gravimeter FG5-108 being made in cooperation with the VNIIM has concluded with a system for delivering the laser light to the interferometer. Some theoretical investigations have been conducted with the aim of obtaining better corrections to the position of the free-falling mass in the gravimeter. The preparation of the ICAG-2009 and of the technical protocol of the key comparison of absolute gravimeters concluded. About 25 absolute gravimeters will participate to the international comparison between September and October 2009, from which 17 will provide results for the key comparison. A campaign of measurements with about ten relative gravimeters started in July 2009 to provide support to the absolute measurements. Some measurements will be made also on the new site at the BIPM where the watt balance will be operated in the future.

The total number of publications of the section during the period is 53.

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 2006*, *for 2007* and *for 2008* volume **3**, complemented by computer-readable files on the BIPM website (http://www.bipm.org), provides the definitive results for at the end of each year.

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. Research into time scale algorithms is conducted in the Section with the aim of improving the long-term stability of EAL and the accuracy of TAI.

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 is well adapted to the caesium clock behaviour, but not for the hydrogen maser, whose frequency presents a drift. A new mathematical expression for the prediction of the hydrogen maser frequency is proposed taking into account the drift. Tests over a 3-year period have been performed applying the linear prediction to the caesium clocks and the quadratic prediction to the H-masers. The results seem to indicate that non-modelling of the frequency drift of H-masers could be responsible for 20% of the drift of EAL with respect to TAI observed in the past five years. EAL still shows a significant drift; further work needs to be done in the next period.

Stability of TAI

Some 87 % of the clocks used in the calculation of time scales are either commercial cæsium 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, during 2008. 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 0.4×10^{-15} 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 triennium, individual measurements of the TAI frequency have been provided by twelve primary frequency standards, including eight cæsium 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 year preceding 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 $+5.7 \times 10^{-15}$, 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 initiated (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. We have provided an updated computation of TT(BIPM), named TT(BIPM08), valid until December 2008, which has an estimated accuracy of order 0.5×10^{-15}. Studies aiming at improving the computation of TT(BIPM) have been undertaken, in order to keep it in line with improvements in primary frequency standards.

Primary frequency standards and secondary representations of the second

Members of the BIPM Time, Frequency and Gravimetry section 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 continue 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 68 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 single- frequency receivers; with dual-frequency, multi-channel GPS geodetic type receivers (P3); and 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, and they represent today only 6% of the total number. Ten TWSTFT links are officially used for the computation of TAI, representing 15% of the time links. More TW links exist in the Asia-Pacific region, not already officially introduced in the calculation, and some European laboratories are close to contributing.

Following the recommendation of the CCTF in 2006 the section started in April 2008 a pilot experiment, TAIPPP, where time laboratories contribute GPS phase and code data and where the BIPM uses the Precise Point Positioning technique to generate monthly solutions, in slightly deferred time after the regular TAI computation. The CCTF, at its last meeting in June 2009 approved the report on the pilot experiment, and agreed on the introduction of TAIPPP links in the calculation of time links for TAI. The number of laboratories regularly participating today is 25. Comparison of the TAIPPP links with others obtained by TWSTFT and P3 are published monthly on the ftp server of the section. Plans exist for starting processing TAIPPP links officially in Circular T in October 2009.

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 GPS links are corrected for satellite positions using IGS (International GNSS Service) post-processed, precise satellite ephemerides, 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; four others are in preparation for their introduction or re-introduction into TAI, or are used for particular studies as the T2L2 experiment. The TWSTFT technique applied to clock comparison in TAI is reaching its potential capabilities with the sessions scheduled every two hours.

Results of time links and link comparison using GPS single-frequency, dual-frequency and TW observations are published monthly on the ftp server of the TFG section (*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 GPS time equipment in time 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.

Progress has been possible on the measurement of relative delays of GLONASS equipment thanks to the cooperation with the Space Research Centre in Warsaw (Poland). The measurements have already started with a TTS-3 receiver having visited in the third trimester of this year the national metrology institute of the Russian Federation, VNIIFTRI.

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.

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, Frequency and Gravimetry section 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. Updates to the *Conventions* (2003) have been posted on the website (http://tai.bipm.org/iers/convupdt). These updates consider several new models for effects that affect the positions of Earth's points at the mm level, which are now significant. These modifications are studied with the help of the Advisory Board for the *IERS Conventions* updates, including representatives of all groups involved in the IERS. Following the conclusions of the Workshop on the IERS Conventions, held at the BIPM on 20 – 21 September 2007, a new registered edition of the IERS Conventions is now planned to be assembled within one year.

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, and work has progressed in the framework of the IAU, IVS and IERS for the construction of a new conventional reference frame to be submitted to the IAU 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.

At present, preparations are in full progress for the ICAG2009 in which some 20 lasers are supposed to be measured. As a consequence of the prioritization of activities of the BIPM by the CIPM, modifications occurred in the section staff, and at the moment of elaborating this report there are doubts on the possibility of making these measurements. Furthermore, a study of beam characteristics for the beams in the interferometer of the participating gravimeters was planned in order to account for small corrections related to diffraction effects.

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 of July 2009.

Gravimetry

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 broken motor of the dropping chamber is replaced and the re-adjustment of dropping controller is in progress.

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 has been completed and provides 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). At present, twenty seven absolute gravimeters have announced their participation in the comparison. Of these, seventeen gravimeters will take part in the Key Comparison CCM.G-K1 which is the part of ICAG-2009. The measurements of the remaining subset of gravimeters will be 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. All the results of the participating gravimeters will be included in the evaluation of the results of the KCD for CCM.G-K1 and as the result of ICAG2009 as a whole while only the results of the gravimeters from KC subset will be submitted to KCDB of the BIPM.

Preliminary schedules for the absolute and relative measurements have been prepared and distributed among participants. It is estimated that five gravity stations of the microgravity network at the BIPM is a suitable number for their homogeneous measurement and optimal adjustment.

The BIPM is at present working with the preparation of the verification of the laser frequencies of the lasers used in the interferometric measurement of the displacement of the falling test body and the frequencies of the reference Rb clocks of the absolute gravimeters. It is planned to monitor the stability of the gravity field at the BIPM using the gravimeter FG5-108 belonging to BIPM.

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 Physicists, Head
Mr Raymond Felder, Physicist (Frequency), retiring 09/2009
Ms Aurélie Harmegnies, Assistant (Time), since 11/2008
Dr Zhiheng Jiang (Time, Gravimetry)
Mrs Hawaï Konaté, Principal Technician (Time)
Mr Jacques Labot, Principal Technician (Frequency)*, retiring 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, Physicist (Frequency, Gravimetry)
Mr Laurent Tisserand, Technician (Time)[1]
Dr Leonid Vitushkin, Principal Research Physicist (Gravimetry)

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International Altimetry Service (IAS)

http://ias.dgfi.badw.de

Chair of the Steering Committee: Wolfgang Bosch (Germany)

Introduction

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. This initiative is non-competitive, but open to identify and pool together international resources in altimetry and to initiate projects completing or gradually improving existing services for the benefit of the altimetry community at large.

Initial activities

The IAS Terms of References were defined and published in Geodesist's Handbook (Drewes, H., 2008, p 796).

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 Sub-commission 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 Full 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) – rejected in the very last stage of the evaluation process.

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

General IAS Politics

Many organizations already provide altimetric data and value-added products. ***It is not Intended to Replace any of the Existing Service Components.*** But the consensus on the need for an IAS suggest that a satellite 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, proposes complementary components for the establishment of an International Altimeter Service and suggest pilot projects, coordinated on voluntary basis and gradually improving existing services for the benefit of the altimetry community at large.

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. It is, however, indicative that 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 particular objectives of an IAS Web site should be:

Improve information and documentation on all altimetry mission data and related products. This should happen independently of mission, agency, or application. 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.

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 is in preparation. 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.

Preparation of 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 floaters, 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.

IAS Pilot Project on Ocean Tides (IAS-PP-OT)

A pilot project on ocean tides has been prepared with a draft Call for participation to be submitted on the occasion of the IAG 2009 General Assembly in Buenos Aires. This Call is seeking proposals of groups, agencies, or individuals to contribute to one or more of the following initial, non-exclusive focal points:

a. Compilation of global ocean tide (OT) models, their error estimates (if available) and their documentation; put them to a common, self-standing format; provide interfaces to other formats or back-transformations to original formats.
b. Provide an Internet portal, allowing to download global ocean tide models, associated documentation (reports, plots, etc.), and software to evaluate the models. The portal should also inform about the work of the IAS-PP-OT, the progress achieved in modelling ocean tides, and links to research groups involved in ocean tide modelling.
c. Compare OT models with each other, document and visualize differences.
d. Provide software allowing to evaluate OT models for ocean areas, at individual observations sites or along the sub-satellite tracks of altimeter satellites; document the interpolation technique and the treatment of admittances.
e. Provide software to transform OT models to a spherical harmonic representation used for orbit and gravity field determination processes, and other computations required for Earth system science studies.
f. Evaluate the impact of different OT models on orbit computation (of LEO's) and gravity field determination by altimeter data (crossover statistics) and analysis of residuals of space gravimetry or gradiometry observations (de-aliasing of GRACE and GOCE).
g. Compile tidal constants, analyse times series of tide gauges, bottom pressure gauges, continuously operating GNSS sites and gravimeter stations in order to validate OT models by means of independent data or to use this data in assimilation approaches.
h. Compile local or regional ocean tides models, compare them with global OT models and investigate approaches to perform a fusion of global and non-global ocean tide models.

Other pilot projects are under preparation.

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IAG Bibliographic Service (IBS)

http://www.bkg.bund.de/nn_159914/EN/FederalOffice/InformationServices/iag__node.html__nnn=true

Chair: Annekathrin Michlenz (Germany)

Overview

The service 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. Since 1984 there are stored literature entries. They cover the whole subject of geodesy, cartography and photogrammetry and the neighbouring files. Every year 1300 new entries are included into the database. In April 2009 the database comprises about 61 500 entries.

In addition to the Fast Bibliography within the IAG Newsletter of the Journal of Geodesy the IAG Bibliographic Service serves mainly to inform the geodesists who are associated in the IAG about current geodetic literature from all over the world.

For the IAG Bibliographic Service geodetic journals and other periodicals, publications of research institutes, manuals und text books as well as congress papers are analyzed. The document lists choose such sources for the service which are relevant to the activities of the Sections, Commissions, Special Commissions und Special Study Groups.

These literature sources are available in the library of the Bundesamt für Kartographie und Geodäsie (BKG) (library symbols F128, L191 or B729).

The topicality of the sources recorded in the IAG Bibliographic Service is dependent on the date of their arriving at the library of the BKG. German-language literature und conference proceedings on geodesy are processes as a rule within 3 weeks after receipt.

Each literature record contains:

- The bibliographic description of the source according to the commonly known rules.
- The descriptors in German. They inform about the content of the recorded source.
- In most cases an abstract, if possible in English. The abstracts are often taken from the source or are processes by the document list on the basis of the summary, the conclusions, or the list of contents of the source.

International Centre for Earth Tides (ICET)

http://www.upf.pf/ICET/

Director: Jean-Pierre Barriot (France, French Polynesia)

Overview

The period from mid-2007 to mid-2009 was essentially devoted to the translation of ICET from Brussels to Papeete. This includes three main points: web site, the "Bulletin des Marées Terrestres, BIM", and GGP data stream validation.

Main Activities

1/ The web site of ICET was entirely migrated from the Royal Observatory of Belgium to the University of French Polynesia.

2/ A prototype of the new ICET database has been tested and presented at the ETS2008 meeting in Vienna. The database is able to store any kind of data related to Earth Tides, and not only cryogenic gravimeter data.

3/ The server that will host the new ICET database as been bought (6000 euros) by the University Central Bureau on Information technologies and Networks (RENATER). The ICET database will be online by December 2009 on a test basis.

4/ A new validation software to treat the GGP data has been written. The purpose of this software is to 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 hope to start routine operations on GGP data by September 2009.

5/ A GGP "header" script is also under completion. The purpose of this script, written in Python, is to enforce a strict standardization of GGP file headers, in order to completely automatize their validation and archiving.

6/ The BIM 144 has been completed and is on line on the ICET website. BIMs 145 and 146 will be on line soon. All together, they will gather more than 25 papers presented at the ETS2008.

7/ The new gPhone gravimeter of the ICET centre has been received late December and is now in operation in Tahiti-Pamatai. We observed on April 16, 2008 a 6.6 Earthquake in the South Sandwich Islands.

8/ ICET is also participating in the deployment in French Polynesia of a network of Tide-Gauge / GPS stations (POGENET, POLynesian GEodetic NETwork), as a contribution to the GGOS effort.

References

Barrio Jean-Pierre. Le réseau POGENET de géodynamique globale et locale en Polynésie Française (Poster), 1ères assises de la recherche française dans le Pacifique et 10ème Inter-Congrès des Sciences du Pacifique, octobre 2006.

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.

Barriot, J.-P., Ducarme, B. Identification of outliers and jumps in gravity time series from superconducting or spring gravimeters. (Oral Session) New Challenges in Earth Dynamics, Jena, Germany, Sept. 1-5, 2008. Bulletin des Marées Terrestres (BIM), 145, July 2009.

Jean-Pierre Barriot, Pascal Ortéga, Abdelali Fadil, Lydie Sichoix and Victoire Laurent, GPS monitoring for natural risk assessments and research in French Polynesia (Oral), 2èmes assises de la recherche française dans le Pacifique et 11ème Inter-Congrès des Sciences du Pacifique, 02-06 mars 2009.

Jean-Pierre Barriot, Pascal Ortéga, Abdelali Fadil, Lydie Sichoix, Dominique Reymond, Yann Dupont, Pascal Mainguy and David 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, 02-06 mars 2009.

International Centre for Global Earth Models (ICGEM)

http://icgem.gfz-potsdam.de/ICGEM/

Director: Jürgen Kusche (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, 106 models are listed with their references and 92 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.

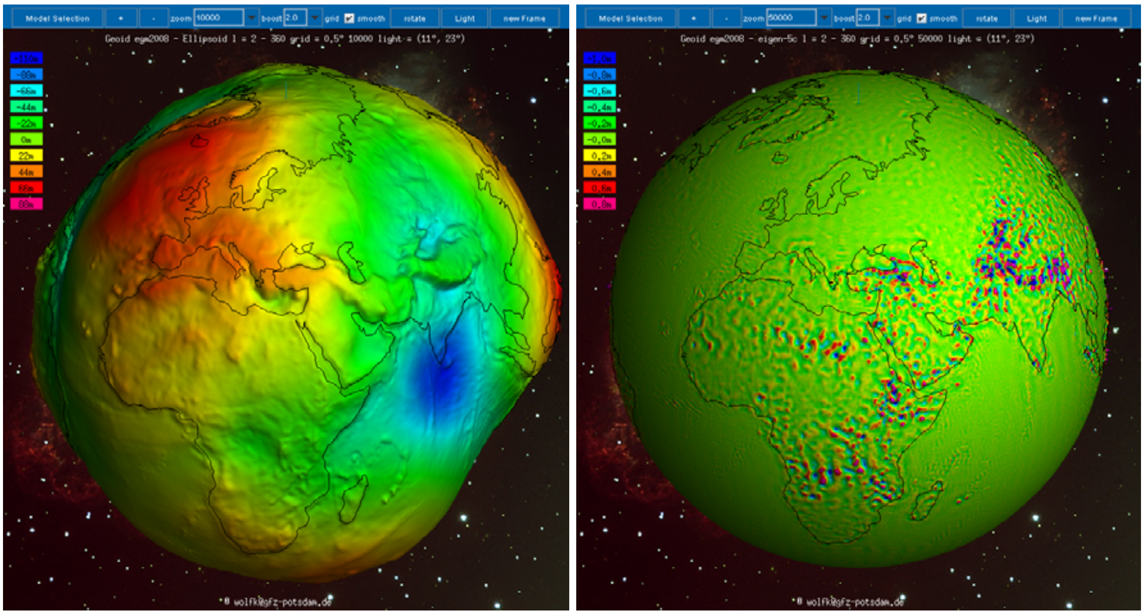

Fig. 1: Visualisation (geoid) of a global gravity field model and of differences of two models

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)
– gravity on the Earth's surface (including the centrifugal acceleration)
– gravity 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 (postscript) are available for download after a few seconds or a few minutes depending on the functional, the maximum degree and the number of grid points.

Figure 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

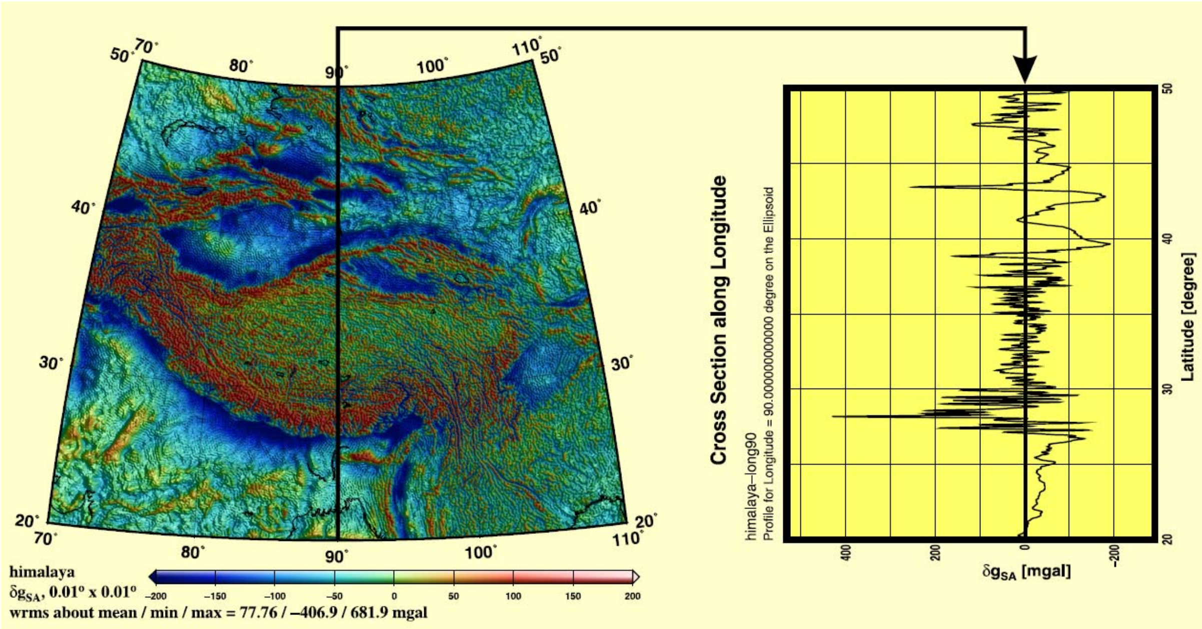

Fig. 3: Example of grid and plot generation by the calculation service: gravity disturbances of the Himalayan region and cross section along a defined longitude from the model EGM2008

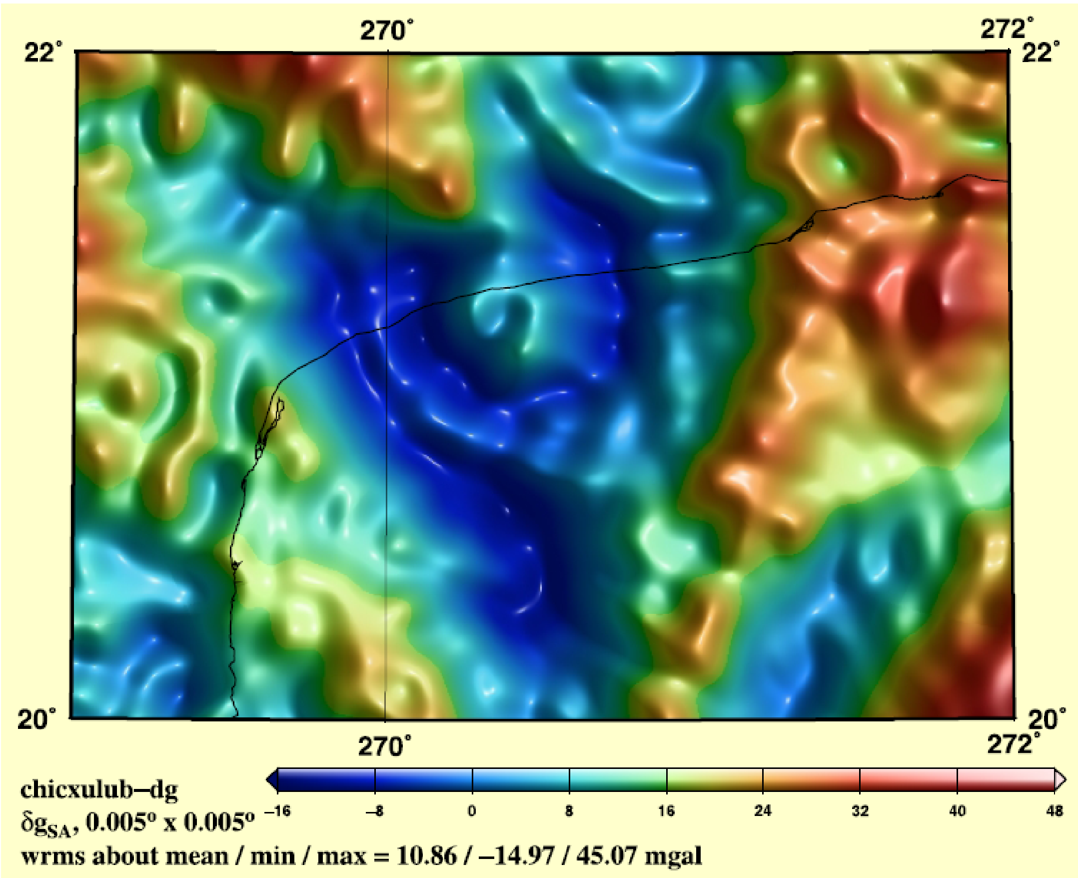

Fig. 4: Example of grid and plot generation by the calculation service: gravity disturbances of the Chicxulub crater region from the model EGM2008

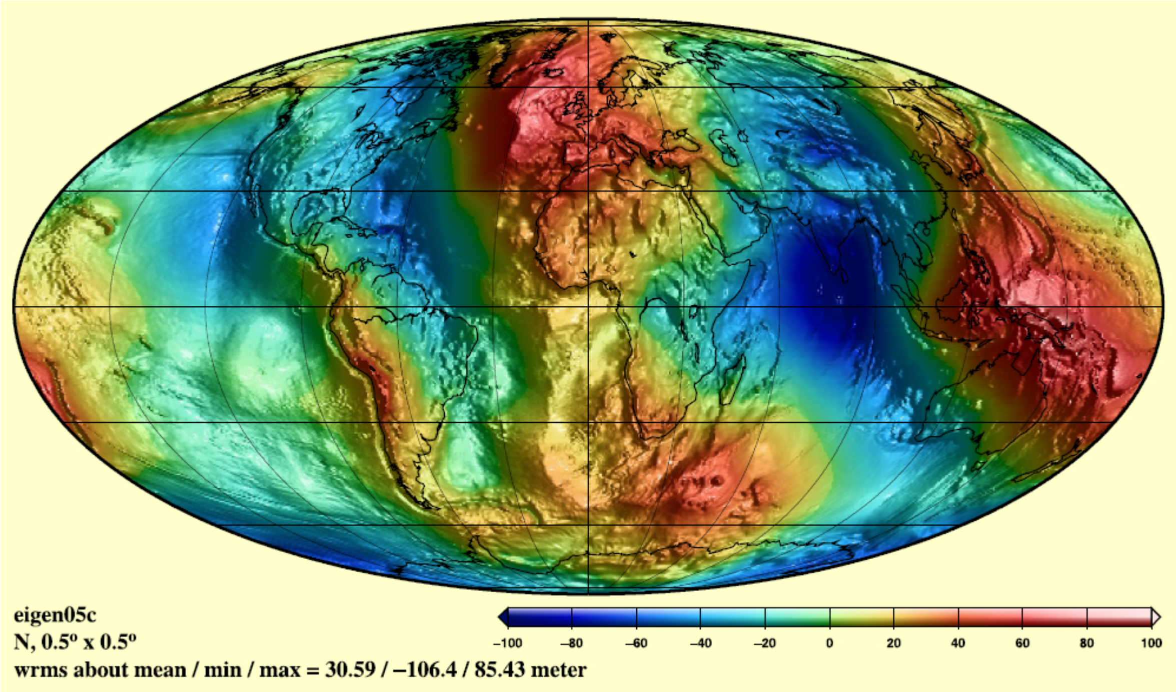

Fig. 5: Example of grid and plot generation by the calculation service: global geoid from the model EIGEN-5C

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
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
EIGEN-5C	360	0.341 m	0.251 m	0.303 m	0.244 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
ITG-GRACE03	180	0.633 m	0.557 m	0.658 m	0.603 m
AIUB-CHAMP01S	70	0.843 m	0.906 m	1.513 m	0.893 m
ITG-GRACE02S	170	0.623 m	0.511 m	0.639 m	0.489 m
EIGEN-GL04C	360	0.339 m	0.253 m	0.336 m	0.244 m
EIGEN-GL04S1	150	0.630 m	0.576 m	0.748 m	0.464 m
EIGEN-CG03C	360	0.346 m	0.306 m	0.355 m	0.260 m
GGM02C	200	0.473 m	0.378 m	0.515 m	0.376 m
GGM02S	160	0.977 m	1.116 m	1.416 m	1.356 m
EIGEN-CG01C	360	0.351 m	0.270 m	0.370 m	0.263 m
EIGEN-CHAMP03S	140	0.816 m	0.842 m	1.451 m	0.849 m
EIGEN-GRACE02S	150	0.739 m	0.643 m	0.828 m	0.538 m
TUM2S	60	0.864 m	0.963 m	1.639 m	1.101 m
DEOS_CHAMP-01C	70	0.813 m	0.887 m	1.499 m	0.886 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]

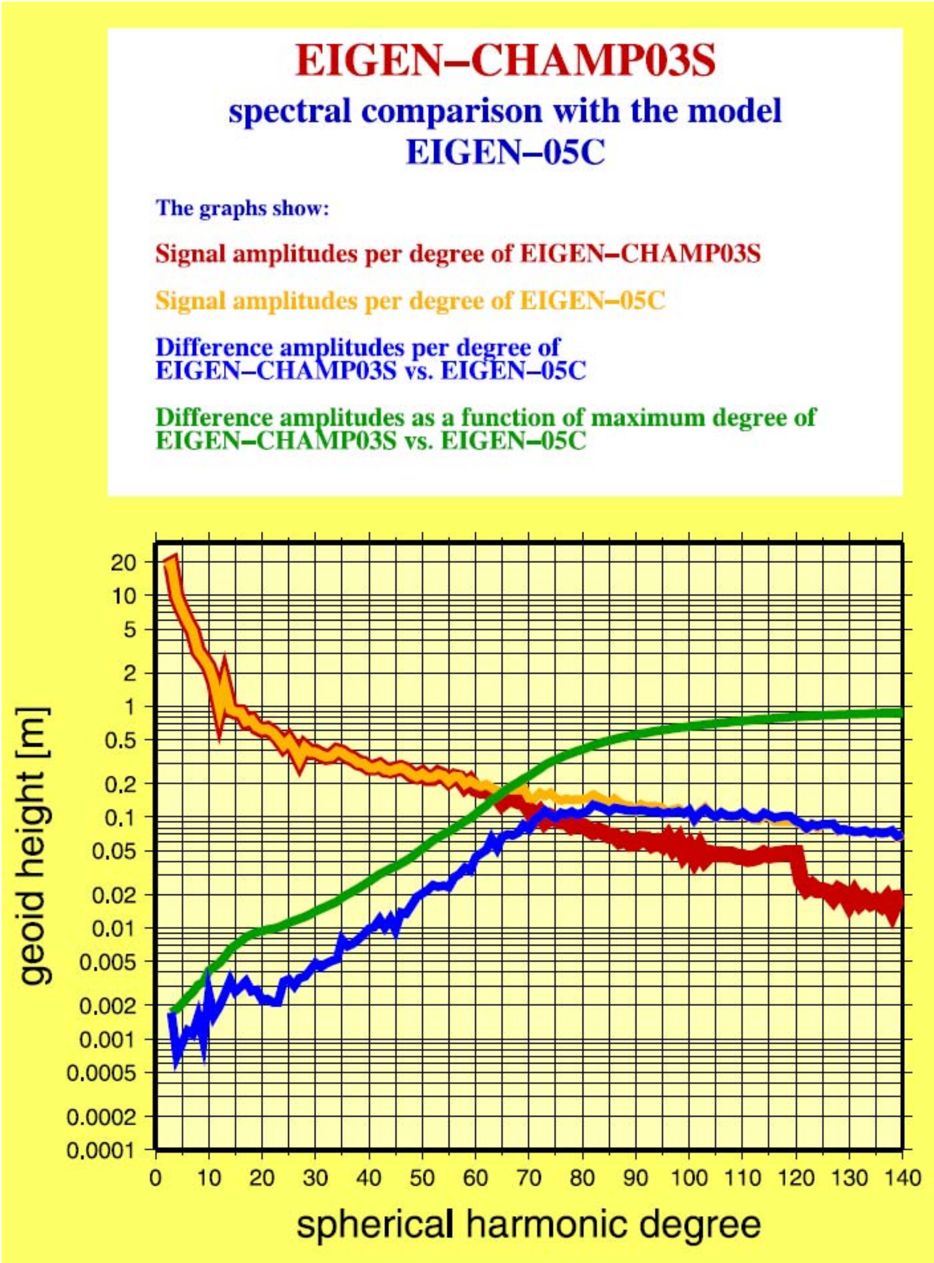

Fig. 7: Comparison of the models in the spectral domain (e.g.: EIGEN-CHAMP03S) with one of the most recent combination models (e.g. EIGEN-5C)

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".

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. (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 Geo-ForschungsZentrum 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. Among the significant events over this period are the release of several Global Digital Elevation Models at varying spatial resolutions, and the steadily increasing requirements 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

Several new GDEMs have been released over the reporting period, including lower resolution models such as GETASSE30 and high/multiple resolution models including ACE2. The ACE2 GDEM was released on 1 July 2009; this model was produced with a core contribution from the SRTM dataset plus over 70 million altimeter derived heights and additional ground truth. The model development was funded by the European Space Agency, and the model is freely available. 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. This and other new and existing GDEMs may be obtained via links from the IDEMS webpages.

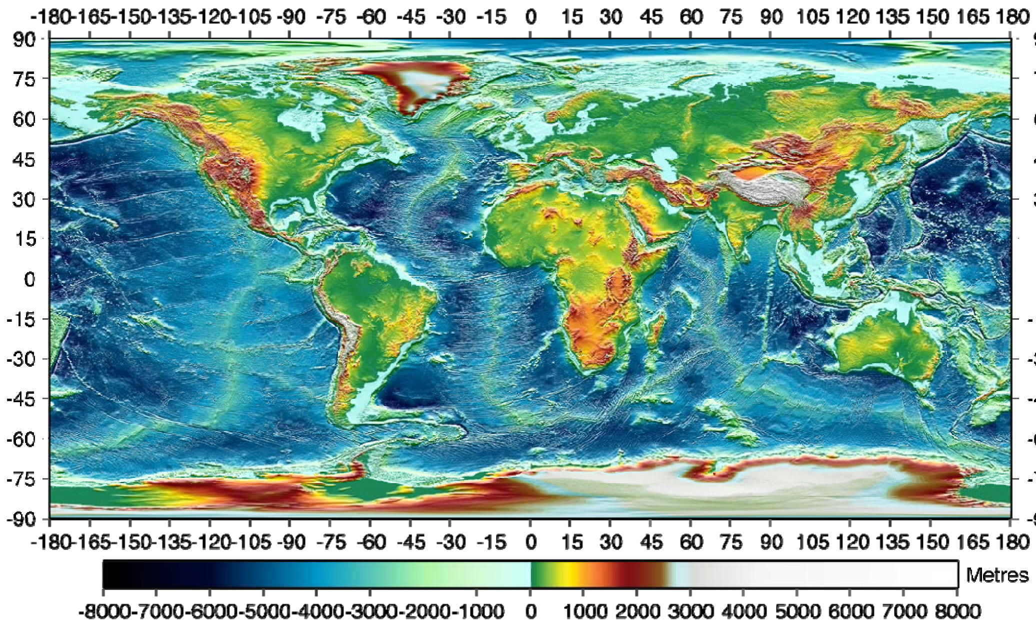

Figure 1.1: Fused ACE2 dataset with DNSC08 bathymetry

A recurring topic of queries and discussion over this period has related to the comparison of GPS measurements with Digital Elevation Models at varying spatial resolutions.

A tutorial will shortly be added to the IDEMS webpages on the effects of generalising DEM data to coarser spatial resolutions, and the implications for comparisons with point measurements such as GPS. This is a recurring area of difficulty, and misunderstandings cause naïve researchers to submit conference/journal papers that contain technical errors.

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. There is sustained interest in representation of inland water within DEMs: several groups report adding max/min water level data in a separate hydrology layer for the largest lakes, and interest in river and lake height changes continues to grow. These data are primarily utilized 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.
To monitor the accessibility and usefulness of this information, enhanced search engine monitoring software has been recently put in place on the IDEMS webpages: results to date show a roughly 50/50 split between take-up of DEM and hydrology related information, which is an interesting and unexpected result. This will be monitored over the next reporting period.

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. It is planned to progressively enhance links to source DEM data and code held in institutes/universities (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.cls.fr/

Director: Pascal Willis (France)

Overview

The current report presents the different activities held by all components of the International DORIS Service (IDS). In a first step, we will present the current status of the DORIS system (available satellites and tracking network). In a second step, we will present the activities of the IDS Central Bureau (IDS Web site management and DORIS-related email distributions). We will then focus on the most recent activities conducted by the Analysis Centres (ACs) and the Analysis Coordination in preparation of ITRF2008. Finally, we will present other activities related to meetings and publications.

DORIS system

DORIS satellites

During this report period (2007-2009), the number of DORIS satellites has remained between five and six (see Table 1).

Table 1: DORIS data available at IGN. As August 2009

Satellite	Start	End	Type
SPOT-2	31-MAR-90 04-NOV-92	04-JUL-90 15-JUL-09	Remote sensing
TOPEX/Poseidon	25-SEP-92	01-NOV-04	Altimetry
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	-	Remote sensing
SPOT-5	11-JUN-02	-	Remote sensing
Jason-1	15-JAN-02	-	Altimetry
ENVISAT	13-JUN-02	-	Altimetry, Environment
Jason-2	12-JUL-08	-	Altimetry

In mid 2008, a new DORIS satellite (Jason-2) was launched including a new generation receiver on-board : digital, 7-channel, allowing direct phase measurement like GPS (instead of Doppler data).

In the near future, several new DORIS satellites are already planned (and approved) : CRYOSAT-2, SARAL, HY-2A, Jason-3, … This should increase or at least stabilize the number of DORIS satellites in the 2010-2016 time period. In July 2009, the SPOT-2 satellite had to be de-orbited and inactivated. A series of manoeuvres changed the orbit so the spacecraft will re-enter the Earth's atmosphere in less than 25 years. SPOT-2 was launched in 1990 with a planned six-month test mission. After 19 years of successful operations, it has greatly exceeded the most optimistic expectations.

DORIS tracking network

The DORIS permanent tracking network remains very stable (Figure 1). About 50% of the DORIS stations are in co-location with other geodetic space techniques : GPS (38), SLR (9) and VLBI (6).

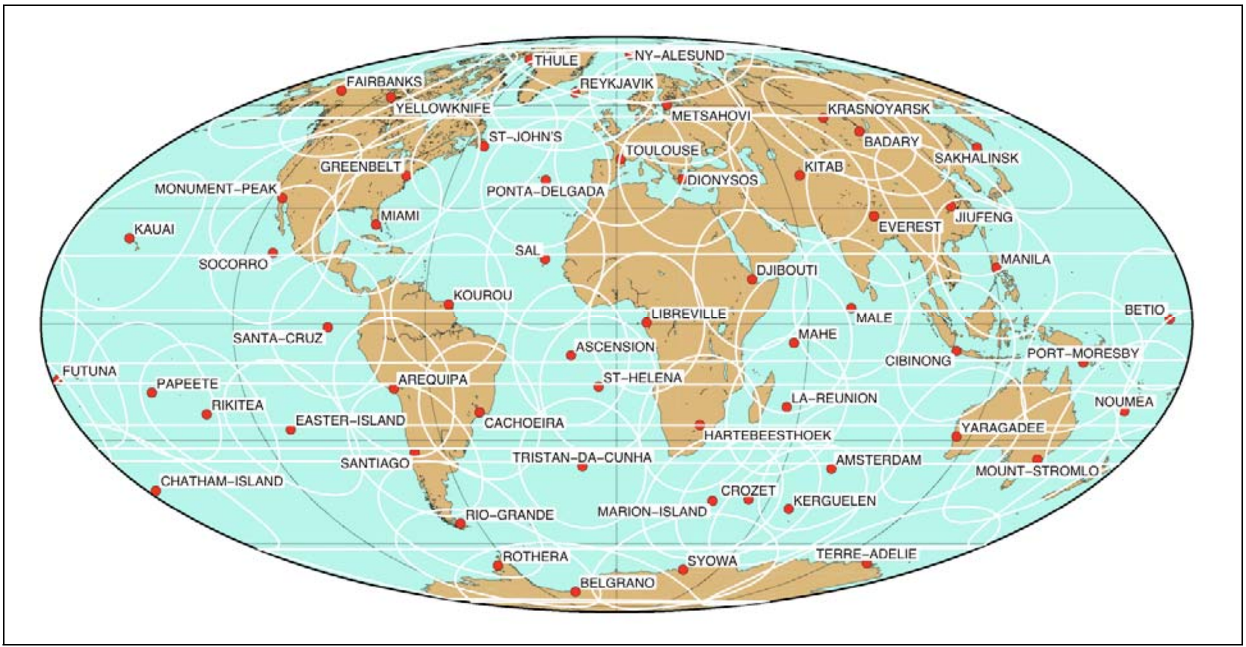

Figure 1: DORIS permanent tracking network. July 2009.

The renovation of the DORIS network is now terminated. Almost of DORIS beacons (55) are third generation beacons (except 2), and use a stable geodetic mount (c.f. Fagard, 2006).

IDS Governing Board

Following the IDS status, a new Governing Board was elected at the end of 2008 (see Table 2).

Table 2: IDS Governing Board following elections in December 2008

Name	Institution	Country	Mandate
Hervé Fagard	IGN	France	Network representative
Pascale Ferrage	CNES	France	Member at large
Frank Lemoine	GSFC	USA	Analysis Coordinator
Chopo Ma	GSFC	USA	IERS representative
Carey Noll	GSFC	USA	Network representative
Michiel Otten	ESOC	Germany	IAG representative
John Ries	U. Texas/CSR	USA	Member at large
Laurent Soudarin	CLS	France	Director IDS Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Centre representative

IDS Central Bureau

IDS Web site

The IDS Central Bureau maintains the IDS Web site at http://ids.cls.fr. The IDS Web site archives information of direct interest to the IDS Analysis Centres and to the DORIS community in general:

- DORIS results such as plots and data of DORIS station coordinate time series at http://ids.cls.fr/html/doris/ids-station-series.php3
- DORIS station site logs at http://ids.cls.fr/html/doris/sitelog.php3
- daily statistics of Precise Orbit Determination (POD) residuals per station
- specific events affecting DORIS satellites (manoeuvres, change of on-board software,..) or stations (discontinuity, data gap or temporary failures,…)

In particular, a kml file was created to allow a virtual tour of DORIS tracking stations on Google Earth.

Access to IDS Web site is still steadily increasing from month to month since Spring 2000. In early 2009, this Web site was accessed about 2000 times each month on a regular basis.

IDS Mail system

Several types of emails are distributed by the IDS Central Bureau :

- DORISMail : general DORIS interest
- DORISReports : reports related to DORIS data and products
  - AWG and IDS Analysis Forum : technical discussion between analysis centres, combination and coordination

Everyone is welcome to subscribe to any of these emails. See more details on http://ids.cls.fr/html/report/doris_mails.html

IDS Data Centres

The IDS data flow organization remains the same, but is now more robust. It is based on two data centres : one on the East Coast of the US (CDDIS a GSFC) and one in Europe (IGN in France). Recently, the two data centres were gradually upgraded in order to be exact mirrors of each other and to be able to continue on an operational basis, even if one of them is inaccessible due to a temporary failure.

These two data centres archive the DORIS data as well as the IDS products (station coordinates and velocity, geocentre motion, earth orientation parameters, ionosphere data, etc.).

IDS Analysis Centre

Like the other technique-services in IAG, IDS has now a large number of independent Analysis Centres.

In preparation for ITRF2008, seven AC's submitted long time series of DORIS results in SINEX format from 1993.0 to 2009.0 (Table 3). Besides these operational groups, several other groups are also considering to join in the future, such as NCL in Newcastle, UK. Even for those using the same software packages (IGN-INASAN for GIPSY/OASIS and GSFC-Geoscience Australia for GEODYN), great care was taken to define the processing strategies to be at the same level of quality but using different approaches (e.g. Gravity field model, tropospheric mapping functions, etc.).

Table 3: List of IDS Analysis Centres submitting time series of weekly station coordinates in preparation of ITRF2008. July 2009.

Acronym	Analysis Centre	Country	Software package
ESA	ESOC	Germany	NAPEOS
GAU	Geoscience Australia	Australia	GEODYN
GOP	Geodetic Observatory Pecny	Czech Rep.	Bernese
GSC	GSFC	USA	GEODYN
IGN	IGN	France	GIPSY/OASIS
INA	INASAN	Russia	GIPSY/OASIS
LCA	CNES/CLS	France	GINS/DYNAMO

This is a complete change for IDS, as in the past only two independent solutions were regularly submitted to the previous ITRF combinations. Several meetings were held by the Analysis Coordinator (Frank Lemoine), inviting all AC's to make them benefit from the experience of the other groups, to compare results, and to prepare for the AC submissions for ITRF2008.

IDS Combination

For the first time, IDS made a combined time series of all available weekly solutions (from 1993.0 to 2009.0).

For the first time, DORIS satellites orbits derived from the seven AC's were systematically inter-compared. This allowed us to isolate processing anomalies and assured that the processing of the DORIS data was at a comparable level for all the AC's. The results were excellent, showing agreement at the 1-2 cm level in the radial component, even without trying to select compatible data processing strategies for models or parameter estimation.

Following the availability of ITRF2005, a new DPOD2005 coordinate data set was derived, expanding to new DORIS stations or to stations not considered in the original ITRF2005, due to non-linear displacements. DORIS stations' discontinuities were also analyzed. A dedicated Web page was created : http://www.ipgp.fr/~willis/DPOD2005.htm

Meetings

In the past 2 years the IDS organized the following meetings :

- IDS Workshop, Venice, Italy, 13-15 March 2006
- DORIS Analysis Working Group Meeting, Paris, France, 13-14 March, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 5-6 June, 2008
- IDS Workshop, Nice, France, 12-14 November, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 23-24 March, 209

All presentations from these meetings are made available by the Central Bureau on the IDs Web site at http://ids.cls.fr/html/events/ids_meetings.html

Publications

In 2006, a DORIS Special Issues was published in the Journal of Geodesy 80(8-11), including 17 peer-reviewed articles.

A second DORIS Special Issue is currently in preparation in Advances in Space Research.

IDS published a 2006-2008 activity report that was broadly distributed to all DORIS participants and relevant services

G. Tavernier, P. Ferrage, H. Fagard, F. Lemoine, C. Noll, R. Noomen, J.C. Ries, L. Soudarin, J.J. Valette, P. Willis, The International DORIS Service, January 2006 – December 2008 Report, 91 pages, http://ids.cls.fr/html/report/governing_board.html#activity.

All DORIS related articles published in international peer-reviewed journals are available o the IDS Web site at http://ids.cls.fr/html/report/peer-reviewed_journals.html

Conclusions

In conclusion, even if the DORIS context is rather stable in terms of network and satellite constellation, a major change happened to the IDS as seven Analysis Centres now actively participate in operational DORIS data processing and as a combined IDS solution is now available in preparation of ITRF2008. The launch of the new Jason-2 satellite should also open some new opportunities in the IDS, as it brings more data (7-channel receiver), better quality (equivalent to 0.3 mm/s) and the possibility to process these data using a GPS-type technique (access to raw DORIS phase measurement instead of Doppler data). In the near future several new satellites of this type should be launched, insuring a minimum of four DORIS satellites for the 2010-2016 time period.

International Earth Rotation and Reference Systems Service (IERS)

http://www.iers.org

Chair of the Directing Board: Chopo Ma (USA)
Director of the Central Bureau: Bernd Richter (Germany)
IERS Central Bureau: Wolfgang Dick (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 the next realization of the International Terrestrial Reference System and the work towards the Second International Celestial Reference Frame have nearly been finished. The IERS Conventions (i.e. standards etc.) have been updated regularly. A new edition of the Conventions is expected at the end of 2009.

The IERS continued to issue Annual Reports, Bulletins, and Newsletters. It held a Workshop on Conventions (September 2007) and organized a GGOS Unified Analysis Workshop and its follow-up meeting (December 2007 and April 2008).

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 2009:

- IERS Annual Reports 2005 and 2006
- IERS Bulletin A, B, C, and D (weekly to half-yearly)
- IERS Messages Nos. 115 to 147

Workshops

The IERS organized the following Workshops:

- *Workshop on Conventions (Sèvres, France, September 20–21, 2007).* The main conclusions of the workshop were among others 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.

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;

Among the most important decisions made by the DB in 2007–2009 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 is under construction.

The work of the *Analysis Coordinator* focused on coordinating the Combination Pilot Project, to prepare the GGOS Unified Analysis Workshop, and to propose a new version of the SINEX data format.

Technique Centres

The Technique Centres are autonomous independent services, which cooperate with the IERS:

- *International GNSS Service* (IGS)
- *International Laser Ranging Service* (ILRS)
- *International VLBI Service for Geodesy and Astrometry* (IVS)
- *International DORIS Service* (IDS)

For the work of the Technique Centres, see their individual reports to IAG.

Product Centres

The *Earth Orientation Centre* is responsible for monitoring of long-term earth orientation parameters, publications for time dissemination and leap second announcements. It issues IERS Bulletins B, C, and D and corresponding data files. An extended EOP Web Service was developed that offers the Earth orientation parameters and the Earth orientation matrix at a given date. The tool allows the computation of the excitation function of the Earth rotation and the comparison with the geophysical excitation functions. Since June 2007 a new IERS EOP reference series, IERS 05 C 04 consistent with ITRF2005 is available. A Technical Note to describe this series is being prepared. In May 2009, Bulletin B was revised following a survey which was made among the community.

The *Rapid Service/Prediction Centre* is responsible for providing Earth orientation parameters on a rapid turnaround basis, primarily for real-time-users and others needing the highest quality EOP information before the IERS final values are available. It issues IERS Bulletin A and corresponding data files. Further work has been dedicated to improvement of the centre's products. The system of the Bulletin A was changed to match the system of the new IERS 05 C 04 series. In January 2009, the centre moved its web site to a new address and changed its style considerably.

The *Convention Centre* prepared a large number of updates to the IERS Conventions (2003). A Conventions Workshop was held in September 2007 (see above) in preparation for a new registered edition, which is expected to be produced in 2009. The Centre maintains a web site including pages for the Conventions updates.

Involvement by *ICRS Centre* personnel in the celestial reference frame VLBI program has continued, increasing the number of observations of ICRF quasars in the southern celestial hemisphere and continuing an extensive observing program in the northern hemisphere. This observing program will eventually result in a new realization of the ICRS, tentatively called ICRF 2. A "Resolution on the Second Realization of the International Celestial Reference Frame" has been prepared for the IAU General Assembly in August 2009.

The *ITRS Centre* participated in complete surveys of some co-location sites, contributed to specifications for ITRF densification, developed the tools and methodology for generating the

ITRF from SINEX inputs from the various space geodesy techniques, and maintained the IERS network. The ITRS Centre, together with the ITRS Combination Centres, is planning to generate a new ITRF solution (ITRF2008, release Sept. 2009) and issued a Call for Participation in November 2008.

The *Global Geophysical Fluids Centre* (GGFC) currently consists of eight Special Bureaus (SB) for Atmosphere, Core, Gravity/Geocentre, Hydrology, Loading, Mantle, Oceans, and Tides. These provide data related to global geophysical fluids such as co-seismic excitation of Earth rotational and gravitational changes, glacial isostatic adjustment, core angular momentum changes, geocentre variations, oceanic tidal angular momentum, oceanic tidal variations in earth rotation, low-degree spherical harmonics of ocean and atmospheric tides, models for global oceanic angular momentum, models for oceanic centre-of-mass, a model for ocean bottom pressure, measurements of ocean bottom pressure, continental water storage and water flux, effective atmospheric angular momentum functions, spherical harmonic coefficients of surface pressure, global friction torque and global mountain torque, and Earth surface deformation due to surface mass loading. In May 2009 the IERS released a Call for Proposals, whose purpose is to restructure the GGFC. The structural changes are being instituted to 1) allow for the establishment of operational products, i.e., those products, which are provided with regularity and which have been evaluated as being reliable and precise; and to 2) allow for inclusion of new operational products.

Combination Centres and Working Groups

Nine *Combination Research Centres* (CRC) have been working on the development of methods and software for the combination of data and products from different techniques. The CRCs were terminated by December 31, 2008. They will be replaced by *Research Centres* which will be responsible for carrying out research on a specific subject, related to a corresponding Product Centre and limited to a term of 4–5 years. Three *ITRS Combination Centres* are responsible for providing ITRF products by combining ITRF inputs.

Areas of work of the *Working Group on Site Survey and Co-location* are standards and documentation (guidelines, survey reports, possibly store reports and data), coordination (share know-how and join efforts btw. survey teams), research (investigate discrepancies btw. 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* is currently being established. The *Working Group on Prediction* 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* is 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 and Director: Riccardo Barzaghi (Italy)

Overview

In the last two years, 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 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 5^{th}-9^{th}, 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. 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.

As it is usually done since 1999, schools on geoid computation have been organized by IGeS in the last two years. A school have been held in Como, in September 15^{th}-19^{th}, 2008.

Also, new schools have been planned in the near future. The next school is going to be held in Universidad National de la Plata, Fac. de Ciencias Astronómicas y Geofísicas , La Plata, Argentina, on September 7^{th}-11^{th} , 2009. A second forthcoming school is going to be organized in Saint Petersburg, in 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.

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.

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.

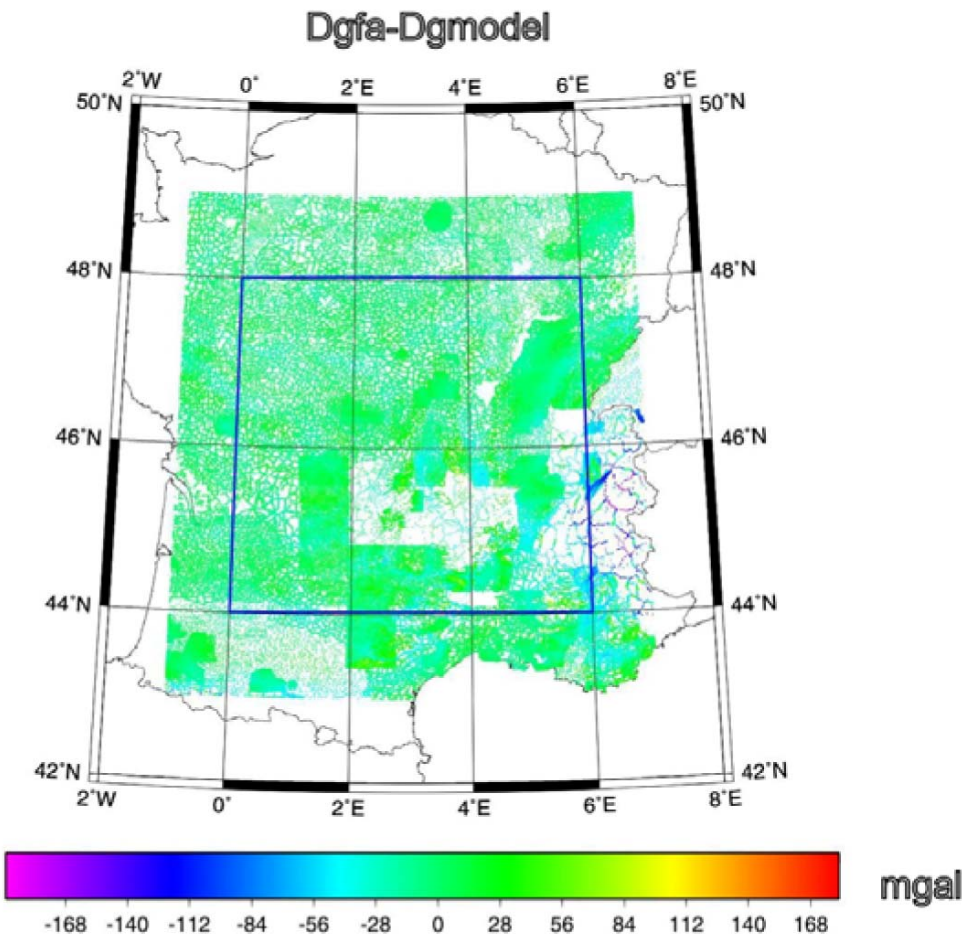

Figure 1. – The test area and the gravity database (residual gravity after geopotential model reduction)

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 col location 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

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*).

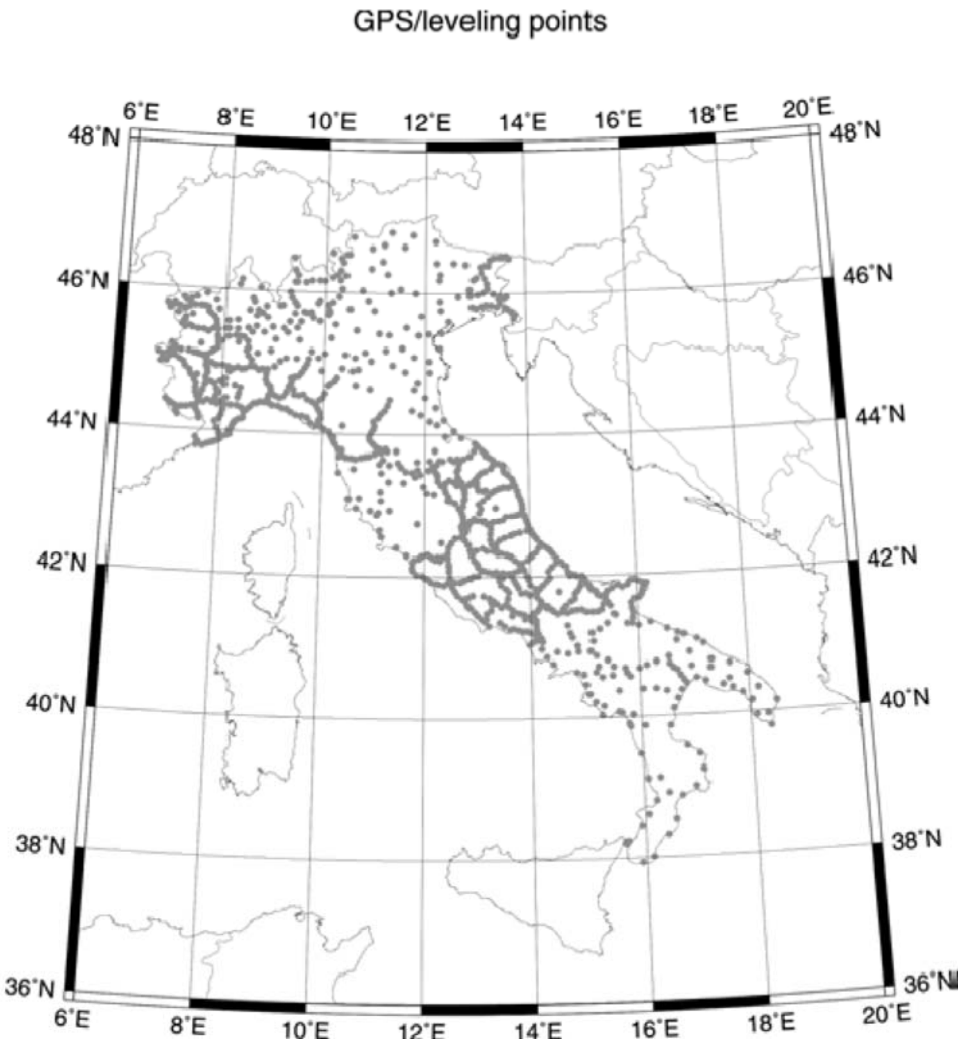

Figure 2. – The test area and the used GPS/leveling points

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 ITALGEO95 (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).

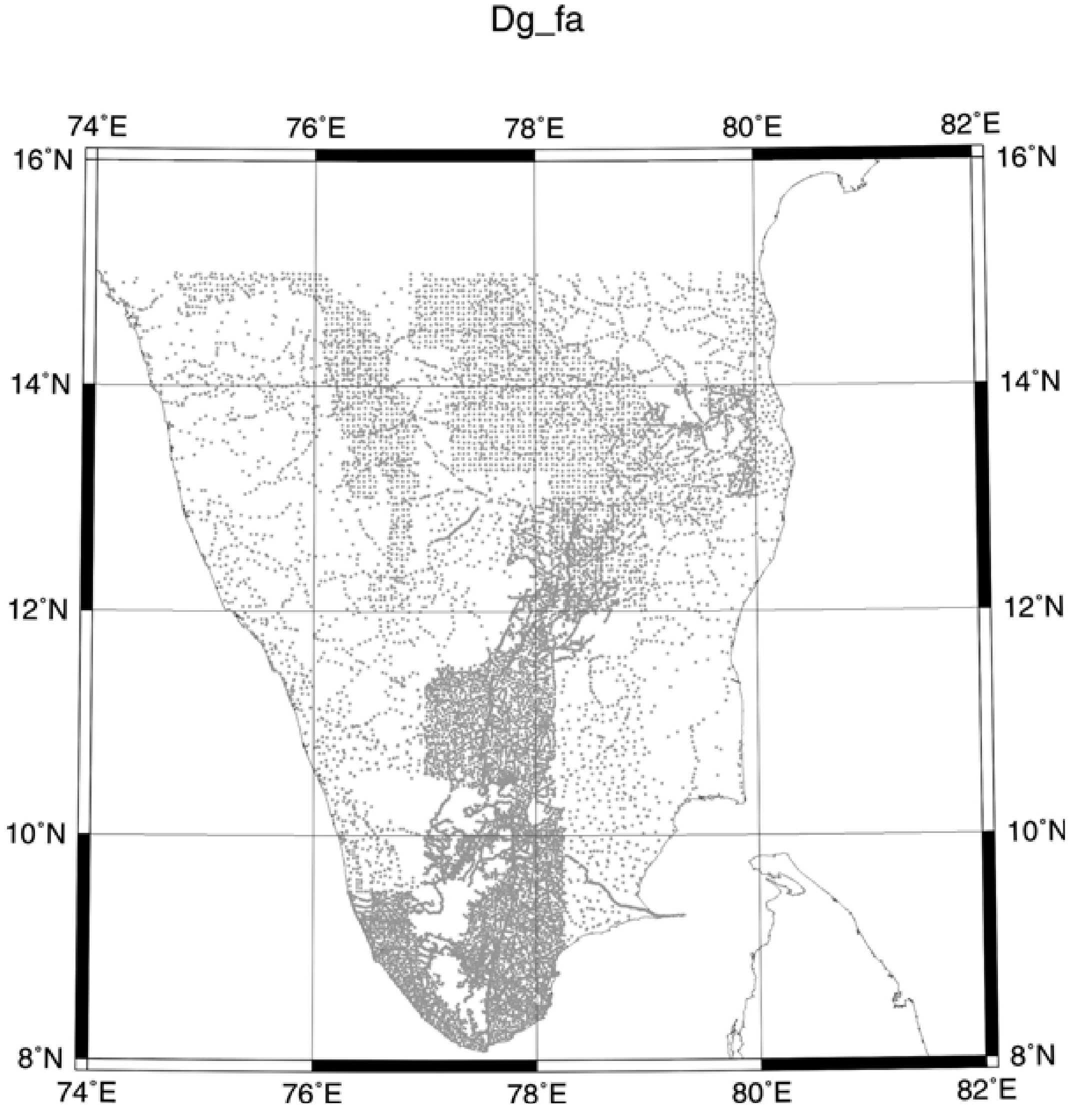

Figure 3. – The South India gravity data base

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 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 include both theoretical lectures and numerical exercises on local geoid computation. On the first day, a seminar on gravity data collection and validation was also given.

Topics were given according to the following schedule:

Monday, September 15th
9:00 – 12:30 / 14:00 – 15:00: Theory for Geoid Computation , The Remove Restore Concept and Collocation (F. Sansò)
15:00-18:00: Seminar on gravity measurements and validation for land and marine gravity data (M.Sarrailh)

Tuesday, September 16th
9:00 – 12:30 The Terrain Effect in Geoid Estimation (R. Forsberg)
14:00 – 15:00 Exercises

Wednesday, September 17th
9:00 – 12:30 The Global Geopotential Models (N. Pavlis)
14:00 – 15:00 Exercises

Thursday, September 18th
9:00 – 12:30 The Collocation Method in Geodesy (C.C. Tscherning)
14:00 – 15:00 Exercises

Friday, September 19th
9:00 – 12:30 The FFT Methods in Geodesy (M. Sideris)
14:00 – 15:00 Exercises

The school was attended by 23 participants coming from 12 countries.

Morning theoretical lessons were given at Palazzo Natta in the historical center of Como while afternoon computer exercise sessions were held in the computer center 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.

As in previous geoid schools, students have been given Lecture Notes, with some upgrading as addendum, IGeS CD with software and data for exercises, the GRAVSOFT manual, and a user guide for FFT exercises. Moreover a final CD has been supplied with all the lectures presented during the week.

This school is going to be followed by two new schools in the near future. The first one will be held at Universidad National de la Plata, Fac. de Ciencias Astronómicas y Geofísicas , La Plata, Argentina, on September 7th-11th , 2009. Furthermore, a second has been planned in Saint Petersburg (Russia) and will be organized in 2010.

4. 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 4.

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.

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

$$\Delta N_i = N_i(GPS/lev) - N_i(EGM2008)$$

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:

$$\hat{N}_{grid} = N_{grid}(EGM\,2008) + \Delta\hat{N}_{grid}$$

$$\Delta\hat{N}_{grid} = Collo(\Delta N_i)$$

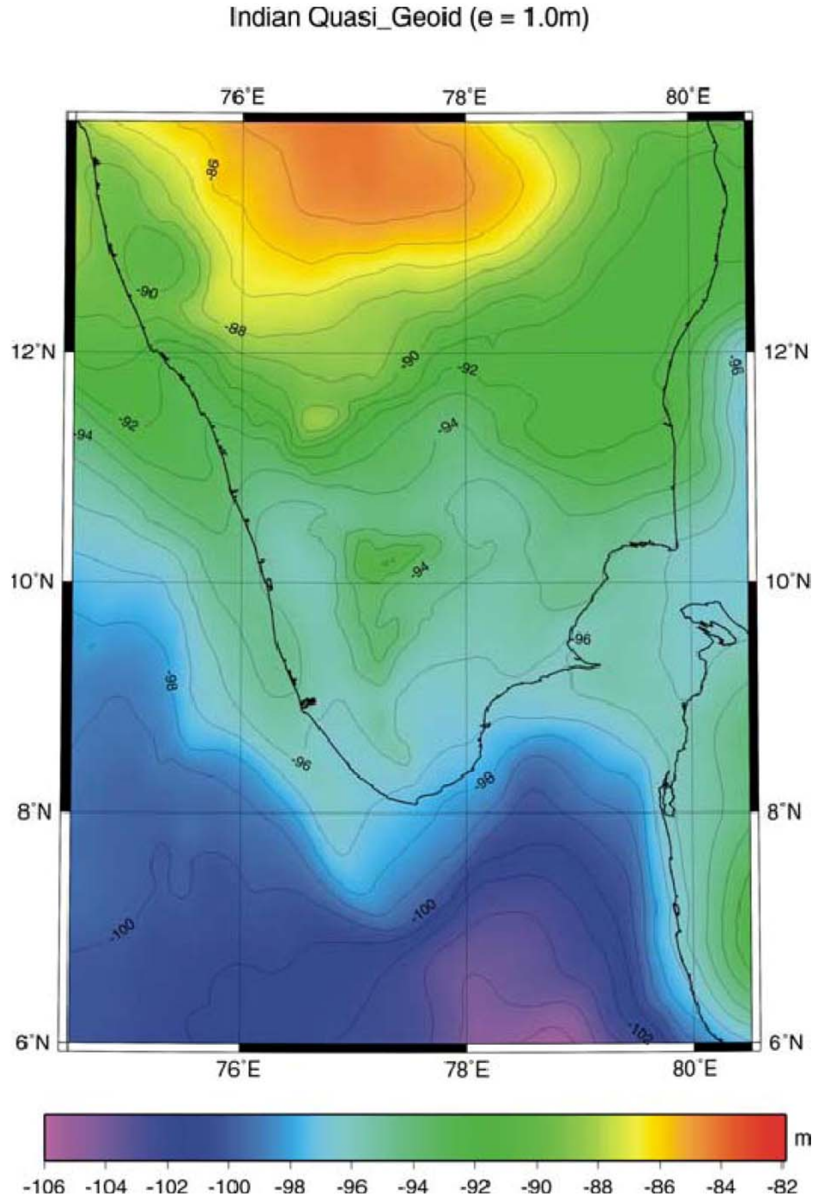

Figure 4. – The South India quasi-geoid

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 GNSS Service (IGS)

http://igscb.jpl.nasa.gov

President: John Dow (Germany)
Director of the Central Bureau: Ruth Neilan (USA)

No report available – the volume will be updated as soon as possible (2009-08-26)

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 belongs to the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) which operates under the auspices and in part thanks to the financial support of the International Council of Scientific Unions (ICSU) and the United Nations Educational Scientific and Cultural Organization (UNESCO).

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 National Center for Spaces Studies (CNES) and of the Observatoire Midi-Pyrenees (OMP), where it has been directed successively by G. Balmino (1979-1998), J-P. Barriot (1998-2007 – with interim of R. Biancale between Sept. 2006 and July 2007) 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). Since 1998, BGI is supported by 10 French Organizations whose contributions to BGI over four year renewable periods are defined by a covenant.

Activities

BGI activities in the last two years were dominated by the following events:

(i) The preparation of a new 4-years project for period 2007-2011 and the renewal of the convention between the supporting organizations of BGI in France. This was accompanied by some changes in the BGI staff, including the nomination of a new Director.

(ii) The initiation of two new global projects of data compilation and valorization: the realization of a global Absolute gravity database in collaboration with Bundesamt für Kartographie und Geodäsie (BKG) Germany; the initiation of the World Gravity Map project in collaboration with Commission for the Geological Map of the World (CGMW).

(iii) The realization of a new web site.

In the same time, BGI also maintained the activities of services relatively to its existing gravity database (integration, validation of new datasets, processing of data requests from external users, etc.). Other actions which were previously initiated at BGI for research projects have been finalized (software for marine data analysis, and geoid computation in West Mediterranean). The main activities are summarized hereafter.

2.1 Definition of a 4-years project (2007-2011)

The BGI project for a 4 years period[1] has been prepared in early 2007 and approved by IAG during the IUGG General Assembly in Perugia, Italy (July 2007). It has been also approved by the French organizations supporting BGI. The contribution of each supporting organization for the next 4 years has been defined in a new covenant[2] that has been submitted for final approval to the main institutions (BRGM, CNES, INSU, IGN, IRD, SHOM, OMP, ESGT). A new partnership has been proposed with IFREMER, the French Institution in charge of the archiving and validation of marine gravity data collected by French research vessels. Another new partnership has been started with Bundesamt für Kartographie und Geodäsie (BKG), Germany for the realization and the maintenance of the Absolute Gravity database (Memorandum Of Understanding).

[1] "International Gravimetric Bureau: Project 2007-2011". Proposal submited to the IAG Commission, IUGG XXI General Assembly, Perugia, Italy, 2007, 42p.

[2] "Convention inter-organismes relative au fonctionnement du Bureau Gravimétrique International ", Déc. 2007, 9p.

The main proposed orientations of the 2007-2011 project are:

- to consolidate the terrestrial gravity databases (relative and absolute) and encourage the collection and compilation of new data sets,
- to initiate the set up of a global Absolute Gravity database,
- to ease the consultation and diffusion of gravity data and products for end-users, through a user friendly Internet Interface,

BGI will also continue operating with its supporting organizations, in Educational, Research and Development activities with the aim to maintain a high level of competence and to improve the efficiency and the quality of its services.

Activities related to gravity database

The main achievements consist in the relative gravity database and in the database of reference gravity stations. Collection of new dataset as well as existing dataset will be encouraged in order to improve the global data coverage and accuracy. Incoming datasets are carefully evaluated and validated using protocols and software already developed at BGI. Global data and products derived from satellite altimetry and gravity missions are to be more and more frequently used to validate land and sea measurements. The achievement of a worldwide Absolute gravity database will be top prioritized in the next few years.

Activities of diffusion of gravity data and products

New functionalities will be implemented to perform direct downloads of open-file data or products from the BGI webpage and allow inter-operability between other sites hosting gravity-related databases. BGI will also contribute to the release of updated digital gravity products (maps, grids…) for educational and research purposes.

Other activities

BGI will intensify his collaboration within IGFS with other services and research groups with the aim to contribute (i) to the preparation, validation and evaluation of new regional or global gravity models, (ii) to the dissemination of educative materials related to gravimetry and (iii) to teaching activities. It will follow the publication of the Newton's Bulletin jointly with the International Geoid Service (IGeS).

2.2 Initiation of a 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 (Ing. BKG - database developer). New functionalities have been implemented to fit with the requirements of BGI data compilation and archiving. The database is now accessible through the two mirrored sites at BGI (http://bgi.dtp.obs-mip.fr/agrav-meta/) and BKG http://agrav.bkg.bund.de/agrav-meta/).

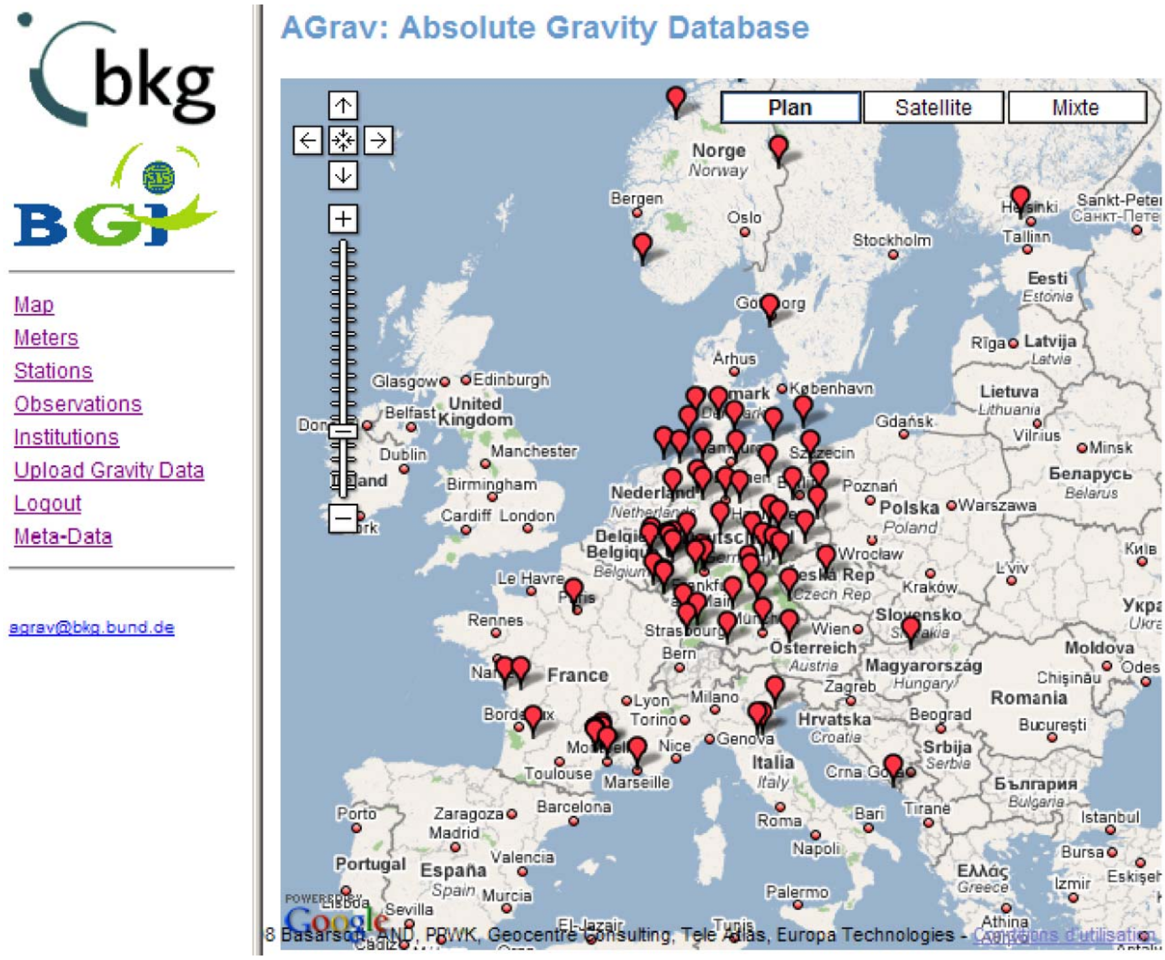

Fig 1: Internet Interface of the Absolute Gravity database (accessible from BGI website) (http://bgi.dtp.obs-mip.fr/agrav-meta/ - http://agrav.bkg.bund.de/agrav-meta/)

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. See communications and publications in the section "references" for more details.

2.3 Initiation of new Internet web site and new Internet services

A new BGI website has been defined in 2008. It is aimed to provide updated information about BGI services and to ease the access to database and to other information (data products, bibliography, software, etc.). The site is still under development and new functionalities will be also implemented to allow direct downloads of non-restricted data and to inter-operating the BGI databases with other regional or global databases. Harmonization of BGI website with those of IGFS and FAGS services has been taking into account.

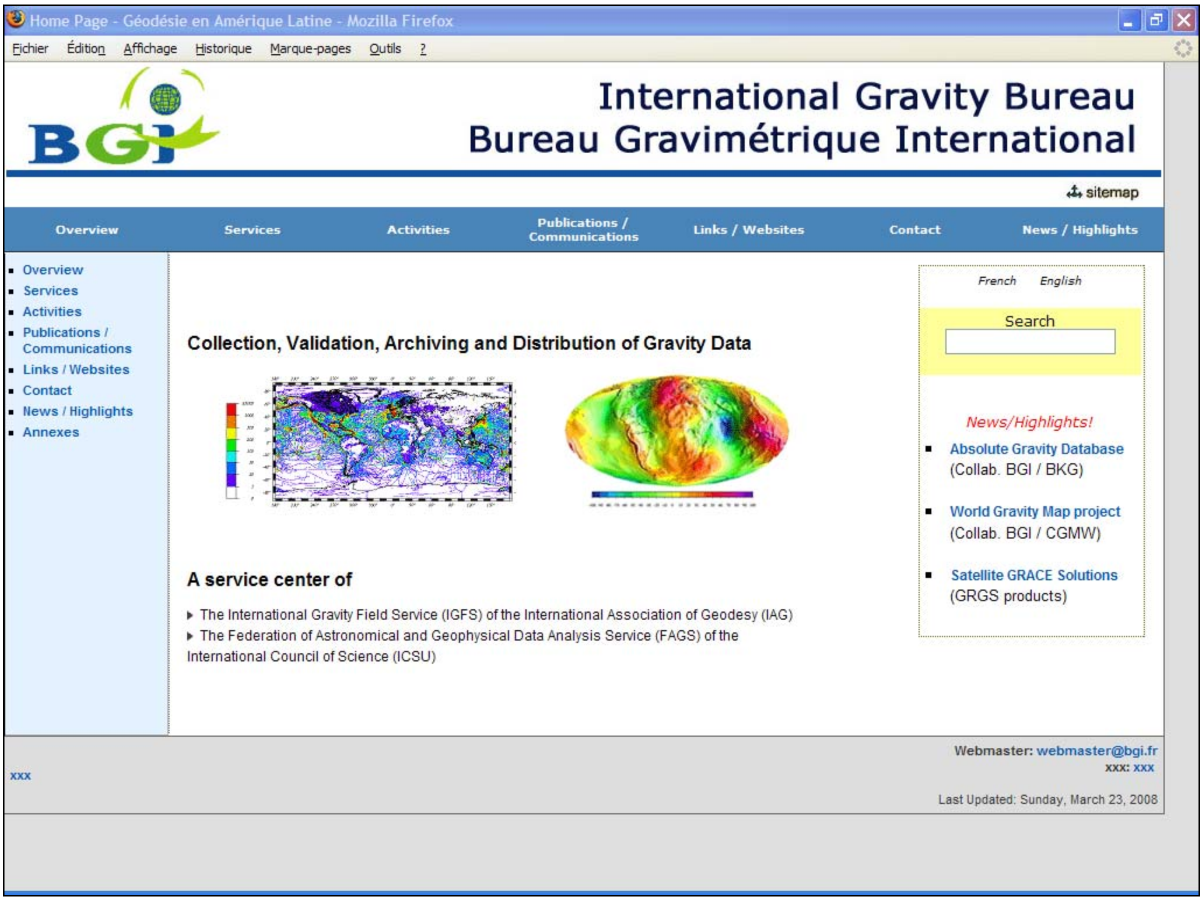

Fig. 2: BGI main webpage (http://www.geodesie.ird.fr/bgi/ - http://bgi.cnes.fr)

2.4 WGM (World Gravity Map) project

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, decided in 2007, 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 anomalies of the earth gravitational field 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.

The WGM project will consist in a 1/50000000 printed map and accompanying digital grids of gravity anomalies (including corrections for free air, Bouguer, terrain and atmospheric effects). The gravity data compilation will include the available measurements issued from land, marine and airborne surveys and archived in the BGI database as well as new gravity datasets collected from recent surveys or available in other global or regional databases. A new call for data collection has been launched by BGI in late 2007. It received a large amount of positive answer from companies and institutions that have collected gravity data.

The project will also benefits from recent improvements provided by the gravity and altimetry satellite missions on global or regional gravity models. Major potential contributions to WGM are provided by recently released global gravity models such as the new EGM08 model (Pavlis et al., 2008) computed by the National Geospatial-Intelligence Agency (NGA, USA) and available at 5'x5' resolution and the new satellite-derived marine gravity & bathymetry models (1'x1') realized by the Danish National Space Center, DTU- Denmark (DNS08 model) or by the Scripps Institution of Oceanography (Sandwell and Smith, 2009).

A complete Bouguer anomaly map has been computed in 2009. The spherical gravity terrain correction has been computed at the global scale using a new software developed at BGI (G. Balmino and G. Moreau).

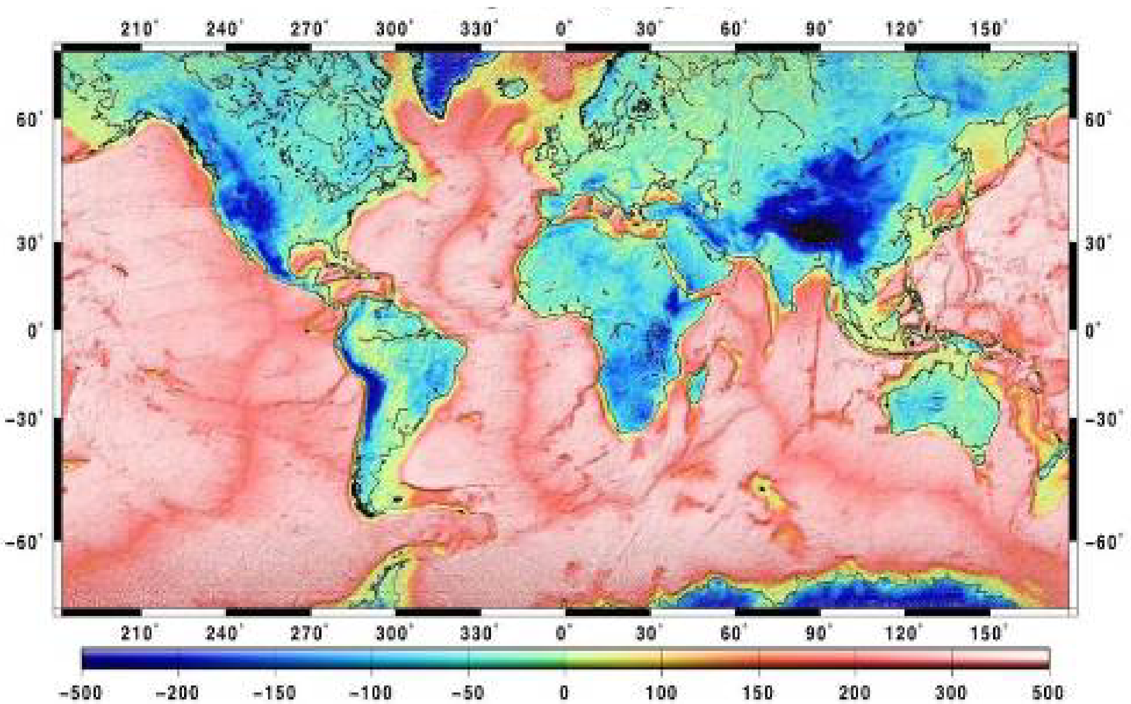

Fig. 3: Global complete Bouguer anomaly map

The WGM project and 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).

2.5 Other activities

Participation of BGI to IAG working groups & International meetings

- IAG International Symposium "Geodesy for Planet Earth" (Buenos Aires, Sept. 2009)
- EGU (European Union in Geosciences) General Assembly (Wien, April 2009)
- IGFS (International Gravity Field Service) / GGOS (Global Geodetic Observing System) Retreat (March 24-28, 2008. Bertinoro, Italy)
- FAGS (Federation of Astronomical and Geophysical Data Analysis Services) Annual Meeting (April 23-24, 2008. Paris, France)

- IAG International Symposium "Gravity, Geoid and Earth Observation - GGEO 2008" (23-27 June, 2008. Chania, Crete, Greece)
- 33th IGC (International Geological Congress) & CCGM General Assembly (Oslo, Norway, 6-14 August 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 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

Contributors in visit at BGI Central Bureau (Toulouse)

- A. Peyrefitte (Contract Ing. CNES-BRGM, France): contribution to WGM project – computation and comparison of global gravity terrain corrections (Sept. 2008 to Sept. 2009)
- G. Martelet (Researcher, BRGM, France): contribution to WGM project – computation and comparison of global gravity terrain corrections (Sept. 2008, June 2009)
- M. Abassi (Researcher, Iran): contribution to geoid computation and analysis using Gravsoft – Application to Ligure sea (summer 2007)
- M. Abassi (Researcher, Iran) - contribution to geoid computation and analysis using Gravsoft – Application to Ligure sea (summer 2008)
- H. Wziontek (BKG Germany) : Installation of Absolute Gravity Database on BGI server (Oct. 2007)

Software developments

- Software for computing spherical gravity terrain correction at global scale (by G. Balmino, G. Moreau)
- Software for validation of marine gravity data (by T. Fayard)

Participation to International Schools

- International Geoid School (La Plata, Argentina, Sept. 2009)
- International Geoid School (Come, Italy, Sept. 2008)

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 (CNES Ing.) in Oct. 2009. New entries on permanent positions are expected in 2009-2010.

BGI permanent staff (full or part time)

S. Bonvalot *Geophysicist*, *IRD France (Director)*

A. Briais *Marine Geophysicist*, *CNRS France (Deputy director)*

R. Biancale *Space geodesy*, *CNES France*

N. Lestieu *Secretary*, *CNRS France*

T. Fayard *Database manager / Software developer, CNES France*

B. Langellier *Database manager, IGN France (retired in March 2007)*

S. Pecquerie *Documentation / Information, CNRS France (retired in July 2008)*

M. Sarrailh *Database manager / Software developer*, *CNES France (retired in Dec . 2008)*

Others contributors (Central Bureau, Toulouse)

G. Balmino *Geodesist, CNES France (consultant)*

G. Moreaux *Geodesist, CLS France (contracted)*

G. Gabalda *Geophysicist, IRD France*

C. Luro *Webmaster, IRD France*

Publications 2007-2009

Publications

Bonvalot, S., Remy, D., Deplus C., Diament, M., Gabalda, G., 2008. Insights on the March 1998 eruption at Piton de la Fournaise volcano (La Réunion) from microgravity monitoring. *Journal of Geophysical Research*. doi: 10.1029/2007JB005084

Hinderer, J., C. de Linage, J.-P. Boy, P. Gegout, F. Masson, Y. Rogister, M. Amalvict, J. Pfeffer, F. Littel, B. Luck, R. Bayer, C. Champollion, P. Collard, N. Le Moigne, M. Diament, S. Deroussi, O. de Viron, R. Biancale, J.-M. Lemoine, S. Bonvalot, G. Gabalda, O. Bock, P. Genthon, M. Boucher, G. Favreau, L. Séguis, M. Descloitres, S. Galle. The GHYRAF (Gravity and Hydrology in Africa) experiment: description and first results. *Journal of Geodynamics* (in press)

Wilmes, H., Wziontek, H., Falk, R., Bonvalot, S. AGrav – the New International Absolute Gravity Database and a Proposed Cooperation with the Global Geodynamics Project (GGP). *Journal of Geodynamics* (in press).

Communications

2009

Bonvalot, S., A. Briais, R. Biancale, T. Fayard, G. Gabalda, N. Lestieu, C. Luro, A. Peyrefitte, M. Sarrailh. International Gravimetric Bureau (BGI): role, activities and projects. International Association of Geodesy, Scientific Assembly 2009, Buenos Aires, Argentina. Aug 31 – Sept 4, 2009.

Bonvalot, S., G. Gabalda, D. Remy, F. Bondoux J. Hinderer, B. Luck, D. Legrand, N. Lemoigne . Gravity changes and crustal deformation in north Chile: results from Absolute Gravity, GPS and InSAR observations.

International Association of Geodesy, Scientific Assembly 2009, Buenos Aires, Argentina. Aug 31 – Sept 4, 2009.

Briais, A., S. Bonvalot, A. Peyrefitte, G. Gabalda, G. Moreaux, M. Sarrailh, T. Fayard, R. Biancale. World Gravity Map (WGM) project: Objectives and Status. International Association of Geodesy, Scientific Assembly 2009, Buenos Aires, Argentina. Aug 31 – Sept 4, 2009.

Wilmes, H., H. Wziontek, R. Falk, J. Ihde, S. Bonvalot, Forsberg, L. Vitushkin. Working Group on Absolute Gravimetry. International Association of Geodesy, Scientific Assembly 2009, Buenos Aires, Argentina. Aug 31 – Sept 4, 2009.

Wziontek, H., H. Wilmes, S. Bonvalot. AGrav: An international database for absolute gravity measurements. International Association of Geodesy, Scientific Assembly 2009, Buenos Aires, Argentina. Aug 31 – Sept 4, 2009.

2008

Bonvalot, S. and BGI team. Annual meeting of FAGS (Federation of Astronomical and Geophysical Data Analysis Services). April 23-24, 2008. Paris, France.

Bonvalot, S. and BGI team. IGFS (International Gravity Field Service) / GGOS (Global Geodetic Observing System) Retreat. March 24-28, 2008. Bertinoro, Italy.

Bonvalot, S., Hinderer, J., Gabalda, G., Luck, B., Remy, D., Bondoux, F. Absolute gravity measurements along the Andean margin: A contribution to earthquake and volcano geodesy. 33th International Geological Congress, Oslo, Norway, 6-14 August 2008

Bonvalot, S., J. Hinderer, G. Gabalda, B. Luck, D. Remy, F. Bondoux. Temporal gravity changes and crustal deformation along the Andean margin: results from combined Absolute gravity, GPS and InSAR observations. IAG International Symposium. Gravity, Geoid and Earth Observation (GGEO 2008). 23-27 June, 2008. Chania, Crete, Greece.

Bonvalot, S., M. Sarrailh, A. Briais, R. Biancale T. Fayard, G. Gabalda. The World Gravity Map (WGM) project: objectives and status. IAG International Symposium. Gravity, Geoid and Earth Observation (GGEO 2008). 23-27 June, 2008. Chania, Crete, Greece.

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Briais, A., Bonvalot, S., Sarrailh, M., Biancale, R., Fayard, T., Gabalda G., and BGI, Team. The new world gravity map project: A tool for geodynamic studies. 33th International Geological Congress, Oslo, Norway, 6-14 August 2008

Briais, B., S. Bonvalot, M. Sarrailh, and the BGI Team. The new World Gravity Map project : a tool for geo-dynamic studies. IAG International Symposium. Gravity, Geoid and Earth Observation (GGEO 2008). 23-27 June, 2008. Chania, Crete, Greece.

Moreaux, G., G. Balmino, M. Sarrailh, S. Bonvalot, R. Biancale, A. Briais Computing gravity terrain corrections at global scale: An application for the World Gravity Map (WGM) project. IAG International Symposium. Gravity, Geoid and Earth Observation (GGEO 2008). 23-27 June, 2008. Chania, Crete, Greece.

Wziontek, H., H. Wilmes, J. Ihde, S. Bonvalot. AGrav: An international database for absolute gravity measure-ments. IAG International Symposium. Gravity, Geoid and Earth Observation (GGEO 2008). 23-27 June, 2008. Chania, Crete, Greece.

Wziontek, H., Falk, R., Wilmes, H., Bonvalot, S., 2008. AGrav – the New Absolute Gravity Database and a Proposed Cooperation with the GGP Project. *New Challenges in Earth's Dynamics – ETS2008*. Sept 1-5, 2008 – Jena, Germany.

Wziontek, H., Ihde, J., Wilmes, H., Bonvalot, S., An international database for absolute gravity measurements - a joint project of BKG and BGI. *EUG Meeting*, 13-18 April 2008, Vienna, Austria.

2007

Abbasi, M., Barriot, J-P., Sarrailh, M., Biancale, R., Bonvalot, S. AIRGRAV: a New Software for Processing of the Aerogravimetric Data. International Symposium on Terrestrial Gravimetry: Static and mobile measurements (TG-SMM 2007). 20-23 August 2007, St Petersburg, Russia.

Bonvalot S., Biancale R., Briais A., Sarrailh M. and BGI team. "World Gravity Map (WGM) project, Proposal, Dec 2007, 19p.

Bonvalot S. and BGI team. International Gravimetric Bureau: Project 2007-2011. Proposal submited to the IAG commission at the IUGG XXI General Assembly, Perugia, Italy, 2007, 42p.

De Linage, C., Hinderer, J., Boy, J-P. , Masson, F, Gegout, P., Diament, M., de Viron, O., Bayer, R, Balmino, G., Biancale, R, Bonvalot, S., Genthon, P. GHYRAF (Gravity and HYdrology in AFrica): a New Experiment Combining Hydrology and Geodesy to Investigate Water Storage Changes from the Sahara to the Equatorial Monsoon Zone. American Geophysical Union (AGU) Fall meeting, San Francisco. Geophysical Research Abstracts, 2007.

Hinderer, J., de Linage, C., Boy, J-P. , Gegout, P., Masson, F., Diament, M., de Viron, O., Bayer, R, Balmino, G., Biancale, R, Bonvalot, S., Genthon, P. GHYRAF (Gravity and HYdrology in AFrica): an experiment to validate GRACE in Africa from the Sahara to the Equatorial Monsoon Zone. American Geophysical Union (AGU) Fall meeting, San Francisco. Geophysical Research Abstracts, 2007.

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 IGFS was approved by IAG at the IUGG General Assembly in Sapporo 2003. 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*
- International Geoid Service (IGeS) – *director R. Bazargi, Italy*
- International Center for Earth Tides (ICET) – *director J. P. Barriot, Tahiti*
- International Center for Global Earth Model (ICGEM) – *director C. Kroner, Germany (t.b.c.)*
- International Digital Elevation Model Service (IDEMS) – *director P. Berry, UK*

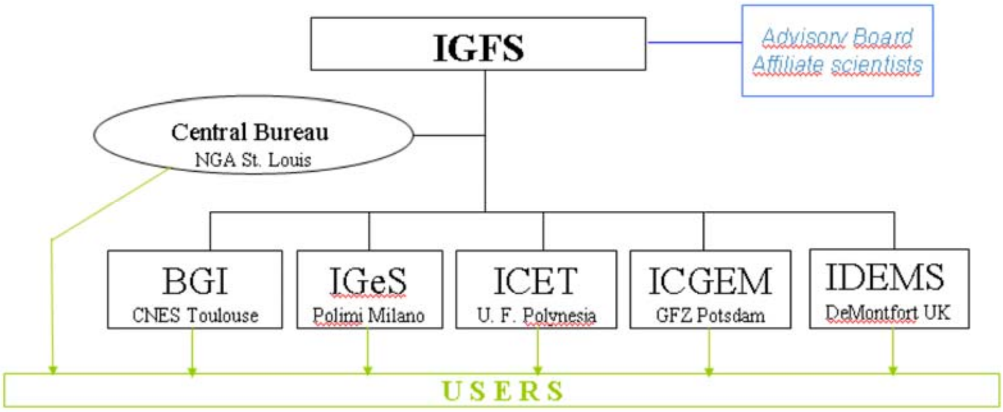
In addition the Geodesy and Geophysics Department at National Geospatial-Intelligence Agency (NGA, *chief geodesist S. Kenyon*), serve a special role as an IGFS Technical Center, interacting both with the IGFS services and directly with the scientific community, supplementing especially BGI and IGeS 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 2005-9 the IGFS has had two working groups:

- *Working Group on Absolute Gravimetry – H. Wilmes, BKG, Germany*
- *Working Group on Evaluation of Global Earth Gravity Models – J. Huang, NRCan, Canada*

The first working group was established in 2007 following the IGFS scientific assembly in Istanbul, 2006. The second – a joint group WG with the IAG Commission II – has just completed its work following the general release of EGM08.

Activities of the IGFS in the period 2007-09

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 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).



Other main activities carried 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 Copenhagen and Como (June 2006 and Sept 2008).

The IGFS is also represented in the GGOS and IERS directing boards.

Web sites of the IGFS services:

- BGI – http://bgi.cnes.fr
- IGeS – http://www.iges.polimi.it
- ICET – http://www.astro.oma.be/ICET
- ICGEM – http://icgem.gfz-potdam.de/ICGEM/ICGEM.html
- IDEMS - http://www.cse.dmu.ac.uk/EAPRS/iag/index.html

Meetings of the 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. This retreat was held immediately before the GGOS retreat at the same place.

During the Bertinoro IGFS Retreat the status and plans of the IGFS was reviewed, and it was decided that a Central Bureau is needed to get the necessary momentum in coordinating the Gravity Field activities. A roadmap laid out for a call for a Central Bureau. This call was issued in May 2009, with proposals due by July 15, 2009.

Potential lacking service elements in the portfolio of gravity field related services were also discussed and identified. These elements includes such items as future combination temporal gravity solutions (e.g., unified combination GRACE solutions between different centers) and the realization of a practical global vertical datum. There was also identified needs for more outreach material concerning the gravity field in general, as well as needs for concerted efforts to map the remaining continental and coastal regions of the earth with intermediate-wavelength gravity data, notably by airborne gravity projects.

Upcoming activities of the IGFS include the Central Bureau establishment (tentatively by Jan. 1, 2010), as well as the 2nd General Assembly of the IGFS, to be held in Fairbanks, Alaska, Sept. 2010 (t.b.c.).

International Laser Ranging Service (ILRS)

http://ilrs.gsfc.nasa.gov

Chair of the Governing Board: Werner Gurtner (Switzerland)
Director of the Central Bureau: Michael Pearlman (USA)

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 observable is the precise time-of-flight of an ultra-short laser pulse to and from a retro-reflector array on a satellite. The Service also produces analogous lunar ranging observations. These data sets are 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 requirements, and 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).

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 infor-

mation from the Operations and Regional Data Centres, and provide these data on-line to the Analysis Centres. They 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 CB has been actively providing new facilities to expedite communication and performance review, and adding to the technical and scientific database. The information available via the ILRS Web Site has grown enormously since its inception, and many new links to related organizations and sites have been established. The site provides 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 much more.

The Central Bureau maintains the ILRS Web site, *http://ilrs.gsfc.nasa.gov*, as the primary vehicle for the distribution of information within the ILRS community. Enhancements to the ILRS Web site continue. The ILRS station information pages were expanded to include various reports and plots to monitor network performance. 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 Web site, 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 October 2008 at the 16th International Workshop on Laser Ranging in Poznan Poland.

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 attracted 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, has been working with new satellite missions to seek ILRS approval for SLR observing support, if such support is deemed necessary for the success of the mission, and is within the operational capabilities of the network. The WG 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 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, has improved tracking on lower satellites and has removed the need for drag and special manoeuvre files as well as virtually all satellite time-bias corrections. The working group also designed and began implementing the Consolidated Laser Ranging Data format (CRD), which accommodates full rate, sampled engineering, and normal point data types for artificial satellite, lunar, and now transponder ranging data. The 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. The format was designed to be flexible and expandable and to incorporate additional statistical and configuration data unavailable in the earlier formats. Implementation and initial 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 due to satellite vulnerability.

Table 1. ILRS Governing Board (as of June 2009)

Zuheir Altamimi	Ex-Officio, President of IAG Commission	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
Werner Gurtner	Appointed, EUROLAS, Governing Board Chair	Switzerland
Giuseppe Bianco	Appointed, EUROLAS	Italy
David Carter	Appointed, NASA	USA
Jan McGarry	Appointed, NASA	USA
Yang Fumin	Appointed, WPLTN	China
Ramesh Govind	Appointed, WPLTN	Australia
Vincenza Luceri	Elected, Analysis Representative, Analysis Working Group Deputy Coordinator	Italy
Erricos C. Pavlis	Elected, Analysis Representative, Analysis Working Group Coordinator	USA
Wolfgang Seemüller	Elected, Data Centres Rep., Data Formats and Procedures WG Coordinator	Germany
Jürgen Mueller	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 retro-reflector arrays and is now working on Etalon.

The Analysis WG completed its pilot projects to assess, document and resolve differences among analysis products from the Analysis and Associate Analysis Centres. Eight centres have qualified as Analysis Centres; four additional centres have expressed interest in becoming Analysis Centres, two of them already in the qualifying process. A Combination Centre and a Backup Combination Centre have been in operation since 2004. The WG has developed and implemented the process to deliver LAGEOS derived site positions and EOP to the IERS as required on a weekly basis. A 1983-2008 reanalysis of the LAGEOS and LAGEOS 2 data was provided to the IERS in support of the development of ITRF2008. Work is underway to add additional official ILRS products including precision orbits and certified data corrections.

The Transponder Working Group has been involved in a number of activities in transponder and one-way ranging. Ground based hardware simulations for 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". The first time transfer experiment T2L2 is under way on the satellite Jason 2. 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 will improve the orbit calculations for the laser altimeter.

ILRS Network

Satellite Laser Ranging (SLR) Network

The present ILRS network includes forty stations in 23 countries (see Figure 1.) Stations designated as operational have met the minimum ILRS qualification for data quantity and quality. A dozen stations dominated the network with the Yarragadee, Mt Stromlo, Zimmerwald, and San Juan stations being the strongest performers. From start-up in 2005, the San Juan Station performance has been dramatic; in 2008 station performance has risen to second only to Yarragadee. There has also been noticeable improvement at Greenbelt, San Fernando, Concepcion, Mount Haleakala, Arequipa and Katzively. The improved orbital coverage over the Pacific region should have a very fundamental impact on our ILRS data products. The Arequipa stations and Mt Haleakala Stations were both rededicated in early 2007 with the NASA TLRS-3 and 4 SLR systems respectively; both are back in operation. In addition to San Juan, the rest of the Chinese SLR network continues its very strong support for the ILRS network. The Changchun station maintained its very strong performance, and data yield continues to improve at the new Shanghai station. The Chinese Mobile TROS system had its first session at the Korea Astronomy and Space Science Institute (KASI), Daejeon, Korea in mid-2008; the next session is scheduled for mid-2009. The Riyadh station continues to do well playing a vital role in the network as the only SLR station on the Arabian Peninsula. Data started flowing again from the Russian Stations, including the new station at Altay. The TIGO system in Concepción, Chile underwent substantial repairs in the 2005-6 time frame and is now performing very well, having reached full operational status in the network. SLR data are again flowing from the new MEO station at Grasse, France; the French Transportable Laser System (FTLRS) conducted a campaign in Burnie, Tasmania in 2008 to support altimeter calibration and validation for Jason. While there it supported the general ILRS requirements.

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 technology that will most likely become more prevalent in the network as time goes on. A 2 kHz laser has been added to the Herstmonceux station; several other stations have this upgrade underway.

A number of stations using the Stanford Counter have experienced timing (range) errors in some cases as large a centimetre. Calibration procedures have not been successful in addressing the problem and several of these stations have now gone to new epoch timing units – in particular the units now made by the University of Latvia. Additional stations have also moved the SPAD detectors.

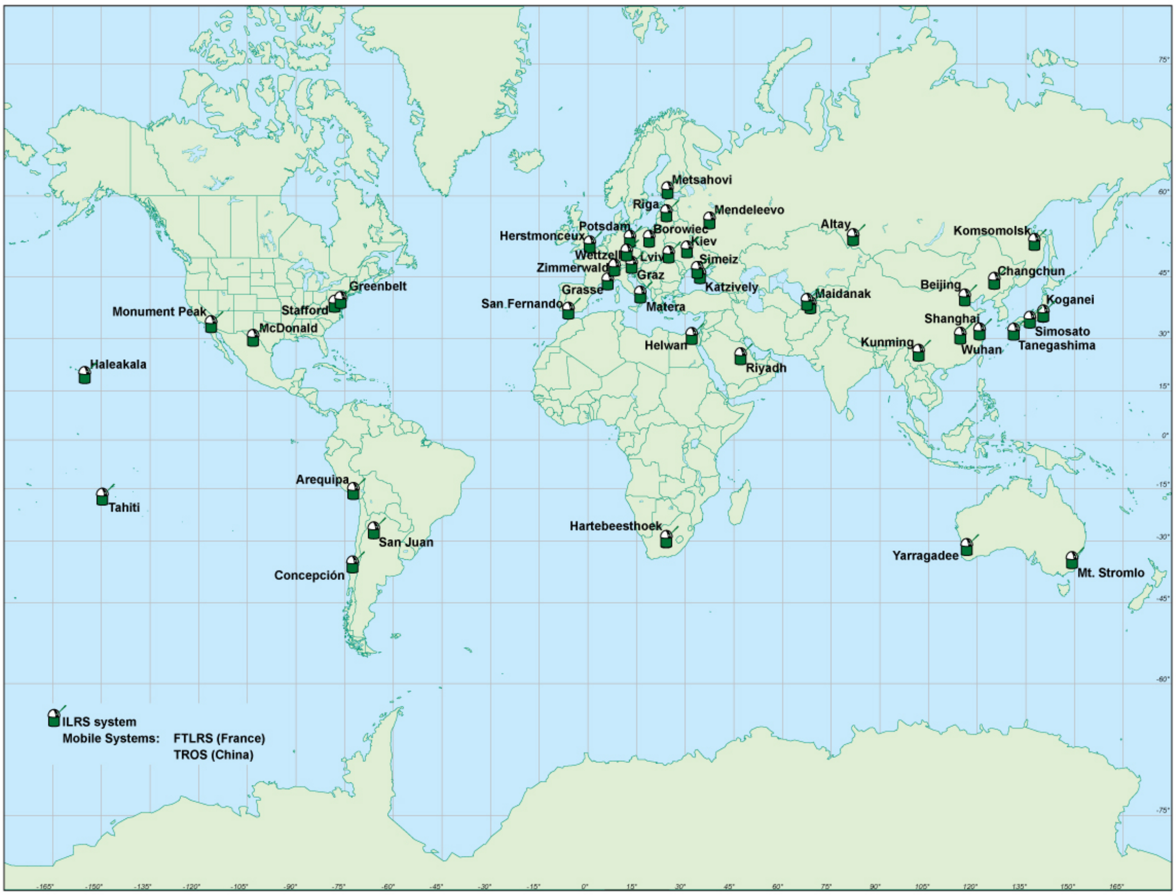


Figure 1. ILRS network (as of June 2009).

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). The LLR experiment has continuously provided range data for about 40 years, generating about 16300 normal points. The main benefit of this space geodetic technique is the determination of a host of 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 the strongest tool 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 (LLR) to retro-reflector arrays on the surface of the Moon (Figure 3). The McDonald Observatory in Texas, USA and Observatoire de la Côte d' Azur, France are the only currently operational LLR sites. The latter has undergone renovation since late 2004, and it is expected to imminently return to action in 2009. The McDonald observatory has major problems to get further LLR tracking funded. Thus no system upgrade could be made in the past years and at the end of 2009, even any financial support for lunar tracking will be cut down, so that lunar laser ranging is not possible anymore. A new site with lunar capability has been built at the Apache Point Observatory, New Mexico, USA, equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A new set of data from APOLLO was released in 2008 with an additional ~200 normal points, and a promise to soon make the data available in the newly adopted ILRS data format.

The Australian station at Mt. Stromlo is expected to join this group in the future, and there are plans for establishing lunar capability at the South African site of Hartebeesthoek, and at Wettzell observatory, Germany, once there are new telescopes installed. Also other modern stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station, Italy in 2005, but all of them suffer from funding restrictions or technical problems when upgrading their systems. Hopefully, further sites may provide lunar data on a routine basis in the near future.

Current LLR data are collected, archived and distributed under the auspices of ILRS. All former and current LLR data are electronically accessible through the EDC in Munich, Germany and the CDDIS in Greenbelt, Maryland.

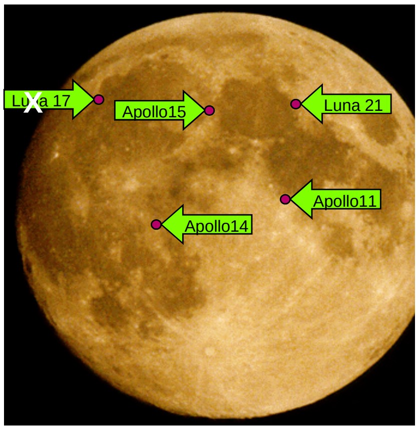


Figure 2. Retro-reflector sites on the Moon, Luna 17 has never been successfully tracked.

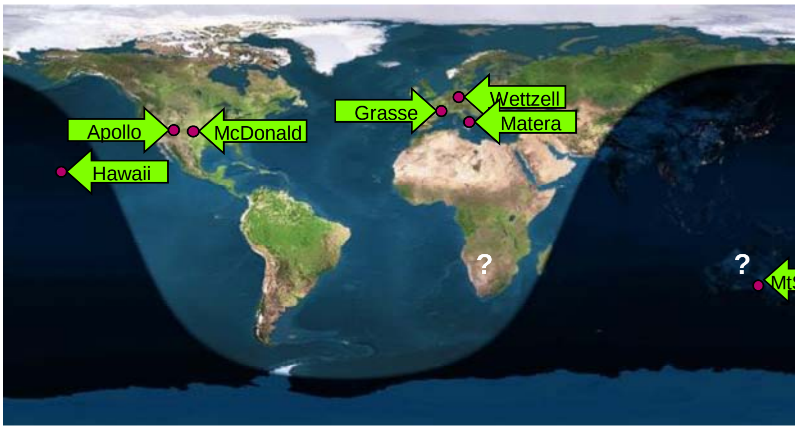


Figure 3. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future.

ILRS Tracking Priorities and Mission Support

The ILRS is currently tracking 28 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, stations have begun 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 June 2009)

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	CHAMP	GFZ	429-474	87.3	
4	TerraSAR-X	Infoterra/DLR/ GFZ/CSR	514	97.44	First priority for acquisition phase only
5	Envisat	ESA	796	98.6	Tandem with ERS-2
6	ERS-2	ESA	800	98.6	Tandem with Envisat
7	Jason-1	NASA/CNES	1,350	66.0	
9	Jason-2	NASA, CNES, Eumetsat, NOAA	1,336	66.0	Tandem with Jason-1
9	Larets	IPIE	691	98.2	
10	Starlette	CNES	815-1,100	49.8	
11	Stella	CNES	815	98.6	
12	Ajisai	NASDA	1,485	50	
13	LAGEOS-2	ASI/NASA	5625	52.6	
14	LAGEOS-1	NASA	5850	109.8	
15	Beacon-C	NASA	950-1,300	41	
16	GIOVE-B	ESA	23,916	56	
17	Etalon-1	Russian Federation	19,100	65.3	
18	Etalon-2	Russian Federation	19,100	65.2	
19	COMPASS-M1	China	21,500	55.5	
20	GLONASS-115	Russian Federation	19,100	65	Replaced GLONASS-99 on 03/31/2009
21	GLONASS-109	Russian Federation	19,100	65	Replaced GLONASS-95 on 05/28/2008
22	GLONASS-102	Russian Federation	19,100	65	Replaced GLONASS-89 on 05/04/2007
23	GPS-36	US DoD	20,100	55.0	
24	GIOVE-A	ESA	29,601	56	

Lunar Priorities			
Priority	**Retro-reflector Array**	**Sponsor**	**Altitude (km)**
1	Apollo 15	NASA	356,400
2	Apollo 11	NASA	356,400
3	Apollo 14	NASA	356,400
4	Luna 21	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 4). New missions added during this reporting period included: ETS-8, GIOVE-B, Jason -2 (with T2L2); COMPASS-M1, SOHLA-1, TerraSAR-X and GOCE. The network continued to support the GLONASS program: GLONASS 102 replaced GLONASS 89 in May 2007. GLONASS 109 replaced GLONASS 95 in March 2008, and GLONASS 115 replaced GLONASS 99 in April 2009. ETS-8 was the first ILRS target in synchronous orbit. In April the GPS receiver on Jason-1 failed and SLR became the primary means of POD. The ANDE satellites reentered in late 2007 and early 2008. The network was successful tracking down to 300 km and in some cases even below. The GFO-1 Mission ceased operating in November 2008. The radio systems aboard had failed several years prior and the SLR was the only means of POD for the altimeter. The SOHLA-1 and OICETS missions are tracked for short campaigns as requested.

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.

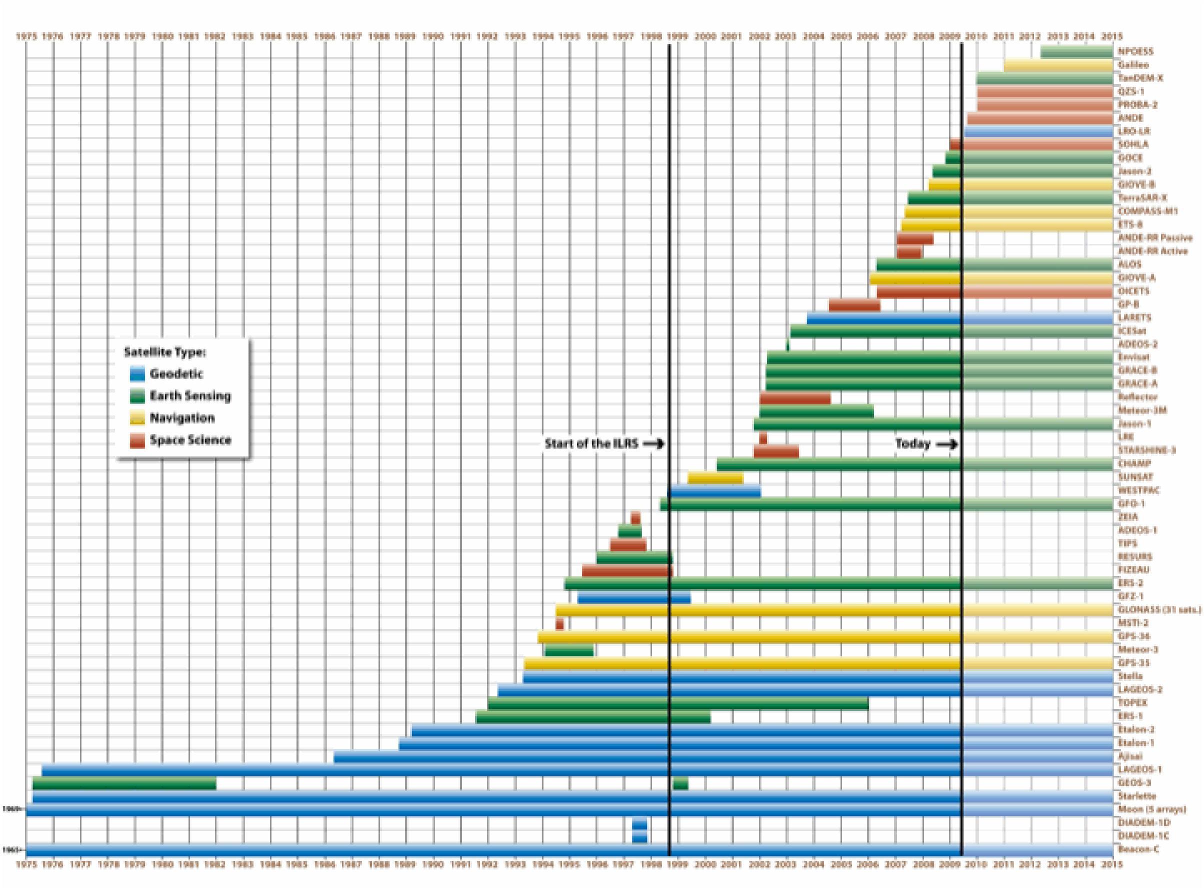


Figure 4. The past, current, and future tracking roster for the ILRS network.

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. The tracking approval process begins with the submission of a Missions

Support Request Form, which is accessible through the ILRS Web site. 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.

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 will be specifically targeted to prepare for and support future human exploration of the Moon. The LRO Laser Ranging (LR) system will use 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 center of the Moon (on the lunar near-side or whenever possible). The LR aspect of the mission will allow 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.

Table 3. Upcoming Missions (as of June 2009)

Mission	Sponsor	Planned Launch Date	Mission Duration (years)	Altitude (km)	Inclination (degrees)	Application
ANDE	NRL	Jul-2009	1-3	350	51.6°	Atmospheric modeling
BLITS	IPIE	Aug-2009	5	832	98.77°	Test of retro-reflector technology
PROBA-2	ESA	Dec-2009	2	721	98°	Technology validation
QZS-1	JAXA	2010	12	32K-40K	45°	
STSAT-1	KAIST	Mid-2009		390-1500	80°	Technology development and Earth brightness
TanDEM-X	DLR, GFZ, EADS, Astrium, InfoTerra	Mid-2009	5	514	97.44°	Digital elevation models
NPOESS	NOAA, NASA, DoD	2013	7	833	98.7°	Sea surface height

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 ITRF2000. 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 2003. This description refers to the status as of January 2009. 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
- 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 benchmark tests developed by the AWG. The official Primary Combination Centre (ASI) and the official Backup Combination Centre (DGFI) follow strict timelines for these routinely provided products.

In addition to operational products, solutions have been provided covering the period back to 1983. A current effort is underway to provide similar solutions on a daily basis, with a minimal 2-day delay, primarily to provide IERS' NEOS centre with robust EOP observations for their weekly forecasting. 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 contributing 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. Figures 5 and 6 show the origin and scale differences with respect to the old ITRF realization, ITRF2005 (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 between early 80's to present,

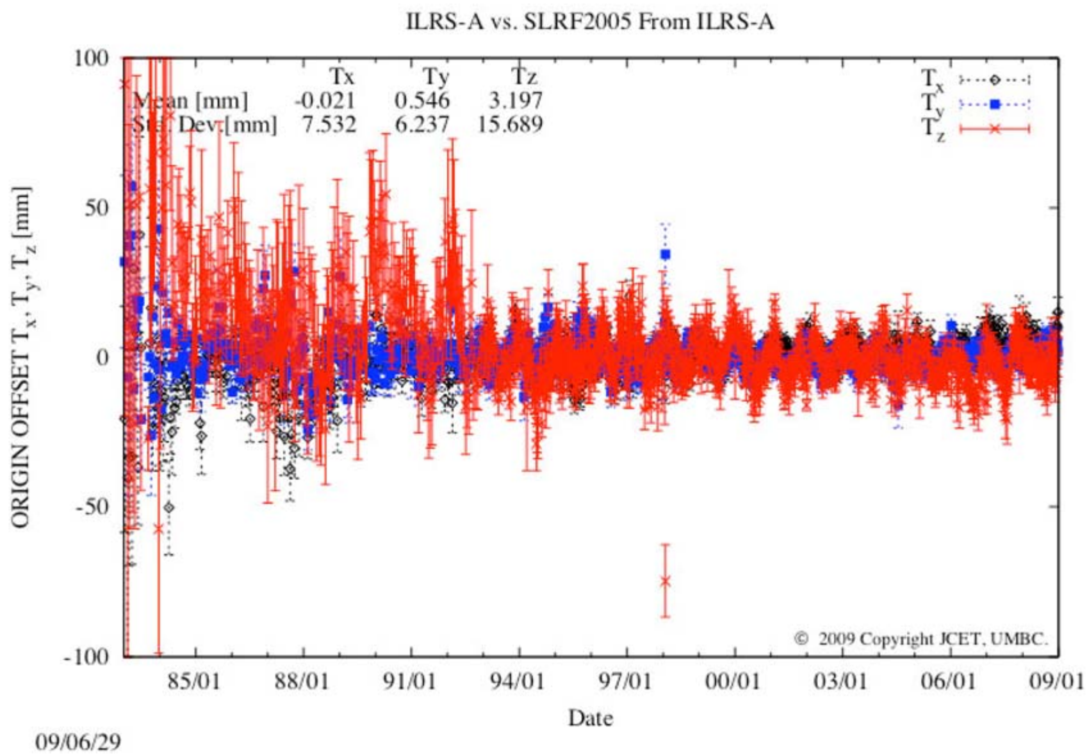


Figure 5. Origin offsets of the weekly product with respect to SLRF2005 (ITRF2005S): 1983-2009.

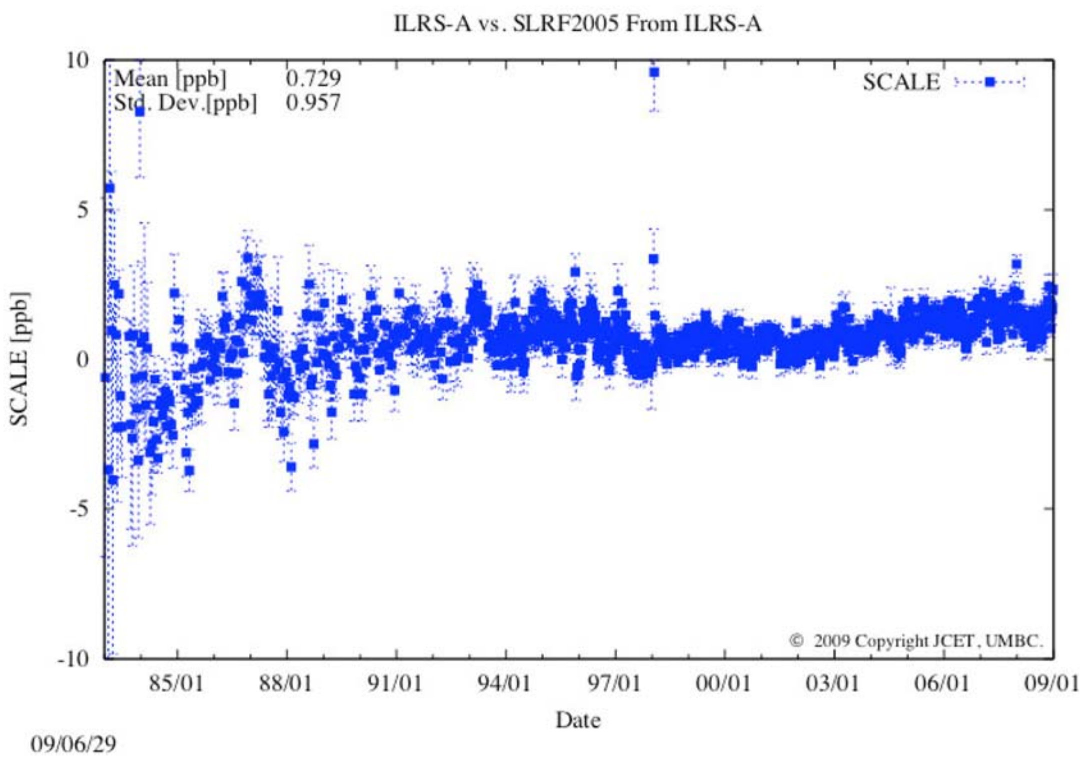


Figure 6. Scale difference of the weekly product with respect to SLRF2005 (ITRF2005S): 1983–2009.

These time series are essentially equivalent to the ones that have been generated operationally since after January 2007 and only differ from that in the applied tropospheric model (Marini-Murray for the old vs. Mendes-Pavlis for the new series) and the modeling of a range biases for a subset of stations. The latter have been the focus of extensive studies and comparisons with engineering tests and logs. After these extensive investigations it became apparent that even for the best sites some of the biases are best determined by analysis rather than engineering tests, and that was the route adopted for the establishment of a database with definite biases for all sites with known bias problems during specified periods. The entire bias database will be made public on the ILRS web pages and it will be maintained in the future for the benefit of all SLR data users. The description of the official contribution to ITRF2008 will be made available on the ILRS pages once the new model is finalized and adopted by ITRS.

The official ILRS Combination (ILRS-A)

ASI produces the official ILRSA combination solution and it is routinely compared with the backup combined solution ILRSB produced by DGFI 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 7);
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

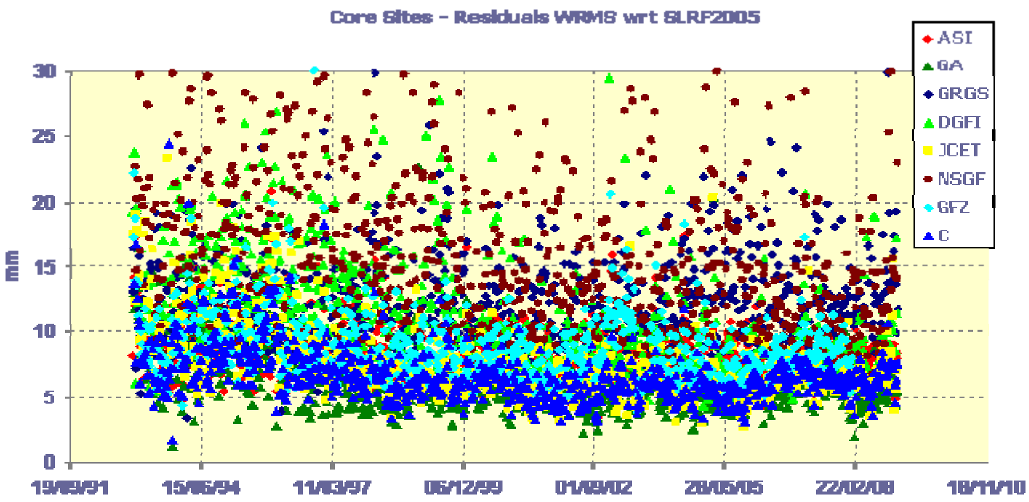


Figure 7. 3D wrms of the core site coordinates residuals with respect to SLRF2005.

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

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 web site hosted by the JCET AC at *http://geodesy.jcet.umbc.edu/ILRS_QCQA/ ILRS_OPS /.*

Meetings and Reports

The ILRS organizes semi-annual 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 Web site.

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 Web site.

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 Web site. 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, minutes of data) and RMS (LAGEOS, Starlette, calibration) are created from this information and available on the ILRS Web site. 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 Web site station pages.

Table 7. Recent ILRS Meetings (as of June 2009)

Timeframe	Location	Meeting
April 2008	Vienna, Austria	ILRS Working Group Meetings
		Analysis Working Group Meeting
October 2008	Poznan, Poland	16th International Workshop on Laser Ranging
		14th ILRS General Assembly and WG Meetings
		Analysis Working Group Meeting
		ILRS Working Group Meetings
April 2009	Vienna, Austria	ILRS Working Group Meetings
		Analysis Working Group Meeting
September 2009	Metsovo, Greece	ILRS Technical Workshop "SLR Tracking of GNSS Constellations"
		15th ILRS General Assembly and WG Meetings
		Analysis Working Group Meeting
		ILRS Working Group Meetings
January 2011	Concepcion, Chile	17th International Workshop on Laser Ranging

International VLBI Service for Geodesy and Astrometry (IVS)

http://ivscc.gsfc.nasa.gov

Chair of the Governing Board: Harald Schuh (Austria)
Director of the Coordinating Centre: 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 2007−2009. In March 2009 the IVS completed the first ten years of its existence. The 10th anniversary was celebrated in a special event in Bordeaux, France. A new Directing Board was elected in December 2008 / January 2009. The VLBI2010 Committee (V2C) submitted 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. A new TRF (VTRF2008) has been computed and is used for the IVS EOP determinations. The use of the ITRF2005 for this purpose has been discontinued due to a deficit partly caused by a pole tide error which was made in the IVS contribution to the ITRF2005. Combination Centres were established as new type of Analysis Centres; BKG/DGFI and KASI were approved as new Combination Centres.

Activities

Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) is an approved service of the International Association of Geodesy (IAG) since 1999, an approved service of the International Astronomical Union (IAU) since 2000, and a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) since 2001. 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 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 is a primary tool for understanding the global phenomena within the "System 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 orientation parameters, generates the basis for many applications and various research topics in the geosciences.

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 Directing Board elections were held in December 2008 / January 2009.

Table 0.1. Members of the IVS Directing Board during the report period (2007–2009).

a) ***Current Board members (June 2009)***

Directing Board Member	Institution, Country	Functions	Recent Term
Dirk Behrend	NVI, Inc./NASA GSFC, USA	Coordinating Center Director	—
Patrick Charlot	Bordeaux Observatory	IAU Representative	—
Andrey Finkelstein	Institute of Applied Astronomy, Russia	At Large Member	Feb 2009 − Feb 2011
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 2011
Ed Himwich	NVI, Inc./NASA GSFC, USA	Network Coordinator	—
Kerry Kingham	U.S. Naval Observatory, USA	Correlators and Operation Centers Representative	Feb 2007 − Feb 2011
Chopo Ma	NASA Goddard Space Flight Center, USA	IERS Representative	—
Ray Norris	CSIRO Australia Telescope Nacional Facility, Australia	FAGS Representative	—
Axel Nothnagel	University of Bonn, Germany	Analysis Coordinator	—
Harald Schuh	Technical University Vienna, Austria	IAG Representative, Chair	—
Kazuhiro Takashima	Geographical Survey Institute, Japan	At Large Member	Feb 2009 − Feb 2011
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	—
Xiuzhong Zhang	Shanghai Astronomical Observatory, China	At Large Member	Feb 2009 − Feb 2011

b) ***Previous Board members in 2007−2009***			
Yoshihiro Fukuzaki; Kazuhiro Takashima	Geographical Survey Institute, Japan	Networks Representative	Feb 2007 − Feb 2009
Arthur Niell	Haystack Observatory, USA	Analysis and Data Centers Representative	Feb 2005 − Feb 2009
Bill Petrachenko	Natural Resources Canada	Technology Development Centers Representative	Feb 2005 − Feb 2009

The IVS organizes bi-annual General Meetings and bi-annual 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 0.2 gives an overview of the recent IVS meetings.

Table 0.2. IVS meetings during the report period (2007-2009).

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

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.

Call for Combination Centres and Additional Analysis Centres

In June 2008 the IVS issued a call soliciting proposals for the installation and operation of IVS Combination Centres and additional Operational Analysis Centres and Associate Analysis Centres. Combination Centres are a new type of Analysis Centres that are tasked with preparing IVS combination products in cooperation with the Analysis Coordinator in a timely fashion. At its 20th meeting in Penticton, BC, Canada in September 2008, the IVS Directing Board approved the proposals from BKG/DGFI, Germany and from the Korea Astronomy & Space Science Institute (KASI) to become Combination Centres. DGFI changed from an Associate to an Operational Analysis Centre and Sternberg Astronomical Institute (SAI) of Moscow State University became a new Operational Analysis Centre.

Working Groups

At the 16th Directing Board meeting held in September 2006 at Haystack Observatory, a *joint IERS/IVS Working Group* was formed, whose aim it is 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 goal is to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I Working Group on the second realization of the ICRF for adoption at the 2009 IAU General Assembly. The ICRF, a catalogue of extragalactic radio sources and their positions, is a unique and fundamental product of the IVS. Since its adoption by the IAU effective 1 January 1998 these objects and positions have defined the axes in the sky to which all other celestial positions are now referred. The ICRF also provides the connection to the kinematically fixed inertial frame in which the variations of the Earth's orientation are measured. Only VLBI can monitor nutation/precession and UT1 because of its unique capability to connect terrestrial and celestial points.

At the 18th Directing Board meeting held in September 2007 at Bonn University, IVS *Working Group on VLBI Data Structures (WG4)* was formed. This working group 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.

At the 21st Directing Board meeting held in March 2009 at Bordeaux Observatory, two new working groups were created. The *Working Group on Space Science Applications (WG5)* will investigate synergies between IVS and VLBI space science applications, look for mutually beneficial collaborations, and eventually give recommendations for future actions. The *Working Group on VLBI Education and Training (WG6)* will explore educational activities, such as summer schools or training seminars, which will help in the formation of a new generation of VLBI experts. For both new working groups the charter and membership are currently being put together.

Observing Program and Special Campaigns

Observing Program

The observing program for 2007–2009 included the following sessions:

- EOP: Two rapid turnaround sessions each week, mostly with seven stations, some with six or eight 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, 2009) TRF sessions with 12–14 stations using all stations at least two times per year. Since 2008 the Japanese domestic VLBI stations of the GARNET (GSI Advanced Radio telescope NETwork) network (Aira, Chichijima, and Shintotsukawa) regularly participate in the TRF sessions.
- 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 where the number of sessions had to be reduced from 16–17 in 2007–2008 to six in 2009 due to the non-availability of Hartebeesthoek (South Africa). HartRAO suffered a major failure of a polar shaft bearing in October 2008 and is down for an undetermined time. A repair or replacement of the bearing or the provision of a substitute antenna is expected to take two years or longer.
- Monthly R&D sessions to investigate instrumental effects, research the network offset problem, and study ways for technique and product improvement.
- Tri-annual ~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 0.1). 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 geophysical signals, and technique improvement. The UT-day observation scheme will shed light on the question of whether the combination with the other geodetic space techniques (GPS, SLR, DORIS) improves with commensurate observation periods.

Figure 0.1: Geographical distribution of the eleven IVS stations that participated in the CONT08 campaign in August 2008.

Analysis

Earth Orientation Parameters

The official IVS Earth orientation parameter (EOP) series are produced and published routinely by the IVS Analysis Coordinator's office at the Institute of Geodesy and Geoinformation of the University of Bonn, Germany. 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 Centres 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.

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 $d\psi$, $d\varepsilon$ 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 Centres agrees to better than 60 microarcseconds, while the combined IVS polar motion results agree with the IGS pole at the 100−130 microarcsecond 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 Centre, 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, a model for the annual mean pole was used, which was not in agreement with the IERS Conventions 2003. Therefore, all analysis centres using CALC/SOLVE reprocessed their solutions 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 also affected by this oversight, though not to the full extent.

VTRF2008

In 2008, it became obvious that a new TRF for the IVS EOP determinations had to be computed for several reasons. ITRF2005, used in 2007 and 2008, has a noticeable deficit due to the pole tide error which had been made in the IVS contribution to ITRF2005. The post-quake movements of Gilmore Creek (Fairbanks, Alaska) in ITRF2005 lacked the continuity of the piece-wise linear elements, thus, introducing discontinuities. In addition, for the Russian sites of Svetloe, Zelenchukskaya, and Badary either only a limited number of observations or no observations at all were available for the computation of ITRF2005. This has changed and, of course, all other stations took their benefit from more data in the new computations as well.

A new TRF (VTRF2008) has been computed from the individual combined SINEX files of all geodetic VLBI sessions available. These have been pre-reduced for EOP so that only the coefficients for the site coordinate parameters remained. In a stacking process, these sets of normal equations have then been combined to a full TRF normal equation system for site positions and velocities. The subsequent inversion process provided the complete TRF including its variance-covariance information. VTRF2008 is being used for all combinations since December 2008.

Other IVS Products

In addition to the aforementioned products EOP, CRF, and TRF the IVS continued to provide tropospheric parameters as well as time series of baseline lengths on a regular basis. These two products were described in more detail in the IAG Travaux 2007. More information on these products and the previously mentioned products is available on the IVS Web site at the URL: http://ivscc.gsfc.nasa.gov/products-data/products.html.

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 modelling 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 get partly reduced. Consequently, Earth orientation parameters from VLBI observations may also be affected, mainly with an annual signature.

Technology Development

VLBI2010

The IVS VLBI2010 Committee (V2C) submitted a Progress Report on 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.

In addition to writing the Progress Report, the V2C was active in several face-to-face meetings (see e.g. Table 0.2) and numerous telecons. A very important meeting 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 the VLBI2010 system as well as its backward compatibility. 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.

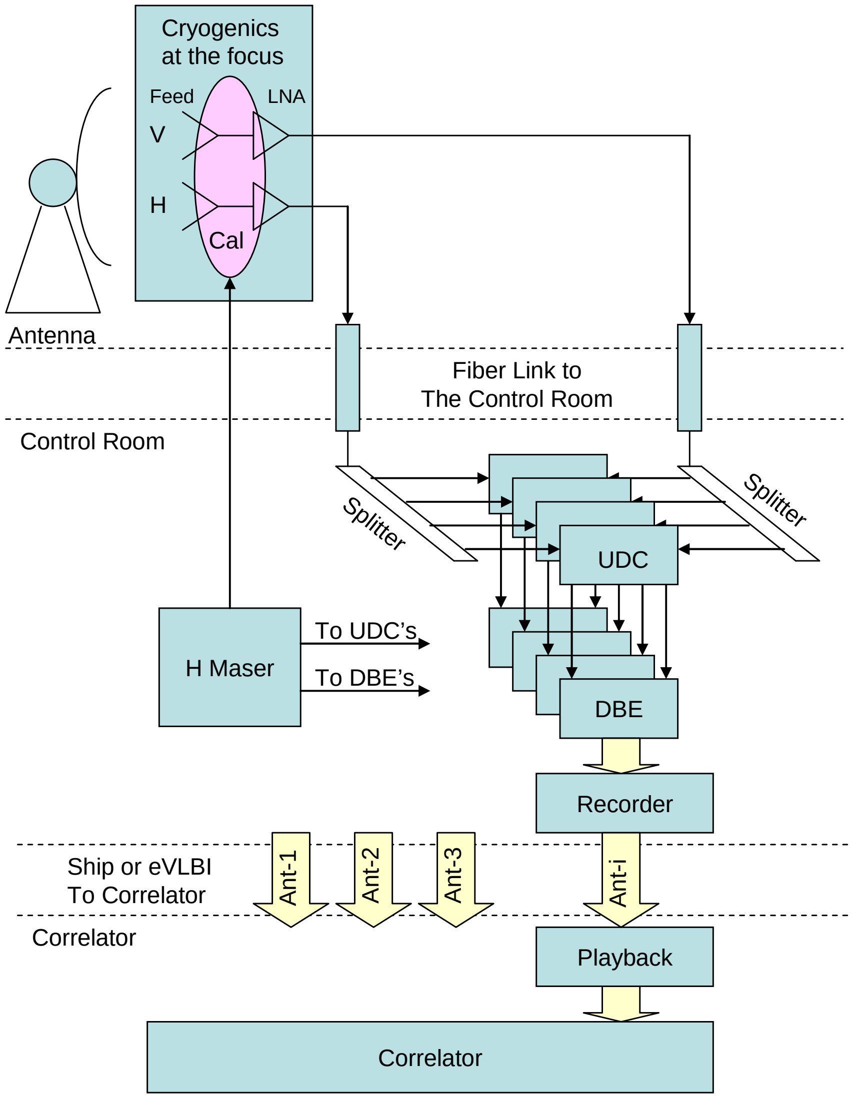


Figure 0.1: VLBI2010 block diagram. The architecture differs significantly from the existing geodetic VLBI systems. This is driven by the needs for short source-switching intervals, improved delay measurement precision, smaller drifts of the electronics, and improved automation and operational efficiency. 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.

It is foreseen that the VLBI2010 system will be fully defined by the end of 2010 and its capability demonstrated in the aforementioned campaign in 2012.

In order to provide strategic leadership for VLBI2010 and to give a face to the outside world for the project, a VLBI2010 Project Executive Group (V2PEG) was formed. The strategic tasks of V2PEG include developing time lines, transition plans, maintaining specifications and cost estimates, and promoting the expansion of the VLBI2010 network toward a global distribution. The V2PEG members are at a high level of recognition in the geodetic and astrometric community and thus are closer to the places where actual decisions are made, are more aware of the larger context of VLBI2010, and in general add credibility to outside interactions.

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.pol.ac.uk/psmsl

Director: Lesley J. Rickards (UK)

Overview

The Permanent Service for Mean Sea Level (PSMSL) is based at the 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 in 2008 PSMSL celebrated its 75th anniversary. To mark this milestone PSMSL organised two major symposia. The first was a session "Observations and Causes of Sea Level Change: A Session to Mark the 75th Anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the EGU 2008 General Assembly in Vienna in April, which attracted a large number of papers and posters, and the second at the British Association Science Festival in September. This latter meeting entitled "Liverpool, Home of Sea Level Science: Sea Level Rise and Climate Change" with distinguished speakers from the UK and abroad, was held in Liverpool, designated the European Capital of Culture for 2008. PSMSL also partially sponsored The Geological Society of London's William Smith meeting "Observations and Causes of Sea-Level Changes on Millennial to Decadal Timescales".

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 during 2007 and 2008 over 4000 station-years of data were entered into the PSMSL database, increasing the total PSMSL data holdings to over 57000 station-years. Although data receipts were a little below average in 2007, 2008 saw a large increase compared to the norm of recent 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 750 site years of high-frequency delayed-mode were received during the period June 2007 to April 2009.

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. In 2006 the PSMSL and POL took a major interest 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.

Subsequently, in December 2007, Dr. Philip Woodworth attended a ceremony at Inmarsat headquarters in London which included the signing of an agreement between the Intergovernmental Oceanographic Commission (IOC) and Inmarsat for the use of the BGAN system in the Indian Ocean Tsunami Warning System (IOTWS). BGAN allows return of real-time data from almost anywhere on earth and thus has the potential to improve the speed of tsunami warnings and to save lives. The value of this has been recognised with two awards: the prestigious Denny Medal from the Institute of Marine Engineering, Science and Technology (IMarEst) and a "Highly Commended" award from the UK Institution of Engineering and Technology, Innovation Awards 2009 (North West).

Activities

1. Introduction

The Permanent Service for Mean Sea Level (PSMSL) is based at the 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 has been formed, with Dr. Philip Woodworth, the previous PSMSL Director and FAGS Secretary, as a member. Dr. Lesley Rickards will be a member of the newly formed World Data System Scientific Committee. However, as far as PSMSL is concerned, there should be little change in function.

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, the PSMSL organised two major symposia. The first was a session "Observations and Causes of Sea Level Change: A Session to Mark the 75th Anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the EGU 2008 conference in Vienna in April, which attracted a large number of papers and posters, and the second at the British Association Science Festival in September. This latter meeting entitled "Liverpool, Home of Sea Level Science: Sea Level Rise and Climate Change" with distinguished speakers from the UK and abroad, was held in Liverpool, designated the European Capital of Culture for 2008. In addition, PSMSL partially sponsored The Geological Society of London's William Smith meeting "Observations and Causes of Sea-Level Changes on Millennial to Decadal Timescales".

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 (the parent body of POL); 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 (both at Liverpool and both delayed-mode, although technically one within POL and one within BODC). The proposal was graded as 'alpha-5', the highest possible, which provided a clear way forward.

3. PSMSL Data Receipts for 2007 and 2008

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 during 2007 and 2008 over 4000 station-years of data were entered into the PSMSL database, increasing the total PSMSL data holdings to over 57000 station-years. Although data receipts were a little below average in 2007, 2008 saw a large increase compared to the norm of recent years. Most data originated from Europe and North America. However, large data sets were also obtained from Asia, Australasia and southern Africa (see Figures 1a and 1b). Major gaps in data receipts persist in other parts of Africa which are receiving special attention through ODINAFRICA (see section 4.4 below).

The figures 2 (a) and (b) below show (a) the all of the stations that have contributed to the PSMSL and (b) the year of the most recent data received from each site.

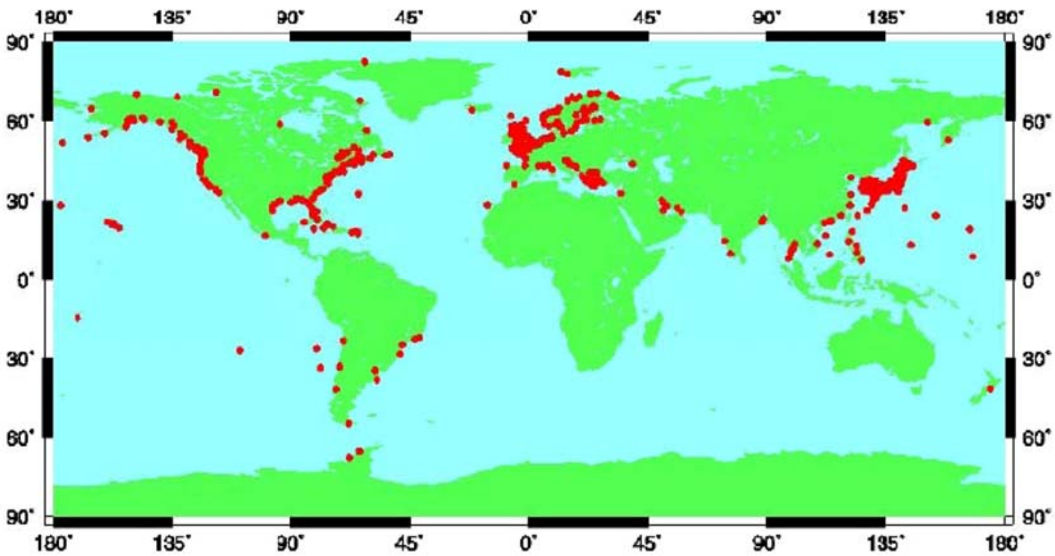

Figure 1a: New PSMSL data for 2007

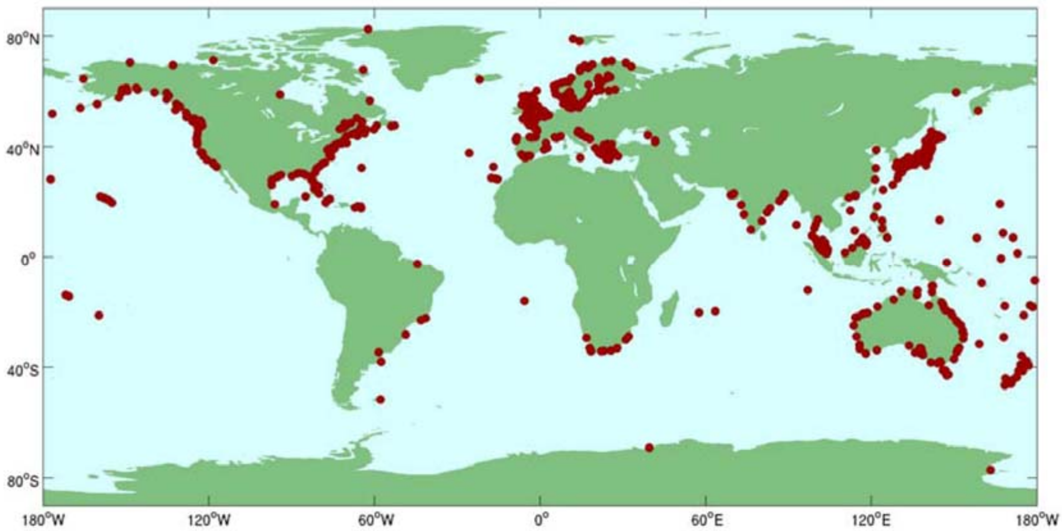

Figure 1b: New PSMSL data for 2008

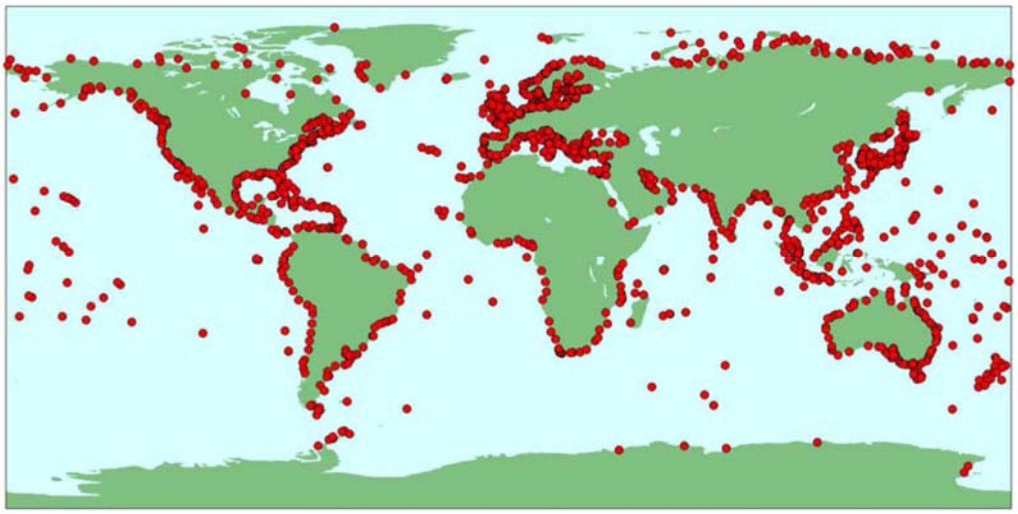

Figure 2a: Stations providing data to PSMSL

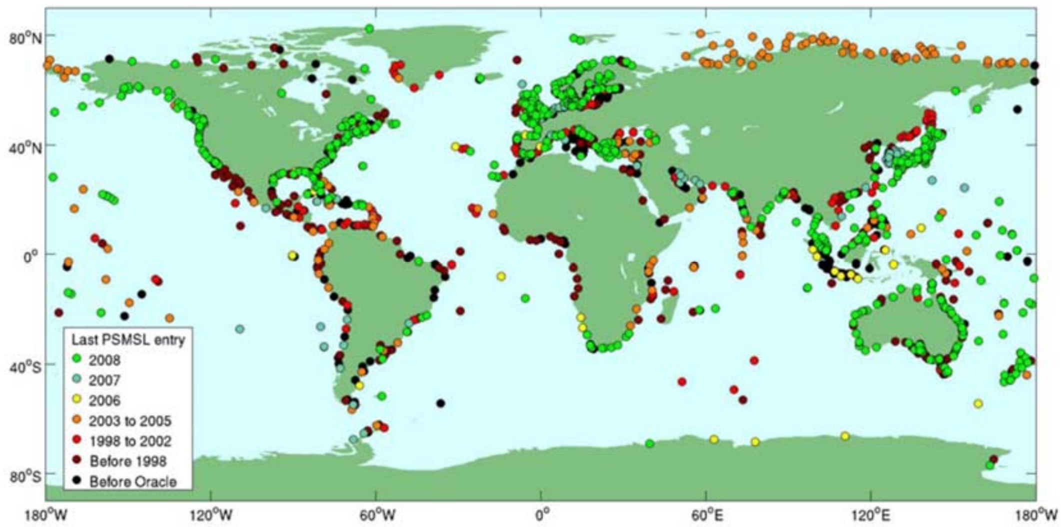

Figure 2b: Year of most recent data received by PSMSL

4. Delayed Mode High Frequency (DM HF) Data Receipts for 2007-2009

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 750 site years of high-frequency delayed-mode were received during the period June 2007- April 2009, adding to the 5000 site years already held.

Once again data have been received from important data sparse regions. Six gauges that form part of the ODINAFRICA network have supplied over a year's worth of quality controlled data. 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, and 2008 been the latest year supplied.

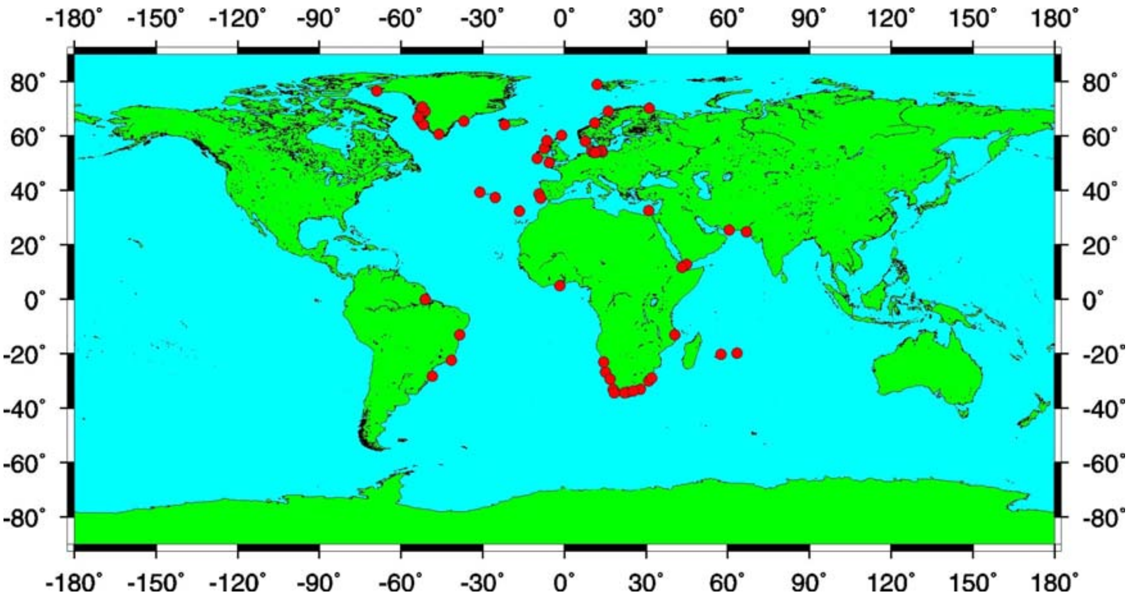

Figure 3: New DM HF Data received from mid-2007 to mid-2009

5. GLOSS Activities

5.1 New GLOSS and PSMSL Web Sites

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 GLOS 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.

The current PSMSL web site (www.pol.ac.uk/psmsl) was launched in 2007 with a revised home page and the addition of a section with commentaries on the interpretation of long sea level records. Plans are now underway for a completely redesigned PSMSL web-site a new structure and simpler navigation with improved data delivery.

5.2 GLOSS Status from a PSMSL Viewpoint (October 2008)

For a number of years, the PSMSL has provided an annual summary of the status of the GLOSS Core Network (GCN) from its viewpoint. A review of its status as of October 2008 can be found at the above GLOSS web-site. 2007 showed a modestly improvement compared to that a year ago, but 2008 showed a decrease in the Category 1 stations which needs to be addressed. 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.

5.3 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.

5.4 New GLOSS and ODINAFRICA Tide Gauges

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. Currently eleven tide gauges have been installed in Africa and the Indian Ocean. These are: Aden (Yemen), Chabahar (Iran), Djibouti (Djibouti), Karachi (Pakistan), Inhambane (Mozambique), Lagos (Nigeria), Nouakchott (Mauritania), Pemba (Mozambique), Pointe Noire (Republic of Congo), Port Sonara (Cameroon) and Takoradi (Ghana). Eight 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. PSMSL is moving towards devising effective methods for maintenance and assurance of data flow from the newly installed sites. A new data logger and replacement batteries have been dispatched and should resolve the problems at the two sites. Delayed-mode quality controlled 15 minute data with documentation are available for download from the GLOSS web-site from Aden, Chabahar, Djibouti, Karachi, Pemba and Takoradi. Inhambane and Nouakchott will be added soon.

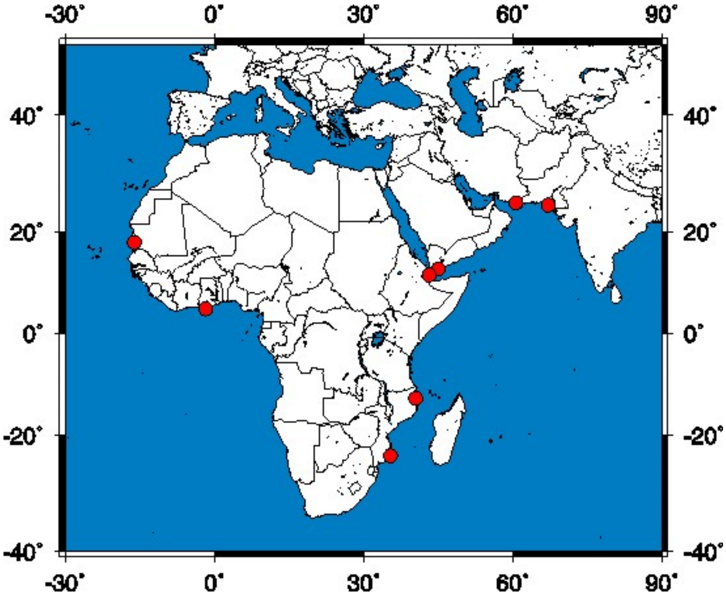

Figure 4: African and Indian Ocean tide gauges on the GLOSS web-site

6. 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.

Over the last few years the PSMSL and POL have taken a major interest 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. Work carried out has been described in the sections above. 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.

The usefulness of this has been recognised as four PSMSL and POL scientists (Simon Holgate, Peter Foden, Jeff Pugh and Philip Woodworth) were awarded the prestigious Denny Medal from the Institute of Marine Engineering, Science and Technology (IMarEst) for their

Meetings and Annual Reports

IAG Annual Report to IUGG 2007.pdf

IAG Annual Report to IUGG 2008.pdf

Meeting Summary 1st IAG EC 2007-2011 (Perugia, July 10, 2007).pdf

Meeting Summary 2nd IAG EC 2007-2011 (San Francisco, Dec. 8, 2007).pdf

Meeting Summary 3rd IAG EC 2007-2011 (Vienna, Apr. 19, 2008).pdf

Meeting Summary 4th IAG EC 2007-2011 (San Francisco, Dec. 14, 2008).pdf