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INTERNATIONAL ASSOCIATION OF GEODESY - TRAVAUX 2007

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International Association of Geodesy (IAG)

Report of IAG Commission 1 “Reference Frames” for the period 2003 - 2007

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Munich, June 2007

Preface

The present volume of the IAG Commission 1 Bulletins contains the final report on the activities of Commission 1 "Reference Frames" from its establishment in the frame of the new IAG structure in July 2003 to the end of the first legislature period in mid 2007. The presidents and chair persons of the Sub-commissions, Projects, Study Groups and Working Groups, respectively, present a summary of the research work done during these four years and the main results achieved.

The establishment of the Commission within the new IAG structure and in the environment of the IAG services was a great challenge for all officers. The particularities of basic research to be done in the commissions and its differentiation with respect to the investigations and developments in the services had to be sounded out and characterized by specific themes, topics, projects and studies. The principal guiding idea was to dedicate the commission's work to research free of enforcements by product generation requirements, and governed only by the systematic search for improved scientific knowledge.

There was a very good cooperation among all persons involved in Commission 1 throughout the complete legislature period. We thank in particular all the Commission's officers and associated scientists for their successful work during the past four years. But we also acknowledge the valuable contribution of all people behind the lead persons, which are not visible in general, but are essential for the prosperity. We wish the Commission all the best for the next period.

Munich, June 2007

Hermann Drewes
President
IAG Commission 1 – Reference Frames

IAG Commission 1
Reference Frames

Report for the Period 2003 – 2007

HERMANN DREWES

Introduction

The International Association of Geodesy (IAG) implemented a new structure at the XXIII General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Sapporo, Japan, July 2003 (Beutler 2004). The structure comprises Commissions, Services, Inter-commission Committees, IAG Projects, and the Communication and Outreach Branch. Commission 1 deals with research related to geometric reference systems. The principal objectives are determined by the Terms of Reference (ibid., pp. 607-626):

- Definition, establishment, maintenance, and improvement of geodetic reference frames;
- Advanced development of terrestrial and space geodetic observation techniques for this purpose;
- Analysis and processing methods for parameter estimation related to reference frames;
- Theory and coordination of astrometric observations for reference frame purposes.

Commission 1 integrates and continues to some extend the scientific work of the previous IAG Commissions VIII "International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)" and X "Global and Regional Geodetic Networks" which were discontinued in 2003 with the establishment of the new IAG structure. In this sense, Commission 1 continues as the Sub-commission B2 "CSTG" of the ICSU Committee on Space Research (COSPAR).

The commission's research focuses primarily on basic research, i.e., foundations of reference systems, optimal use of geodetic observations and methodology for the realization of reference frames, estimation theory. The application of research results, in particular the realization of reference systems in terms of reference frames, is done in close cooperation with the IAG Services relevant for geometric reference systems. These are in particular the

- International Earth Rotation and Reference Systems Service (IERS),
- International GNSS Service (IGS),
- International Laser Ranging Service (ILRS),
- International VLBI Service for Geodesy and Astrometry (IVS),
- International DORIS Service (IDS).

Structure of Commission 1

The Commission is structured into four Sub-Commissions (SC), two Inter-Commission Projects (IC-P), two Inter-Commission Study Groups (IC-SG), and three Inter-Commission Working Groups (IC-WG):

President: Hermann Drewes (Germany)
Vice-President: C.K. Shum (USA)

SC1.1	Coordination of Space Techniques (President: M. Rothacher, Germany)
SC1.2	Global Reference Frames (President: C. Boucher, France)
SC1.3	Regional Reference Frames (President: Z. Altamimi, France)
SC1.3a	Europe (Chair: J.A. Torres, Portugal)
SC1.3b	South and Central America (Chair: L.P. Fortes, Brazil)
SC1.3c	North America (Chairs: M.Craymer, Canada, R. Snay, USA)
SC1.3d	Africa (Chair: R. Wonnacott, South Africa)
SC1.3e	Asia-Pacific (Chair: J. Manning, Australia)
SC1.3f	Antarctica (Chair: R. Dietrich, Germany)
SC1.4	Interaction of Celestial and Terrestrial Reference Frames (President: H. Schuh, Austria)
IC-P1.1	Satellite Altimetry (jointly with Commissions 2 and 3, Chair: W. Bosch, Germany)
IC-P1.2	Vertical Reference Frames (jointly with Commission 2, Chair: J. Ihde, Germany)
IC-SG1.1	Ionosphere Modelling and Analysis (jointly with Commission 4 and COSPAR, Chair: M. Schmidt, Germany)
IC-SG1.2	Use of GNSS for Reference Frames (jointly with Commission 4 and IGS, Chair: R. Weber, Austria)
IC-WG1:	Quality measures, quality control, and quality improvement (jointly with ICC on Theory, Chair: H. Kutterer, Germany)
IC-WG2:	Integrated Theory for Crustal Deformation (jointly with Commission 3 and ICCT, Chair: K. Heki, Japan)
IC-WG3:	Satellite Gravity Theory (jointly with Comm. 2 and ICCT, Chair: N. Sneeuw, Germany)

For specific research themes, there are Working Groups established within the sub-commissions. While the Sub-Commissions are designed for a longer time of activity, Projects, Study Groups, and Working Groups may be discontinued after some years period.

According to the IAG Bylaws, a Commission Steering Committee is responsible for maintaining the activities. It is composed in Commission 1 by the

President:	H. Drewes
Vice President:	C.K. Shum
President SC1.1:	M. Rothacher
President SC1.2:	C. Boucher
President SC1.3:	Z. Altamini
President SC1.4:	H. Schuh
Services' representatives:	W. Gurtner, C. Ma, J. Ries
Members at large:	J. Manning, R. Wonnacott

Main Commission Activities 2003-2007

The first meeting of the Commission Steering Committee was held immediately after the establishment of the Commission in Sapporo, Japan, 7 July 2003. Six Steering Committee members were present. As the meeting was declared an open Commission 1 session, also five of the other officers and several guests participated (see annex). The main point of discussion was the set-up of the Commission's structure, the Terms of Reference, and the objectives of the individual entities (Sub-Commissions, Projects, Study Groups, Working Groups). A major topic was the link to and the cooperation with the IAG Services and other scientific bodies (e.g., IUGG, IAU, COSPAR).

The second Steering Committee meeting took place during the General Assembly of the European Geoscience Union (EGU) in Nice, France, 28 April 2004. It was again held as an open session with a total of 24 participants, 9 of them members of the Steering Committee and 7 other Commission 1 officers. There were detailed reports and discussions on the initiated work of the Sub-Commissions, Projects, and Study Groups. The planned activities of the Commission in the IAG Project "Global Geodetic Observing System (GGOS)" and within COSPAR were drafted. It was agreed to continue the former CSTG Bulletin as the Commission 1 Bulletin for presentation of the research work.

The third Steering Committee meeting was held again as an open session during the IAG Scientific Assembly, Cairns, Australia, 23 August, 2005. It was attended by 20 participants in total, 5 of them Steering Committee members and 10 Commission officers. Main topics were reports on IAG and COSPAR developments, the installation of the new Inter-commission Project 3.2 (Working Group of European Geoscientists for the Establishment of Networks for Earth-science Research, WEGENER), the changes of the Chair of ICP1.1 (M. Schmidt replacing C. Brunini) and of Sub-commission 1.4 (H. Schuh replacing S. Y. Zhu), and the reports of the Commission 1 entities (Sub-commissions, Projects, Study Groups and Working Groups). The Commission 1 Bulletin No. 19 (Mid-term report of the Commission) was released.

The fourth Steering Committee meeting took place during the Commission 1 Symposium (see below) in Munich, Germany, 10 October 2006. There were 12 participants, among them 7 Steering Committee members and 3 other Commission officers. Discussed topics included reports on international meetings relevant for Commission 1 (IERS, IGFS, IGS, ILRS, IVS, ICCT, GGOS), the upcoming elections of new IAG officers, and the preparation of the IUGG General Assembly, Perugia 2007. Report were given from the Commissions officers (Sub-commissions, Projects, Study Groups) and the Local Organizing Committee of the GRF2006 Symposium.

Officers of Commission 1 participated in many meetings of other IAG bodies, in particular the Services IERS, IDS, IGS, ILRS, IVS, and IAG's Global Geodetic Observing System (GGOS). There was also a strong link to other Unions and Associations such as ICSU (mainly COSPAR and ILP), IAU, IUGS, and to the United Nations' Office of Outer Space Affairs (UN OOSA) and the United Nations' Cartographic Conferences (UN CC).

From 9 to 14 October 2006, the Commission organized in Munich, Germany the IAG Symposium "Geodetic Reference Frames (GRF2006)". The topics included all the objectives of the Commission which were discussed in 16 oral and 3 poster sessions, each 1.5 hours in length. Three of the sessions were held during one common day together with the XXIII Congress of the Fédération Internationale des Géomètres (FIG) and the German INTERGEO Congress under the themes "Global Change", "Positioning Forum", and "Geodesy Forum". An opening and a closing session completed the programme. A total of 166 scientists from 31 countries participated in the GRF2006 Symposium giving 72 oral and 42 poster presentations. The symposium proceedings will be published in the IAG Symposia series at Springer.

Figure 1: Logos of the Commission 1 Symposium 2006

Highlights of the Research of Commissions, Projects, Study Groups and Working Groups

The extensive and very successful work of the Sub-Commissions, Projects, Study Groups and Working Groups is presented in detail in the individual chapters of the Commission 1 report and/or in the reports of the corresponding Commissions and the Inter-commission Committee, respectively. Some excellent results shall be highlighted here briefly.

Sub-Commission 1.1 "Coordination of Space Techniques" studied in particular the effects influencing different space techniques, e.g., caused by the satellite orbits or by the atmosphere. Based on the results, new combination methodologies of the different observation types were developed. This was done in close cooperation with the IAG Services, in particular the IERS Combination Research Centres. Several scientists were active in both, Sub-Commission 1.1 and in the services; the SC1.1 President is likewise IERS Analysis Coordinator. Many activities (pilot projects and studies) were initiated together with the IERS.

Sub-Commission 1.2 "Global Reference Frames" worked closely together with the IERS Product Centre for the International Terrestrial Reference Frame (ITRF) and the ITRS Combination Centres at IGN, Paris, and DGFI Munich. A highlight was the computation of the International Terrestrial Reference Frame 2005 (ITRF2005) which was derived for the first time from epoch time series (weekly or session-wise, respectively) provided as combined solutions from the respective services and includes, besides station positions and velocities, the Earth Orientation Parameters (EOP). The datum definition and the surveys (local ties) at co-location sites have intensively been discussed.

Sub-Commission 1.3 "Regional Reference Frames" was extremely active in the coordination of the installation of the African Reference Frame (AFREF). Many meetings with African and international representatives have been organized or attended by Commission 1 officers. Progress has also been made in the reference frames of Europe, North, Central and South America, Australia, and in Antarctica, which continuously improve the processing methodologies and provide new products (combined geometric-gravimetric, ionosphere, etc.) to the users.

Sub-Commission 1.4 "Interaction of Celestial and Terrestrial Reference Frames" studied mainly the consistency of and between the various reference frames. This included the issues of the new definitions of the International Astronomical Union (IAU2000) as well as studies of the current CRF realization, inconsistencies in software packages w.r.t. the CRF, effects of errors in the CRF on the TRF and other products (e.g., EOP). This is a basic research for the computation of a new CRF in future.

Inter-Commission Project 1.1 "Satellite Altimetry" was very active w.r.t. the establishment of an International Altimetry Service (IAS). An interdisciplinary planning group was set up and released a "Call for proposals to establish and host the IAS Integrating Office (IO)". A major objective was the identification of the scientific requirements to provide a long time series of altimeter observations consistently to the broad users community.

Inter-Commission Project 1.2 "Vertical Reference Frames" did some important steps towards the establishment of a worldwide unified vertical reference frame (global height system). The basic requirements were discussed in many meetings and preliminary realizations of a reference surface were presented. Conventions for a unified vertical reference system have been drafted to be submitted to the IAG Executive Committee.

Inter-Commission Study Group 1.1 "Ionosphere Modelling and Analysis" aims at the establishment of a scientific link between geodetic and aeronomy experts in order to derive ionosphere models based on physics and mathematics by incorporating statistical approaches. Existing ionosphere models like IRI and NeQuick, respectively their four dimensional representation and the possibilities of improvements using space geodetic observations were studied.

Inter-Commission Study Group 1.2 "Use of GNSS for Reference Frames" is a joint effort with the IGS. Major activities were directed to the identification of synergies of different Global Navigation Satellite Systems and to compile recommendations to GNSS system design entities. Special focus was laid on GLONASS and the upcoming GALILEO system.

The Inter-Commission Working Groups are reporting to the Inter-Commission Committee on Theory (ICCT) and may be found there in detail. As a highlight we mention the investigations on the improvement of quality measures for estimated geodetic parameters, which is also published in the Commission 1 report.

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Annex

Participants of the Commission 1 Steering Committee Meetings 2003 – 2007

1. Sapporo, Japan, 7 July 2003, 12:00 – 13:30

H. Drewes*, Germany, President
C.K. Shum*, USA, Vice-president
M. Rothacher*, Germany, President Sub-commission 1.1
Z. Altamimi, France*, President Sub-commission 1.3
S.Y. Zhu, Germany*, President Sub-commission 1.4
J. Agria Torres[+], Portugal, Chair Sub-commission 1.3a
L.P. Fortes, Brazil[+], Chair Sub-commission 1.3b
J. Manning, Australia*, Chair Sub-commission 1.3e
R. Dietrich, Germany[+], Chair Sub-commission 1.3f
W. Bosch, Germany[+], Chair Inter-commission Project 1.1
J. Ihde, Germany[+], Chair Inter-commission Project 1.2
Other guests

2. Nice, France, 28 April 2004, 18:30 – 20:30

H. Drewes*, Germany, President
C.K. Shum*, USA, Vice-president
M. Rothacher*, Germany, President Sub-commission 1.1
C. Boucher*, France, President Sub-commission 1.2
Z. Altamimi*, France, President Sub-commission 1.3
J. Agria Torres[+], Portugal, Chair Sub-commission 1.3a
L.P. Fortes, Brazil[+], Chair Sub-commission 1.3b
R. Wonnacott*, South Africa, Chair Sub-commission 1.3d
J. Manning*, Australia, Chair Sub-commission 1.3e
R. Dietrich[+], Germany, Chair Sub-commission 1.3f
W. Bosch[+], Germany, Chair Inter-commission Project 1.1
J. Ihde[+], Germany, Chair Inter-commission Project 1.2
M. Schmidt[+], Germany, Chair Intercom. Study Group 1.1
R. Weber[+], Austria, Chair Inter-comm. Study Group 1.2
W. Gurtner*, Switzerland, Services' representative
C. Ma*, USA, Services' representative
B. Richter[i], Germany, Director IERS Central Bureau
A. Moore[i], USA, IGS network coordinator
M. Pearlman[i]. USA, Director ILRS Central Bureau
H. Schuh[i], Austria, IVS Directing Board member
Other guests

3. Cairns, Australia, 23 August 2005, 18:00 – 20:00

H. Drewes*, Germany, President
M. Rothacher*, Germany, President Sub-commission 1.1
Z. Altamimi*, France, President Sub-commission 1.3
J. Agria Torres[+], Portugal, Chair Sub-commission 1.3a
L.P. Fortes[+], Brazil, Chair Sub-commission 1.3b
M. Craymer[+], USA, Chair Sub-commission 1.3c
J. Manning*, Australia, Chair Sub-commission 1.3e
R. Dietrich[+], Germany, Chair Sub-commission 1.3f
H. Schuh[i], Austria, designated Chair Sub-commission 1.4
W. Bosch[+], Germany, Chair Inter-commission Project 1.1
J. Ihde[+], Germany, Chair Inter-commission Project 1.2
S. Zerbini[+], Italy, Chair Inter-commission Project 3.2
M. Schmidt[+], Germany, Chair Intercom. Study Group 1.1
R. Weber[+], Austria, Chair Intercomm. Study Group 1.2
H. Kutterer[+], Germany, Intercomm. Working Group 1
J. Ries*, USA, Services' representative
B. Richter[i], Germany, Director IERS Central Bureau
G. Tavernier[i], France, Chair DORIS Governing Board
Other guests

4. Munich, Germany, 10 October 2006, 18:00 – 20:00

H. Drewes*, Germany, President
C. K. Shum*, USA, Vice-president
M. Rothacher*, Germany, President Sub-commission 1.1
Z. Altamimi*, France, President Sub-commission 1.3
M. Craymer[+], USA, Chair Sub-commission 1.3c
R. Wonnacott*, South Africa, Chair Sub-commission 1.3d
A. Rülke[i], Substituting Chair Sub-commission 1.3e
W. Bosch[+], Germany, Chair Inter-commission Project 1.1
M. Schmidt*, Germany, Chair Intercom. Study Group 1.1
R. Weber[+], Austria, Chair Intercomm. Study Group 1.2
C. Ma*, USA, Services' representative
Other guests

(* = Steering Committee member,
[+] = Commission officer, [i] = invited participant)

Sub-Commission 1.1
Coordination of Space Techniques

Report for the Period 2003 – 2007

MARKUS ROTHACHER, HENNO BOOMKAMP, DETLEF ANGERMANN, JOHANNES BÖHM

Objectives

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

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

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

General Remarks

Within Sub-Commission 1.1 three working groups have been established in order to make progress towards the goals described above:

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

All these working groups are very important as steps towards GGOS, the Global Geodetic Observing System, the only project 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. Through the activities of the IERS considerable progress has already been made towards a rigorous combination of geodetic/geophysical parameters that are estimated by more than one technique.

The next step will be the inclusion of quasar coordinates, thus consistently linking the celestial and terrestrial reference frame. Although initial studies have been done already, considerable progress is still possible in the combination of global gravity field parameters with geometry and Earth rotation or the combination of the space geodetic techniques onboard satellites. Here the Sub-Commission saw and sees its most important tasks: to encourage research groups to work in this field in order to finally develop a consistent set of products ranging from the reference frames over Earth orientation parameters and the gravity field to information on the atmosphere.

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

Report of Working Group 1 (SC1.1-WG1)

Introduction: scientific working groups versus reality

What is called a Working Group is in practice mainly a network of colleagues in a certain scientific field, who would probably communicate with each other anyway, and with many other people, even if there was no formal IAG Working Group for doing so. Nonetheless, the framework of a Working Group provides a focal point to which various activities can be correlated, and the explicitly formulated objectives of a Working Group can every now and then help to steer developments in a certain desired direction. Even if that would be all that is achieved, it is better than nothing, but fortunately there is more to report.

As with most scientific Working Groups, the easiest part of the group's activities is to make initial plans, to which all participants enthusiastically agree. In the course of subsequent years, external developments in the world of science should lead to changes in the emphasis of the Working Group – if not, the group is isolated from reality -, while at least some of the attempts to engage in concrete projects will be frustrated by the absence of resources that participating centres can commit to the Working Group. The art of keeping such a Working group alive, and even achieving a relevant contribution to the initial objectives, involves tolerance, opportunism and flexibility. To give an overview of the current status of the Working Group, this report will discuss one example in every of these three categories.

Tolerance is needed to accept that many desirable projects just never happen, because there are no resources, or because initially promised institutional support simply evaporates for whatever reason. Voluntary contributions to scientific working groups tend to have the lowest priority on any managers's list of things to do. In this category, the disappointing developments around the initially planned IAG website must be reported, but rather with a reasonable sense of reality than with frustration.

Opportunism is needed to recognize issues that appear unexpectedly, that clearly fit in the Working Group's objectives, but that had never been considered in the initial objectives. Instead of passively observing such developments, the Working Group should try to influence them in a way that assists the global objectives. In this category, an apparent correlation will be described that has been observed between GPS orbit error, ITRF reference frame error and some components in the time-variable part of the GRACE gravity field solutions. This is a good example of how an IAG Working Group can help to maintain a global view over different, but correlated, disciplines.

Flexibility is needed to work around the discrepancy between ambitious plans and the near-complete absence of resources. Fortunately the world of science contains many clever people, and most of them are short of resources in one way or another. By result, some very useful ideas have appeared over the years to cope with this problem. In this category, the DIGGER initiative will be reported as a beautiful way to provide real processing power to GGOS or other grand schemes, like IGS reprocessing.

Website status

A website forms an important platform for exchanging information among Working Group members, for collecting and linking relevant information in a uniform way, and to create a clear presence of the Working Group. Among the initial plans of the Working Group 1.1.1, an important component was to set up a web-based database on precise orbit determination and satellite tracking, to be maintained at ESOC.
Such a website has in fact been created, including a web-ring facility that was a nice idea to link the internet sites of various research groups in the field of precise orbit determination. The website forms part of the new internet site of the ESOC Navigation Support Office, which among other things hosts the ESA IGS Analysis Centre. Unfortunately, even after three years ESOC has not yet put this new website on-line, for reasons that are rather unclear. There has been some discussion about perhaps hosting a WG website at CDDIS instead. This would require manual interaction from CDDIS staff for every modification of the site, which just did not seem practical. A rather disappointing detail is that by now the acquired two-year license for the web-ring facility has already expired before the site has come online.

Via this way it is suggested that the responsible ESA manager, who curiously enough also presides the Governing Board of one of the IAG services, can comment on the ESOC website situation in one of the upcoming meetings. In the meantime, Figure 1 provides a screen shot of what could in fact be a very nice website, if only it would be visible on the public internet.

Figure 1: The new web-site of the Navigation Support Office, hosting the sites of IAG Working Group 1.1.1 and the IGS LEO Working Group … if one day it comes on-line.

Example of multi-technique reference frame analysis

A more interesting topic that may be reported here is an example of analysis that appeared more or less spontaneously among members of the Working Group, and various other people. On several occasions during the past years, annual signals have been reported that are observed in the IGS station position solutions relative to the ITRF solutions (e.g. [1], [2]). Figure 2 shows examples of annual signals in some IGS stations, taken from the IERS website [2]. An interesting discussion has started on the nature of these signals.

Comparing the position residuals of IGS sites with those of collocated SLR and DORIS sites *suggests* that the annual signals are actual site displacements, and not just artefacts of an individual tracking data technique. shows the ITRF position residuals for the SLR sites Hollas (7210) and Yaragadee (7090) and DORIS sites KOKA and YARA, which are more or less collocated with MKEA and PERT respectively. The SLR stations show very similar behaviour as the IGS sites, even the amplitude and phase of the annual signals coincide very well. The DORIS stations show a less pronounced effect, but by nature a Doppler technique will be less sensitive to very slow position changes, while the overall noise of the DORIS station position estimates is also higher than that of SLR and IGS.

A physical explanation of such annual signals has come from the GRACE mission. Various recent publications discuss the temporal variability in the GRACE gravity models, for instance [3], [4], [5]. In all cases, the annual and semi-annual signals in the GRACE gravity field can be correlated in a convincing way with the annual hydrological cycle (see Figure 4). Such real mass displacements at the Earth's surface should have a similar geometrical effect on station coordinates as solid Earth tides or ocean loading. However, it is remarkable that the annual signal in site positions is indeed of the same order of magnitude as the annual geoid signal, but that there does not seem to be a clear geographical correlation between the two displacements.

For instance, the ITRF residuals of the Kourou station in Figure 2 could probably be explained quite well by geoid height variations under the hydrological variability in the Amazon region. However, looking at the annual position signals of the stations Perth (Australia), Whitehorse (Alaska) and Mauna Kea (Hawaii), it is clear that the order of magnitude of their position residuals is not notably lower than that of Kourou, even though the hydrological variability in these areas is almost zero.

It has now been suggested that the annual signals in the ITRF residuals may be caused by the presence of *some* stations in the solution that are notably affected by physical uplifts under the annual hydrological cycle (e.g. Kourou), similar to the effects of solid Earth tides or ocean loading. Because GPS (and SLR) solutions are always *network* solutions, the station positions and satellite orbits are globally correlated. The presence of *some* stations with annual oscillations may then lead to a spread of these signals throughout the network, via the estimated satellite orbit. This could then explain similar annual signals in the position coordinates from stations like PERT, which do not suffer from hydrological oscillations themselves.

The above discussion is not yet completed, and can hopefully be complemented by some experiments or an analysis campaign of the Working Group.

The DIGGER initiative

An example of an idea that could circumvent the discrepancy between Working Group ambitions and absence of real analysis resources, is an idea that has been called Digger. The acronym DIGGER stands for DCP on the Internet for Global Geodetic Reprocessing, where DCP is a term from computer architecture that means Distributed Cellular Processing.

An obvious way to remove inconsistencies between space geodetic techniques – and an excellent tool in support of GGOS – is the coherent reprocessing of all existing space geodetic datasets. Initiatives for historic reprocessing are in fact being deployed, for instance by IGS. Because the reprocessing itself would improve various geodetic models, while the geodetic datasets keep growing with time, reprocessing should by nature become a regularly repeated effort. It is of course also a massive computational effort, which is a problem considering the modest resources that IAG and its services can dedicate to this work.

The DIGGER idea emerged from some private conversations during the IGS Workshop 2006, when various difficulties surrounding the IGS reprocessing were discussed. Although at present it is still only an idea, some initial analysis has been done and shows that there are no technical objections against making this system a reality. The idea must therefore be cultivated and promoted until hopefully a large organisation like ESA or NASA will run the necessary initial project to build this system. For that reason, the concept is reported here as well. Alternatively, it may be possible to get the support from a computational centre like EPCC [7] to develop the DIGGER system in the form of a research project with a real practical application. Contacts to investigate this possibility have been made.

The job of reprocessing historic space geodetic datasets consists of many thousands of similar, relatively small processes. If these tasks are executed more or less sequentially on a small number of computers, it will clearly take a very long time to complete, and any form of trial-and-error is probably prohibitive. On the other hand, if all these thousands of small jobs can be executed more or less in parallel, the total duration of the reprocessing effort is of the same order of magnitude as the duration of a single job, i.e. probably just a few hours.

Some rough estimates showed that a network of around 3500 modern PC's should have no trouble of reprocessing *all* existing space geodetic data within a few hours, including the time that is required for performing new global combination solutions and such. No single organisation can be expected to make such a large cluster available to an IAG sub-commission, but fortunately there are literally hundreds of organisations that are somehow affiliated with IAG or one of its services. Most of these organisations have significant amounts of computers in their offices and laboratories.

Most of these computers are connected to the internet, and most of these computers are only used during office hours. This means that there is more than enough computing power available to IAG, but it needs to be bundled. This is known as Distributed Cellular Processing, or DCP.

The idea of DIGGER is to organize the computational power of thousands of unused computers in one large cluster for Distributed Cellular Processing via the internet. The reprocessing effort for the historic datasets of GPS, DORIS, SLR, altimetry and VLBI can be split into thousands of small cellular processes, clustered via a hierarchy of Job Control Nodes and distributed via "nightly tarballs", as is done with several similar initiatives. A single process within this army of processes can be distributed very efficiently to any voluntarily participating node via the internet. Each process is small enough to be performed within a few nightly hours, during which the computer would normally not be doing anything at all. For reasons of redundancy, each process should probably be assigned to several different nodes, but such details can be worked out quite easily. The processing results, possibly in the form of normal equations, are returned to one or more server nodes which combine the lower level results into higher level global results.

The DIGGER network would allow full reprocessing of all historic data within a few hours. Interested scientists can request a reprocessing job, for instance to try a new model. A binary that contains the model can be distributed via the internet, after which all nodes immediately use the new model. In this way, reprocessing allows for true experimentation.

At first glance, the concept appeared to be rather fantastic, but after an initial assessment of required elements versus available technology, the only valid conclusion was that all required ingredients are essentially available, or can be provided at a realistically small effort. A good example of a working DCP approach is being used by Berkeley University in the form of its SETI-at-home project [6].

A project like DIGGER would also provide a way to expose initiatives like GGOS to a wide public, and it would give participating centres the feeling that they are actually involved with a relevant international project. Already for reasons of promotion and publicity, attempts for working towards a real DIGGER system will continue.

Conclusions

The IAG Working Group 1.1.1 seems to end up doing some different things than it initially planned to do, while some of the initial plans have not yet been realized. It is nonetheless reasonable to conclude that at least some activity has taken place that would probably not have happened without the formal framework of an IAG Working Group. The main source of frustration is the off-line website, but some positive ideas like DIGGER probably offer a fair compensation.

The list of members of this – and any other – Working Group must probably be regarded as just a core group of colleagues in a certain field, without limiting interactions with any further interested party. In practice, a large and almost random group of other people are somehow involved in helping the Working Group objectives, typically by contributing to e-mail discussions. The Working Group is therefore either much larger than the formal list of members, or it does not really exist as a well-defined group. Neither of the two should be considered as a problem.

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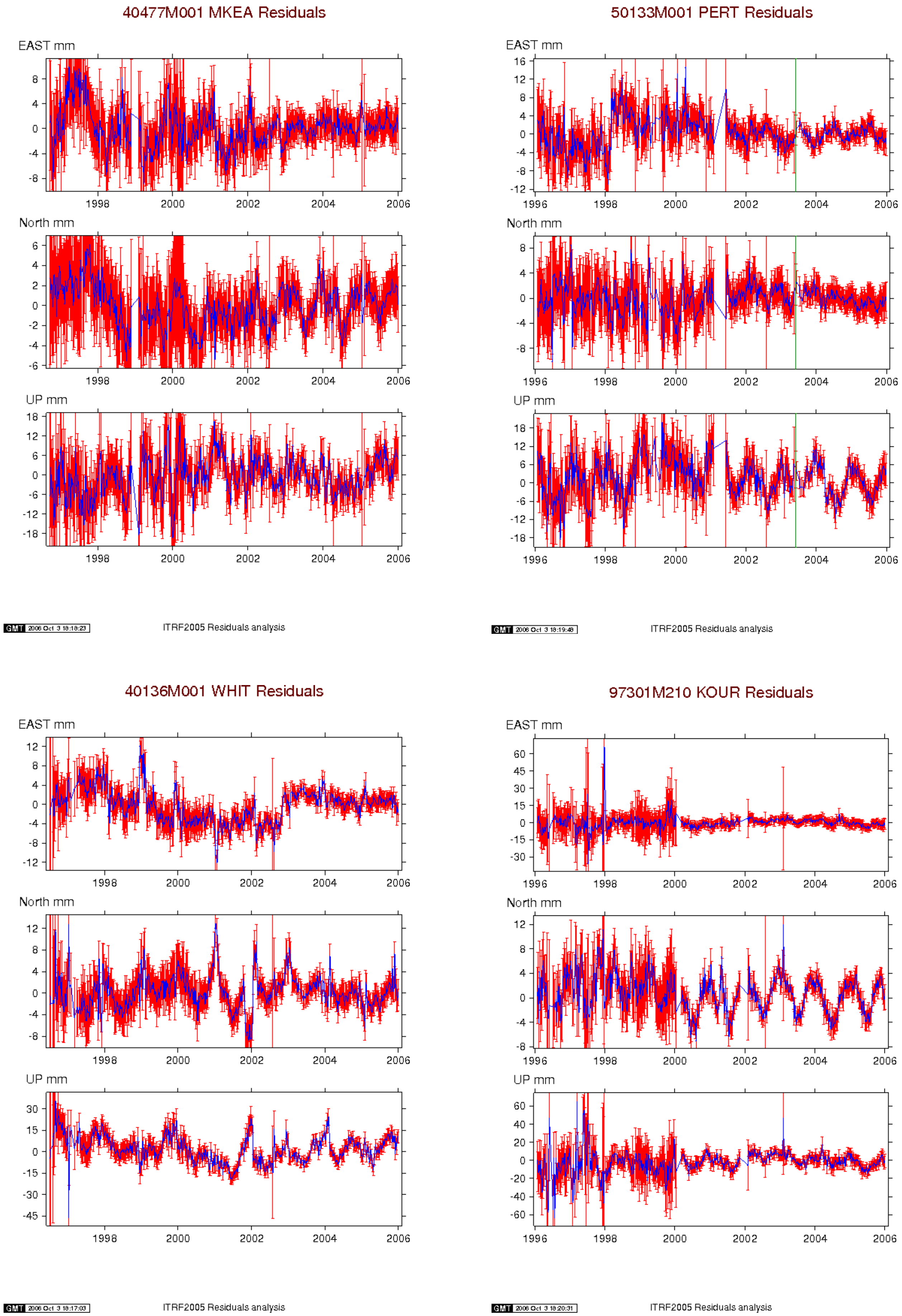

Figure 2: Examples of ITRF position residuals (IGS stations, from IERS [2])

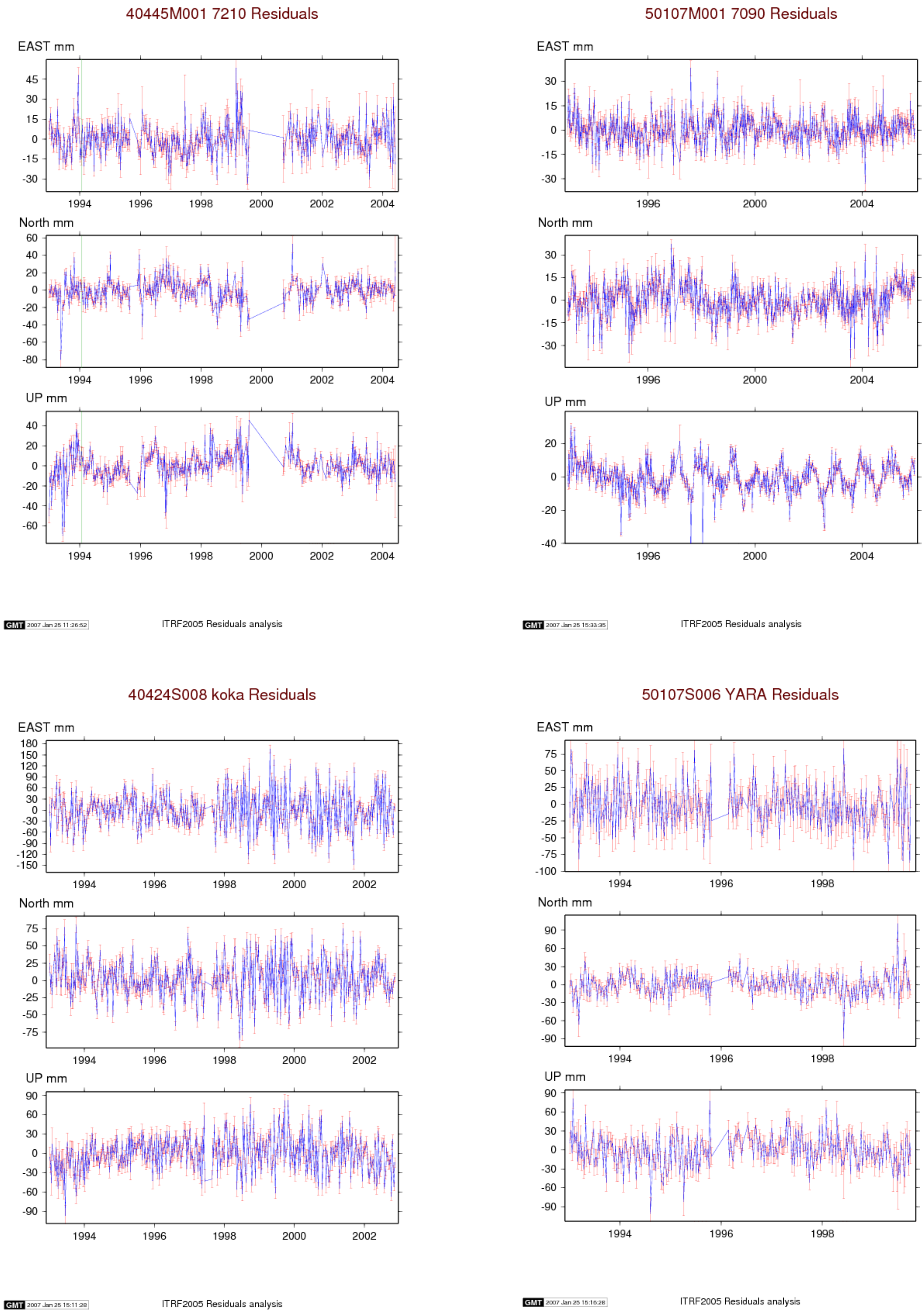

Figure 3: ITRF position residuals for SLR sites Hollas (7210) and Yaragadee (7090), and for DORIS sites KOKA and YARA, also from [2].

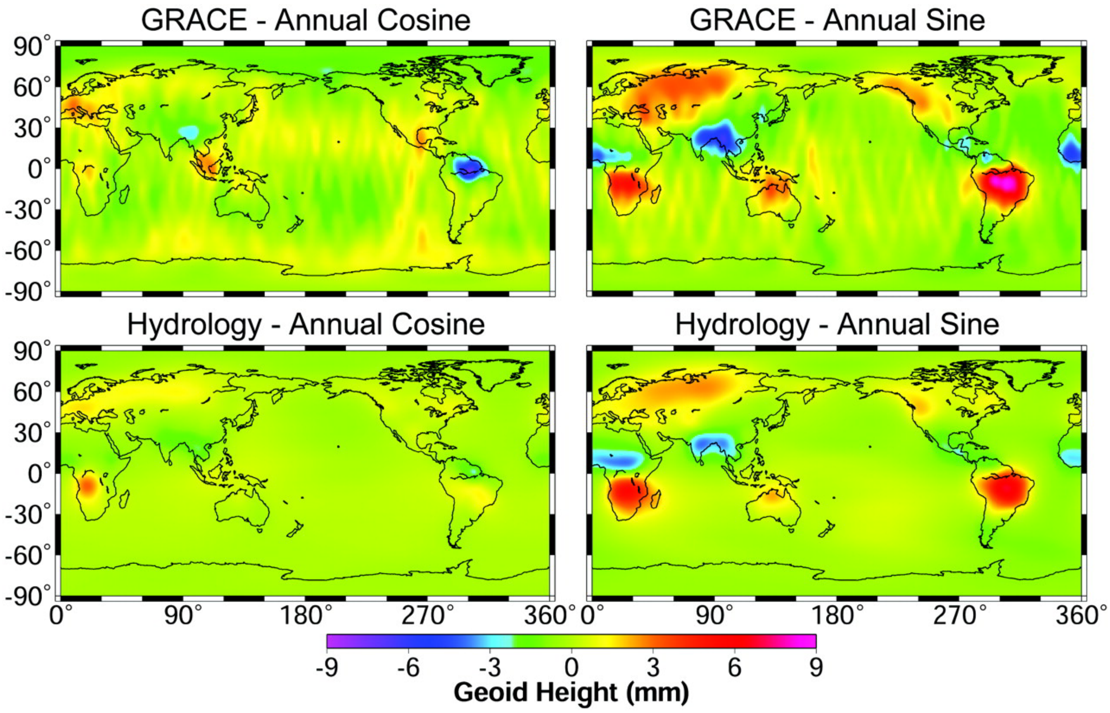

Figure 4: Annual geoid height variability observed by GRACE, [4], and correlation with the annual hydrological cycle

Report of Working Group 2 (SC1.1-WG2)

Objectives

The Working Group 2 (WG 2) of Sub-Commission 1.1 "Coordination of Space Techniques" has been established within the IAG organizational structure as a joint WG together with Commission 2, Commission 3, and the Global Geodetic Observing System (GGOS). The long-term objective of WG 2 is to investigate the interaction between the terrestrial reference frame, Earth rotation and the gravity field and to develop methods for a consistent determination of the relevant parameters of this three fields by combining all the contributing space geodetic observation techniques.

The main research topics are:

– Study the theoretical and practical interactions/ relationships between parameters and models describing the terrestrial reference frame (station positions and their temporal variations), Earth rotation (pole coordinates, UT1, nutation, …), and the gravity field (low-degree spherical harmonic coefficients of the gravity field).
– Analyses of different space techniques concerning the sensitivity for the estimation of the relevant parameter types of these three fields and the correlations between them, and assess systematic biases between different techniques.
– Assess and investigate the consistency between space geodetic solutions for the parameters of the terrestrial reference frame, Earth rotation and the gravity field.
– Investigate methods and techniques 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 (e.g., JASON-1, CHAMP, GRACE).

Interaction with the activities of the IERS

The International Earth Rotation and Reference Systems Service (IERS) is responsible for the establishment and maintenance of the reference frames. The core IERS products comprise the International Terrestrial Reference Frame (ITRF), the International Celestial Reference Frame (ICRS), and the Earth Orientation Parameters (EOP). Thus the IERS is directly involved in two of the mentioned fields (geometry and Earth rotation). The space geodetic observation techniques contributing to the IERS combinations are the Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). During the period of this report, the IERS activities were, besides the routine product generation, also concentrated on the development of rigorous combination methods to further improve the consistenty between the IERS products. Towards this aim, the IERS Combination Pilot Project (CPP) has been initiated in 2004 (as a follow-on-project of the IERS SINEX Combination Campaign) to develop suitable combination methods and to prepare the routine generation of consistent IERS products on a weekly basis (Rothacher et al., 2006).

The objectives and the research activities of this WG go far beyond the mission of the IERS, as also the gravity field, as well as the interactions of the gravity field with geometry and Earth rotation are addressed. The data to be analysed within WG 2 include GNSS, SLR, VLBI and DORIS observations, and in addition satellite altimetry as well as GPS receivers onboard Low Earth Orbiting (LEO) satellites (like, e.g., JASON-1, CHAMP, and GRACE).

Working Group activities

During the period of this report various activities related to the integration of geometry, Earth rotation and the gravity field, and the interactions between these three fields were carried out, which are among others:

– Analysis of the strengths (and weaknesses) of the different space techniques concerning the estimation of parameters of Earth rotation (e.g., pole coordinates, length of day, etc.), of the gravity field (primarily the low-degree spherical harmonic coefficients) and of the terrestrial reference frame.
– Assessment and study of systematic biases between different techniques and products, which can be considered as a major error source for the parameter estimation.
– Investigations towards the development of a suitable methodology for the combined adjustment of all the relevant space geodetic observations (e.g., modelling, spatial and temporal resolution for the parameter estimation, weighting of the techniques, realization of a consistent datum).
– Studies related to the connection of the different techniques, e.g. by terrestrial measurements ("local ties"), on the satellite level (e.g. LEO) or by combining common parameters (EOP or tropospheric parameters).

The results of two exemplary studies are provided below:

– A VLBI solution with simultaneous estimation of station positions and velocities (TRF), celestial coordinates of the radio sources (CRF), and the full set of Earth orientation parameters (EOP) was computed at DGFI (Tesmer et al., 2004). A major goal was the comparison of this completely undistorbed VLBI solution to the IERS C04 series for the EOP, and the ITRF2000 to assess the consistency between the terrestrial reference frame and the Earth rotation parameters. Assuming that the VLBI solution is free of (systematic) errors, the results indicate inconsistencies between the IERS C04 and the (VLBI part) of ITRF2000. As an example for the results of this study the differences for the pole estimates and UT1 are shown in Fig. 1.
– The contribution of the different space geodetic observation techniques for the realization of the geodetic datum, which is a key issue for the development of suitable combination methods, has been studied. For that purpose investigations were performed on the basis of weekly and daily solutions for GPS, SLR, DORIS and VLBI (Angermann et al., 2006). Examples for the formal errors and the correlation matrix of the datum parameters are displayed in Figure 2.

During the period of this report, two projects, that are related to the activities of this working group have been initiated by German institutions:

– In the framework of the project GGOS-D (German part of GGOS) consistent observation time series are generated and combined into consistent parameter series of site coordinates, Earth rotation, and low-degree gravity field coefficients. This joint project of the "GeoForschungsZentrum Potsdam (GFZ)", the "Bundesamt für Kartographie und Geodäsie (BKG)", the Institute of Geodesy and Geoinformation of the University Bonn(IGG) and "Deutsches Geodätisches Forschungsinstitut (DGFI)" has started in 2005.
– 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" aims towards the development of suitable combination methods for a consistent estimation of the relevant geodetic parameters. This is a joint project of GFZ Potsdam and DGFI, which has started in 2006.

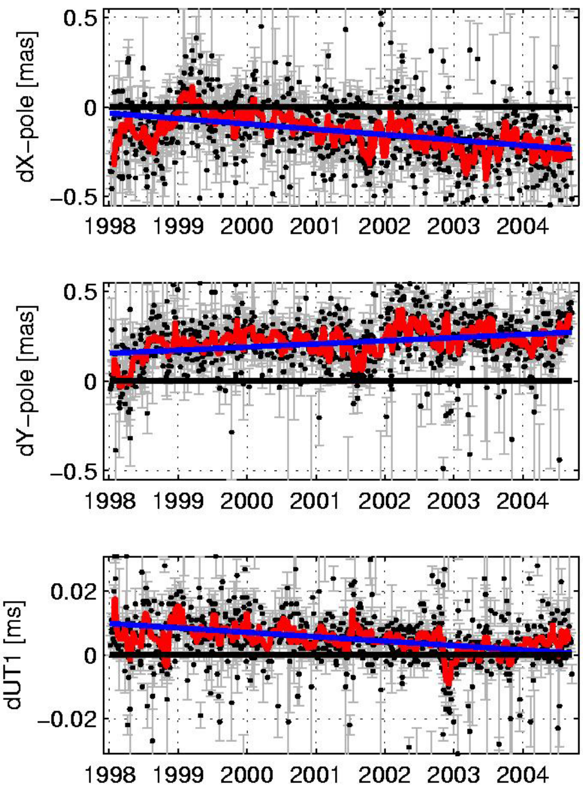

Figure 1: Differences between the EOP of the VLBI solution and the IERS C04 from 1998 until 2004 (solid curves show the median of 10 values and a best-fitting linear function).

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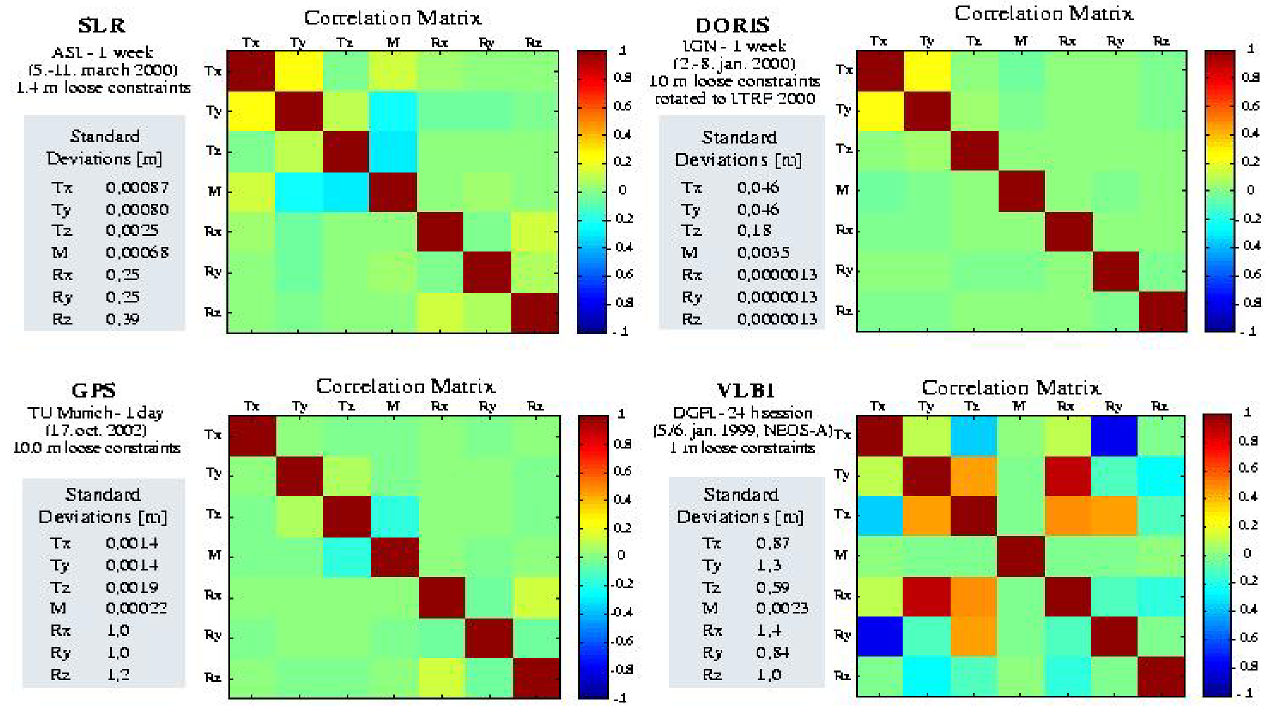

Figure 2: Standard deviations and correlation matrix of the datum information obtained from VLBI, SLR, GPS and DORIS data. The standard deviations are in [m] on the Earth surface.

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

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 of 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 atmosphere delays in the neutral atmosphere ('troposphere') as well as in the ionosphere over all techniques.

Several 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 15-days continuous VLBI campaigns CONT02 and CONT05, or Steigenberger et al. (2007) for long time series from VLBI and GPS. The best agreement is found between the zenith delays from GPS and VLBI with a standard deviation of about 5 mm, and it is shown by Schmid et al. (2005) that the biases between the techniques decrease when using absolute phase center patterns. However, there remains a significant influence on the zenith delays at those GPS antennas covered by a radome.

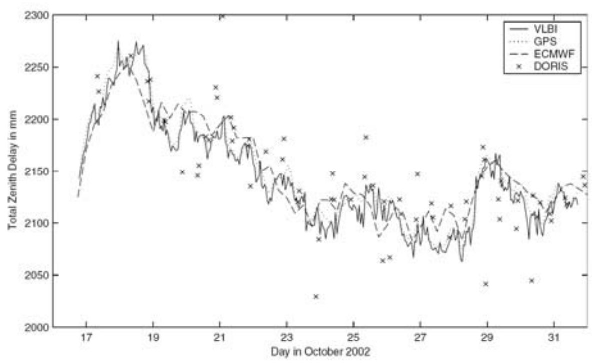

Figure 1 (Snajdrova et al. 2005): Total zenith delays at Ny-Ålesund during CONT02 from VLBI (solid line), GPS (dotted line), ECMWF (dashed line), and DORIS (crosses for epochs).

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 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. E.g., combined zenith delays can take advantage of the better long term stability and accuracy from VLBI which is not affected by multipath effects or antenna changes, and of the high precision of GNSS due to the large number of satellites and their continuous observations. Krügel et al. (2007) have shown that the combination of troposphere parameters from VLBI and GPS for CONT02 is not only improving the repeatability of the station height components, but is also revealing errors in the local ties (Figure 2).

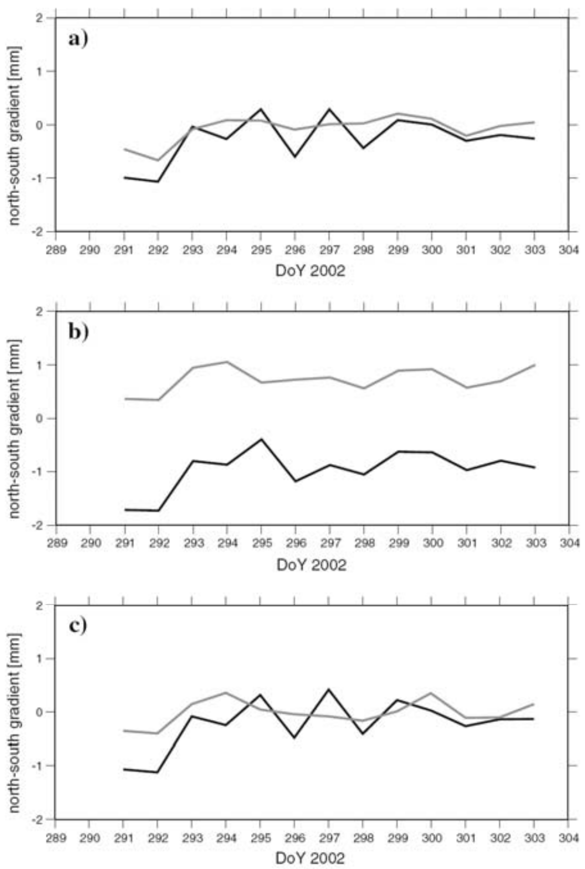

Figure 2 (Krügel et al. 2007): North-south gradient of Fairbanks estimated from VLBI (black) and GPS (grey). (a) Single technique solutions, (b) combination with all local ties, (c) combination with all local ties except for the north component of Fairbanks.

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 (e.g. 18:15, or 18:30, ..), offset and rate should be set up for each interval, and the time intervals should be short because they can be concatenated at a later stage if necessary.

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, requiring that special care is taken to derive consistent values for the different techniques. For the estimation of the residual troposphere parameters, not only the wet mapping functions are needed but also the gradient model. Although the differences are not very large, analysts should use consistent models for the gradients as discussed by Steigenberger et al. (2007).

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 (Hernándes-Pajares 2005a) comparisons of TEC values are carried out between those values determined from IGS TEC maps and TEC values from altimeter observations (e.g. JASON, TOPEX, ENVISAT). These comparisons, which are only possible over the oceans and thus provide a lower boundary for the GPS TEC performance, yield a mean bias of about zero and a mean standard deviation over all latitudes of about 5 TECU (Figure 3), but comparisons near the coast (with close GPS stations) imply 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) results in a standard deviation better than 1 TECU over all latitudes (Hernándes-Pajares 2005b). Hobiger et al. (2006) provide comparisons of TEC values between GPS and VLBI over the VLBI radio telescopes. They find a mean bias (VLBI minus GPS) above all sites of −2.8 TECU and an RMS of ±10 TECU (Figure 4).

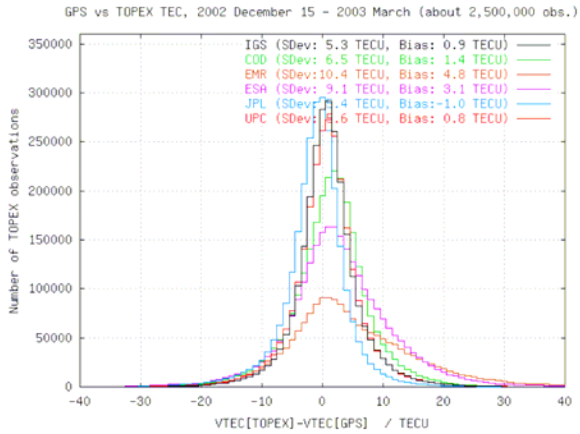

Figure 3: (Hernándes-Pajares 2005a). Histogram representing the distribution of IGS (and the individual Analysis Centers) TEC discrepancies with the TOPEX TEC during the period 2002 December 15 to 2003 March 15 with about 2.5 million TOPEX observations.

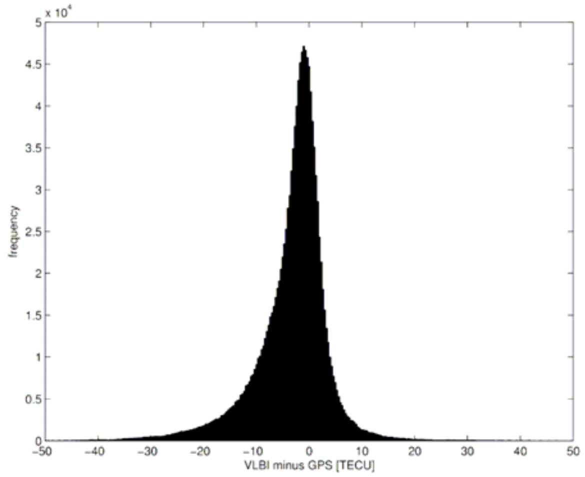

Figure 4: (Hobiger et al. 2006). Histogram of differences between VLBI and GPS taken at all IVS stations. The bias VLBI minus GPS is at -2.8 TECU, the RMS at ±10 TECU.

Outlook

In the next years it will be extremely important for Sub-Commission 1.1 to work as closely as possible together with GGOS and to support its activities with the scientific expertise available within the WGs of Sub-Commission 1.1.

An important goal of Sub-Commission 1.1 will still be the development of a much better understanding of the interactions between the parameters describing geometry, Earth rotation, and the gravity field, as well as the study of methods to validate the combination results, e.g., by comparing them with independent geophysical information.

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Sub-Commission 1.2
Global Reference Frames

Report for the Period 2003 – 2007

CLAUDE BOUCHER

Introduction

The IAG Sub-Commission 1.2 was created in 2003 as a part of the new structure of the International Association of Geodesy (IAG).

According to its Terms of Reference, the IAG 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, addresses fundamental issues of multi-technique global geodetic observatories (local ties, site effects) and studies methods and approaches for the combined processing of heterogeneous observation data.

The work is done in close cooperation with the International Earth Rotation and Reference Systems Service (IERS), the other relevant IAG services (IGS, ILRS, IVS, IDS), and the IAG Project "Global Geodetic Observing System (GGOS)". Theoretical aspects (e.g., quality measures, relativistic modeling) are investigated in cooperation with the Inter-Commission Committee on Theory.

The assigned objectives given by the IAG for the 2003-2007 period are:

- Definition of the global terrestrial reference frame (origin, scale and orientation, time evolution, standards, conventions, models);
- Fundamentals of the realization of the global terrestrial reference frame (e.g., co-location problems: local ties, datum problems: coordinates origin, geo-centre, time evolution: linear and non-linear velocities, 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) and their contribution to specific TRF parameters;
- Combination methodology of individual techniques' solutions and analysis of the underlying models, parameters datum definitions etc.;
- Definition of common standards and models for all techniques;
- Practical implementation of the concept of Global Geodetic Observatory

Structure

The initial structure was established in a top-down way with proposed chairs as described below, and was published in the Geodesist Handbook. Five Working groups were proposed:

SC1.2-WG1: Datum Definition of Global Terrestrial Reference Frames (jointly with IERS and ICCT); Chairman: Geoff Blewitt (USA)
SC1.2-WG2: Global Geodetic Observatories; Chairman: not assigned
SC1.2-WG3: Integrated Theory for crustal deformation and Reference Frames (joint with ICCT); Chairman: Kosuke Heki (Japan)
SC1.2-WG4: ITRS/ITRF propagation to national and international organizations; Chairman: Claude Boucher (France)
SC1.2-WG5 Site Surveys and Co-locations (jointly with IERS); Chairman: John Dawson (Australia)

In fact, the first WG was not formally active, and we supported the proposal of the contacted chair not to actually run it, considering that numerous works in this field were already in progress. WG 2 and 3 were never actually implemented. The two last got some progress, as described below.

On a pure organizational point of view, we recommend for future work not to establish groups according to this top-down approach, but rather on the opposite way, namely only if a volunteer chair has been identified. Of course, research topics considered as important can still be selected and publicized in order to get some volunteers.

Furthermore, we must recognize the major contribution to our activities provided by IERS, not only through the joint WG 5, but also through other activities such as combination research centers, ITRF activities or Conventions.

Another noticeable structure is GGOS, in particular about ITRS, as reported below. Detailed reports about various relevant activities are presented in the next chapter. Finally, a general symposium was organized in Munich by the Commission 1 on October 9-12 2006.

Activities

Activities related to the field of interest of the Sub-Commission were various and numerous. As the SC1.1 was not organized as an international observatory, it is unrealistic to try to be exhaustive. Therefore we decided to give only an overview of what happened during the 2003-2007 period, following some key words. Readers will therefore be able to look directly at their specific field on interest. The remark about non exhaustivity is also valid for the list of references given in appendix 1.

Combinations

This topic was mainly investigated in the frame of IERS, and particularly its pilot experiment, as well as the tremendous work done by the ITRS combination centers (IGN, DGFI and NRCan). The production of the new ITRF2005 solution was a specific challenge, also by involving the so-called Technique Centers to product a unique intra-technique combination, which was successfully done by IGS, ILRS and IVS, but not (yet) by IDS. We refer to IERS publications for further details.

Concepts and Terminology

An effort to improve and refine the concepts and the related terminology has been done in cooperation with the IAU Division I Working Group on "Nomenclature for Fundamental Astronomy" (NFA) chaired by Nicole Capitaine. Some of the proposed terms were also included in the new edition of the IERS Conventions (2003) (McCarthy D,G Petit,2004)

It is useful to remind here the main terms:

Geocentric Terrestrial Reference System (GTRS)

"System of geocentric spacetime coordinates from General Relativity, related to GCRS by a spatial rotation which takes into account the Earth orientation Parameters, and co-rotating with the Earth"

This definition has been formally adopted by the IAU WG on NFA.

As a result, and considering the state of IUGG and IAG resolutions on this topic, in particular the IUGG Resolution 2 and IAG Resolution 1, both adopted in Vienna in August 1991, we prepared a new resolution to be adopted by the forthcoming General Assembly to be held in Perugia, Italy in July 2007.

This text endorses in particular the definition of GTRS given above. A draft version can be found in the appendix 2.

Terrestrial Reference Frame (TRF)

"Set of points with coordinates expressed in a selected coordinate system related to a (G)TRS"

Two major types of TRF are currently considered and used

- Dynamical: ephemerides (e.g. GPS broadcast message, IGS precise orbits…),
- Kinematical: crust-based TRF (IERS Conventions 2003) see after

In practice, a TRF designates a set of numerical data together with rules to compute exact coordinates of a given point at a given epoch from these data, implying the adoption of conventional corrections or interpolation algorithms. Again, a detailed presentation of the ITRF solution series is given in IERS,2004 as well as various publications from IERS.

International Terrestrial Reference System (ITRS)

ITRS is currently the GTRS operationally defined and realized by the IERS, as recognized by the IAG Resolution 1 of Vienna, 1991. We consider that a more explicit recognition of ITRS as preferred unifying system is desirable. In this mind, the proposed resolution also includes this point. See at the item ITRS below for more.

Crust-based Terrestrial Reference Frame

This concept mentioned before was explicitly introduced in the IERS Conventions 2003, chapter 4.

It designate any frame consisting in points located on and anchored to the Earth land topographic surface. These points are geodetic benchmarks or space geodetic instrument reference points. The actual position of such points and their time variations have then a dual role:

1) as source of numerical and metrological realization of the system, whence the concept of crust-based TRF,
2) as sensor of any geophysical effect affecting these positions.

At the physical model level, and following the IERS Conventions (2003), the instantaneous position X of a point at an epoch t is linked to a so-called "regularized" position:

$$X(t) = XR(t) + \Sigma i \, \Delta Xi(t)$$

where $\Delta Xi(t)$ are selected conventional correction models. This is one of the important tasks of the IERS Convention product center and its advisory board to do this selection in agreement with all involved groups, in particular the individual analysis centers of the various techniques.

A further step is to handle the regularized position (piecewise linear, time series…). This is more the responsibility and analysis and combination centers, regarding in particular a consistent choice for each point. Again, we refer to the IERS reports.

Global Geodetic Observatories

It must be recognized that no explicit work has been done in the frame of the sub-commission. The basics were extensively investigated in the past, in particular through the ISGN label defined by the former IAG CSTG commission.

Concerning collocations, which are one important characteristic of this concept, significant works were achieved:

- collocation strategies and local surveys, both investigated by IERS on an operational point of view (see local surveys) and by GGOS on a strategic point of view.
- Important examples of collocated instruments beyond satellite geodetic ones, were given by IGS in two of their projects, namely GPS/tide gauge (TIGA http://igscb.jpl.nasa.gov/projects/tiga/index.html) and GPS/atomic clocks (IGS/BIPM Time experim./ http://igscb.jpl.nasa.gov/projects/clock/index.html)

Global Geodetic Observing System (GGOS)

This IAG project tries to coordinate efforts of the geodetic community and present them as a unified system of observing systems. This includes all IAG services. GGOS recognized reference frames as one of the major outputs, especially in view of various scientific or societal applications. As operational representative of IAG to GEO, GGOS has specifically proposed a task to promote geodetic reference frames.
More information at the GGOS portal (http://www.ggos.org/)

GNSS (GPS, Galileo,GLONASS…)

TRS/TRF issues has also been considered in several GNSS activities:
- An IAG/IGS Working group on GNSS, chaired by Robert Weber, has been active (see IC-SG1.2 report) with several meetings jointly with the ESA GalileoSat project team.
- The formal recognition of ITRS/ITRF as common frame for both GPS and Galileo was stated in the US-EU agreement concerning GPS/Galileo.
- The Galileo project has continued its work related to the implementation of the GTRF, the operational Galileo realization of the ITRS. A project called GGSP has been approved and implies several IAG members from Europe.
- The establishment of an International Committee on GNSS was achieved, with the UN OOSA as secretary. This committee includes GNSS service providers as well as various user communities. IGS and IAG are already members.

See (http://www.unoosa.org/oosa/SAP/gnss/icg.html)

We investigated the possibility to establish a group on geodetic reference system issues and specifically the promotion of ITRS. This was presented to IGS and BIPM who approved the principle to submit the proposal at a forthcoming IGC plenary meeting. (See appendix 3)

IERS

IERS was the major forum for global reference frame activities. We refer to their web site and publications for further details. The main issues are:
- realization of ITRF by the ITRS product center,
- IERS Conventions,
- WG5 as joint IERS/SC1.2 working group,
- Combination pilot project.

For more information, see the IERS portal (http://www.iers.org/)

International Terrestrial Reference System (ITRS)

As mentioned before, we proposed to upgrade to formal adoption of ITRS at IUGG level by submitting a resolution. We also want to publicize an overall description of ITRS and its various realizations under an unified scheme. It is proposed to submit a general paper at IAG to be published in the next Handbook.

This scheme include in particular:

a) The primary realization of ITRS, realized by IERS under the ITRF designation. The most recent solution is ITRF2005. For more information on ITRF, we refer to the web page of the IERS ITRS Product Center (http://itrf.ensg.ign.fr/).
b) The realizations done by each individual technique, with upgrades usually after each new ITRF release. This is in particular the case of IGS which certainly provides the broader access to ITRS.
c) Regional (EUREF, NAREF, SIRGAS… see IAG SC 1.3) and national densification
d) Access through GNSS providers.

Local surveys

The major activities on this topic were achieved by the IERS/SC1.2 WG5. They can be summarized as:

- Site Survey and Standards
  - Develop, test, compare and set standards on site survey methods, including observational techniques, network design, classical adjustment, geometrical modeling 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;
  - Preparation and coordination of a Pilot Project (PP) on site survey. The PP will include a test campaign(s) 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.

- Coordination
  - 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.
- Site Survey Research
  - Investigate new site survey methodologies, including observational techniques, observational modeling, invariant point definition, geometrical modeling and/or direct measurement techniques for invariant point determination, reference frame alignment and structural deformation analysis.
- Future Planning
  - The WG will make recommendations and prepare 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).

The WG5 held several meetings and detailed activity report can be found in their web site (http://www.iers.org/iers/about/wg/wg2.)

Theoretical aspects

Many work has been done, for which a detailed and critical review is out of scope of this general report. We simply list hereafter an unexhaustive list of topics:

– to clarify the different types of possible reference system definitions that might be important for different research fields (sea level, geoid, deformation, Earth orientation, geocenter motion, ...) and for what measurements they are important and study the differences between these systems;
– to assess the uncertainties and quality of the various realizations, how they are affected by geophysical processes, and how the effect of these processes can be modeled in time and space to allow a refined realization of the frames;
– to assess how a stable and consistent reference frame can be realized over decades with the limited number and distribution of stations and observations;
– to study datum definition in a relativistic framework, in particular in view of the CRS/TRS transformation;
– to study the impact of IAU non-rotating origin on TRS, if any.

WGS84

The major realization of WGS84 is nowadays through the GPS operational products. The ephemeral data broadcasted by the system are precisely computed using the WGS84 standards. In particular the frame consisting of the OCS tracking stations is determined in WGS84 and upgraded from time to time. These improvements are done by the US NGA (formerly NIMA and DMA), together with their own extended network as well as IGS data. The results are reported to be consistent with recent ITRF solutions at the 2 cm level.

It is therefore legitimate to state that the GPS TRF is de facto a realization of ITRS. This is exactly what was recognized in the US-EU agreement about GNSS. It is also we strongly recommend to use ITRS as unique preferred name for the system (see ITRS)

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Appendix 2
Draft Resolution to be submitted at the IUGG/IAG General Assembly, Perugia 2007

The International Union of Geodesy and Geophysics

Considering the increasing importance of geodetic reference systems in Geosciences, and more widely in numerous scientific or technical activities, such as Satellite navigation systems or geo-information;

Recognizing the quality of the work done by several IAG services (IERS,IGS, ILRS, IVS, IDS…) to actually realize these systems and provide regular access to numerous users within and beyond the geoscience community;

Noting that the latest resolutions of IUGG and IAG, both adopted in 1991 at the General Assembly of Vienna (IUGG Resolution 2 and IAG Resolution 1) need to be upgraded, considering for instance the recent work done by the IAU in the field of nomenclature;

Endorses the definition of a **Geocentric Terrestrial Reference System (GTRS)** as a "System of geocentric space-time coordinates from General Relativity, related to Geocentric Celestial Reference System by a spatial rotation which takes into account the Earth orientation Parameters, and co-rotating with the Earth", in full agreement with IAU, and recognize that this new designation should be preferred to the term of Conventional Terrestrial Reference System defined and adopted in 1991;

Furthermore adopts the **International Terrestrial Reference System (ITRS)** as preferred GTRS for any scientific application and urges other communities such as geo-information, or navigation to do the same. The ITRS orientation is operationally maintained in continuity to past international agreements.

Appendix 3
Proposal for the IGC:
Proposal to establish a working group on geodetic references within the International Committee on GNSS (ICG)

To : International GNSS Service (IGS)
- John DOW, President -
Bureau International des Poids et Mesures (BIPM)
- Felicitas ARIAS, Head Time section -
From: Claude Boucher November 11, 2006

Context

Promotion of ITRS

There is an emerging demand to recognize the International Terrestrial Reference System (ITRS) as the unique preferred system for geo-referencing in science and applications.

Meanwhile, for various reasons, several communities (for instance civil aviation, hydrography …) has adopted WGS84 to play this role.

In fact, there is no real technical problem, but rather an issue of terminology and proper understanding. A major proof of that is the recent agreement signed by USA and EU about GNSS, and specifically about the interoperability between GPS and Galileo. This document specifies that each system will implement a realization of a system which will be as close as possible to ITRS. It is recognized that WGS84 designates the US implementation of ITRS for GPS (at least for the nominal operational service, i.e. Broadcasted data). As consequence,WGS84 should be understood as a realization of ITRS associated with the operational use of GPS (namely use of message).

The International Committee for GNSS
After the recommendation of an ad hoc group on GNSS in the frame of the UN Committee for the Pacific Uses of Outer Space (COPUOS), an International Committee on GNSS has been established since January 2006.

ICG is an international forum gathering any country, national or international organizations involved in GNSS, either as service provider or user. In particular, IGS and BIPM are already members of ICG.

The UN Office for Outer Space Affairs (OOSA) has offered to ensure the secretariat for ICG.

It is expected that ICAO or IHO will also join ICG.

In its charter, ICG may establish working groups on specific topics upon proposal by one of its members.

Proposal

In recognition of the context , we propose to establish within ICG a working group on geodetic references.

The possible goals of this WG would be :

a) to gather all ICG participants interested by the subject (system and service providers, users, …)
b) to review the present situation
c) to discuss and agree upon a consistent terminology for geodetic references and related understanding
d) to prepare a recommendation about ITRS and its realizations, both from GNSS suppliers and user point of view.
e) To discuss and sketch implementation plans in each concerned community (for instance modification of ICAO resolutions)

Implementation

The proposed scenario is:
a) to approve this proposal by IGS and BIPM.
b) IGS and BIPM jointly propose the establishment of this WG at a forthcoming plenary ICG meeting. This should imply to prepare a suitable working paper, eventually derived from this one.

Finally, a possible option to take into consideration is to extend the scope of this WG to time references.

Appendix 4
Terms of Reference (IAG Handbook)

Terms of Reference

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 frame, addresses fundamental issues of multi-technique global geodetic observatories (local ties, site effects) and studies methods and approaches 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 and the IERS Combination Research Centers (CRC), the other relevant IAG services (IGS, ILRS, IVS, IDS), and the IAG Project "Integrated Global Geodetic Observing System (IGGOS)". Theoretical aspects (e.g., quality measures, relativistic modeling) will be investigated in cooperation with the Inter-Commission Committee on Theory.

Objectives

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

- Definition of the global terrestrial reference frame (origin , scale and orientation, time evolution, standards, conventions, models);
- Fundamentals of the realization of the global terrestrial reference frame (e.g., co-location problems: local ties, datum problems: coordinates origin, geo-centre, time evolution: linear and non-linear velocities, 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) and their contribution to specific TRF parameters;
- Combination methodology of individual techniques' solutions and analysis of the underlying models, parameters datum definitions etc.;
- Definition of common standards and models for all techniques;
- Practical implementation of the concept of Global Geodetic Observatory.

Structure

President: Claude Boucher (France)

Working Groups

SC1.2-WG1: Datum Definition of Global Terrestrial Reference Frames (jointly with IERS and ICCT) Chairman: Geoff Blewitt (USA)
SC1.2-WG2: Global Geodetic Observatories Chairman:
SC1.2-WG3: Integrated Theory for crustal deformation and Reference Frames (joint with ICCT) Chairman: Kosuke Heki (Japan)
SC1.2-WG4: ITRS/ITRF propagation to national and international organizations Chairman: Claude Boucher (France)
SC1.2-WG5 Site Surveys and Co-locations (jointly with IERS) Chairman: John Dawson (Australia)

Members

Zuheir Altamimi (France) IAG SC 1.3
Geoff Blewitt (USA) WG 1
Claude Boucher (France) President
John Dawson (Australia) WG 5
Herman Drewes (Germany) Commission 1
Remi Ferland (Canada) IGS
Kosuke Heki (Japan) WG 3
Johannes Ihde (Germany)
Jim Ray (USA)
Bernd Richter (Germany) IERS
Markus Rothacher (Germany) IERS, SC 1.1
Robert Weber (Austria) SSG 1.2
Pascal Willis (France) IDS
S Y Zhu (Germany) SC 1.4

Sub-Commission 1.3
Regional Reference Frames

Report for the Period 2003 – 2007

ZUHEIR ALTAMIMI

Regional Sub-commissions:

SC1.3a: Europe (EUREF), Chair: JOÃO AGRIA TORRES (Portugal)
SC1.3b: South and Central America (SIRGAS), Chair: LUIZ PAULO FORTES (Brazil)
SC1.3c: North America (NAREF), Co-Chairs: MICHAEL CRAYMER (Canada), RICHARD SNAY (USA)
SC1.3d: Africa (AFREF), Chair: RICHARD WONNACOTT
SC1.3e: South-East Asia and Pacific, Chair: JOHN MANNING (Australia)
SC1.3f: Antarctica (SCAR), Chair: REINHARD DIETRICH (Germany)

This report gathers the contributions of the above regional sub-commissions covering the period 2003-2007. As stated in the Terms of Reference, IAG Sub-commission SC1.3 is concerned with definitions and realizations of regional reference frames and their connection to (and the densification of) 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.

The main sub-commission 1.3 objectives are the following:

– Develop specifications for the definition and realization of regional reference frames, including vertical datums, with full interaction with the Inter-Commission Project ICP 1.2 on Vertical Reference Frames.
– Develop and promote operation of GPS permanent stations, in connection with IGS whenever appropriate, to be the basis for the long-term maintenance of regional reference frames.
– Coordinate activities of the regional subcommissions focusing on exchange and share of competences and results.
– Encourage and stimulate the emerging development of the AFREF project with close cooperation with IGS.
– Encourage and assist, within each regional subcommission, countries to re-define and modernize their national geodetic systems, compatible with the ITRF.

Sub-Commission 1.3a
Reference Frame for Europe (EUREF)

Report for the Period 2003 – 2007

JOÃO AGRIA TORRES, ZUHEIR ALTAMIMI, HELMUT HORNIK

Introduction

The EUREF Sub-Commission was constituted at the IUGG *(International Union of Geodesy and Geophysics*) General Assembly held in Vancouver, 1987, under the umbrella of Commission X - Global and Regional Geodetic Networks of Section 1 – Positioning. As a result of the implementation of the new IAG (*International Association of Geodesy*) structure at the IUGG General Assembly held in Sapporo, 2003, EUREF was integrated within Sub-Commission 1.3, Regional Reference Frames, under Commission 1 – Reference Frames, with the designation *Sub-Commission 1.3a, Reference Frame for Europe (EUREF)*. The present report covers the activities carried out in the period August 2003 – April 2007 and is focused on the following topics:

- Overview and organisation
- EUREF Permanent Network (EPN)
- Improvements and extensions of ETRS89
- European Vertical Reference System (EVRS)
- Symposia
- Outreach and external liaisons
- Publications

Overview and organisation

At the annual Symposium held in Bratislava (June 2004), the Terms of Reference (ToR) of EUREF were adopted. The ToR contain the description of EUREF, its objectives, activities, organization and the rules for membership according to the general rules expressed in the Statutes and By-laws of IUGG and, consequently, of IAG. The complete text can be found in http://www.euref-iag.net/html/Overview_of_EUREF_Terms_of_reference.html.

The long-term objective of EUREF is the definition, realization and maintenance of the European Reference Systems. All the work is done in close cooperation with the pertinent IAG components and EuroGeographics, the consortium of the European NMCA (*National Mapping and Cadastre Agencies*).

The forum where the activities are discussed and decisions are taken is the annual symposium. A fundamental element in the structure is the EUREF Technical Working Group (TWG), with the task to govern current activities, such as:

- to coordinate and develop the EPN;
- to evaluate and classify results of GNSS campaigns as EUREF densification or extension;
- to coordinate the actions for the realisation of a European Height System;
- to identify the relevant actions for the continuation and development of EUREF, with respect to innovation and the changing user needs;
- to set up the working groups to run the projects defined by the plenary;
- to prepare the recommendations for the EUREF plenary.

The TWG is composed by 17 members. It met 11 times in the period covered by the report. Information about TWG membership, agenda of the meetings and some contributions are available at http://www.euref-iag.net/html/twg.html.

EUREF Permanent Network (EPN)

During the period between June 2003 and April 2007, about 70 continuously operating GPS stations were integrated into the EUREF Permanent Network (EPN) bringing the total number of EPN stations to 200. The number of stations providing hourly data has increased from 58% to 84%. In addition, 42% of the EPN stations also submits data to the International GNSS Service, ten of them contributing to the TIGA (Tide Gauge Benchmark monitoring) Pilot Project of the IGS. 37 EPN stations provide GPS+GLONASS data.

The "Procedure for becoming an EPN station" has been completely revised. The new procedure is effective since Dec. 2006, and can be downloaded via the EPN Central Bureau (CB) web site http://epncb.oma.be/. The most important changes concerns the new requirements to submit a commitment letter guaranteeing that the station will be operated following EPN guidelines for a minimal duration of 5 years and the fact that all new EPN stations must have an antenna/radome with true absolute calibrations available from the EPN CB.

In addition, the 'Guidelines for EPN Stations and Operational Centres' have also been reviewed. The new guidelines were issued in order to improve the data flow within the EPN and to guarantee the availability of the EPN data at the regional (European) level. This will be achieved by making all EPN data available to two regional data centres: BKG (Federal Office of

Cartography and Geodesy, Germany) and OLG (Space Research Institute, Department of Satellite Geodesy Austrian Academy of Sciences, Austria). In addition, the new guidelines include now a section with guidelines for stations streaming real-time data.

The web site of the CB has added some new web pages showing the results of the monitoring of the long-term quality of the GPS observations. These pages have proven to be a valuable tool for indicating tracking changes. As a complement to the "Station latency reports" distributed monthly through EUREF mail, the EPN CB web site is now also displaying in graphical form the results of the monitoring of the delays of the hourly data and real-time data files.

Two EPN Analysis Workshops have been held. The first one was held from September 17-18, 2003, in Graz, Austria and the second one from March 15-16, 2006 in Padua, Italy. The minutes of both workshops are available at http://epncb.oma.be/_newsmails/workshops/

The EPN runs two special projects using the installed infra-structure: 'Monitoring of the EPN to produce coordinate time series suitable for geokinematics' and 'Generation of a EUREF-troposphere product'.

The general task of the Time Series Analysis Special Project (TSA_SP) is to promote the use of the EPN products for geophysical studies. Based on the periodically computed cumulative solution of the EPN combined weekly SINEX product, the TSA_SP maintains a database of the station coordinate offsets and outliers, estimates the most up-to-date coordinate and velocity solutions and performs noise and harmonic analysis of the time series. The TSA_SP contributed to the ITRF2005 by providing the offset and outlier database of the EPN stations. After the release of ITRF2005, the regularly updated EPN coordinate and velocity solution computed by the TSA_SP is considered as official for the EPN stations. All results are displayed at the EPNCB web-pages.

The goal of the second one is to derive tropospheric (zenith total delay) parameters as part of the estimation. The basic task within this activity is to produce a combined troposphere solution with input from the individual troposphere solutions of all Analysis Centers, which contribute to the coordinate solution. A 'rapid' combination derived to a given time contributes to the global IGS combined troposphere product. Information about these projects and further information are found at http://epncb.oma.be/organisation/projects/.

Following the request to contribute to the computation of ITRF2005 as a regional densification, the relevant information is being prepared by the analysis coordinator and analysis centres, in collaboration with the chair of the time series special project, in order to fulfil the requirements.
Another project based on the EPN structure is EUREF-IP (IP for *Internet Protocol*), with the goal to collect and disseminate GNSS data in real-time over the Internet. Under this project the transport protocol Ntrip (*Networked Transport of RTCM via Internet Protocol*) was developed. In September 2004 has been included in the standards of RTCM (*Radio Technical Committee for Maritime Services*). EUREF-IP established a specific IP address for its Ntrip Broadcaster service at http://www.euref-ip.net/home.

The total number of world-wide Ntrip Broadcaster installations known today is approximately 85. The total number of reference stations available via Ntrip technology amounts to approximately 1700, 52 of them are EPN stations, which is about one quarter of the EPN stations. Further information is available at http://www.rtcm-ntrip.org/home.

The current EUREF-IP efforts focus on developing a real-time Ntrip Monitoring/Notification system to reach and maintain a professional level of service availability, develop Ntrip towards full HTTP compatibility, introduce UPD as an additional data transport option, and encourage more EPN station operators to participate in EUREF-IP with real-time raw or RTK data.

Use and adoption of ETRS89

The ETRS89 (*European Terrestrial Reference System*) is being adopted as the official system for geo-referencing by several organisations in Europe and most of the European countries. In 2005 it was decided to continue to promote the use and adoption of the ETRS89 and to collect the most accurate and complete information on this subject. Consequently, a survey was conducted jointly by EUREF and EuroGeographics among 41 National Mapping and cadastral Agencies (NMCA). From the 41 countries contacted, 28 answered the questionnaire representing about 68% of the universe. The 3 different situations are as follows:

- 2 will not adopt (7% of the answers);
- 5 will adopt in the near future (18% of the answers);
- 21 have already adopted (75% of the answers).

The countries that informed that will not adopt the ETRS89 are Luxembourg and Turkey. On the other hand, since the realization of the questionnaire, 1 of the countries that announced to adopt the ETRS89 in the near future has already done it, increasing to 22 the number of countries that adopted this system.

Improvements and extensions of ETRS89

The establishment and maintenance of the European Reference Frame is achieved by a network of geodetic reference sites determined at national and multi-national level by GPS campaigns. In the last 4 years, the following campaigns have been validated by the TWG and accepted as class B standard (about 1 cm at the epoch of observation):

EUREF-Slovakia-2001 campaign in Slovakia;
EUREF-Pol-2001 campaign in Poland;
EUREF-Austria-2002 campaign in Austria;

EUREF-Hungary-2002 campaign in Hungary;
EUREF-Armenia-2002 campaign in Armenia;
EUREF-GB-2001 (re-computation of the campaign in Great Britain);
EUREF-NKG-2003 campaign in the Baltic countries. Points of Latvia & Lithuania included in data base;
EUREF-BG-2004 campaign in Bulgaria, combined with the EUREF-BG92/93, previously accepted in 1996.

The majority of these recent campaigns had the purpose to improve the accuracy of the former national reference frames expressed in ETRS89, as well as the densification of the existing network and/or replacement of old markers by GPS permanent stations.

For long-term maintenance of the European Reference Frame, the project European Velocity Field (EVF) aiming at the establishment of a dense velocity field model in Europe was started. The first results were presented at the EUREF Symposium in Riga in 2006.

European Vertical Reference System (EVRS)

The definition of the European Vertical Reference System 2000 (EVRS), including a European Vertical Datum and related parameters as realisation, is being revised, considering that the progress in global gravity models will soon make possible the realization of EVRS as a genuine World Height System.

The UELN (*Unified European Levelling Network*) is being densified and extended with new levelling observations. Contacts are being established with Russia for the inclusion of new levelling data in the Baltic area. The existence of repeated observations in some areas presents the chance to take a first step on the way to a geokinematic height network.

The projects EUVN_DA (*European Vertical GPS Reference Network Densification Action*) and ECGN (*European Combined Geodetic Network*) are under development. Further information about the European Vertical Reference System can be found at http://crs.bkg.bund.de/evrs/.

Symposia

Following the symposium held in Toledo in June 2003, three more symposia took place at Bratislava (Slovakia) in June 2004, at Vienna (Austria) in June 2005, at Riga (Latvia) in June 2006. The 2007 symposium that will take place in London (UK) in June 2007 is in preparation.

These meetings are usually attended by more then 100 participants from more than 30 countries in Europe. The web portal contains the contributions presented at the symposia, as well as the full set of resolutions of all the EUREF symposia since 1990 (http://www.euref-iag.net/html/symposia.html).

Outreach and external liaisons

The old web portal address was replaced by the new one http://www.euref-iag.net. In the mean time, a new address was created in the eu domain, http://www.euref.eu. Both addresses coexist and give access to a portal that links to all the EUREF structures and projects; its main contents are information about the EUREF structure and documentation related with the symposia and TWG meetings.

The liaison with EuroGeographics, the consortium of the National Mapping and Cadastre Agencies (NMCA) in Europe, continued through its Expert Group on Geodesy (ExGG). This liaison is concretized by the support of EuroGeographics to the organization of EUREF symposia, where a special session of ExGG is usually included. In order to upgrade this liaison, a Memorandum of Understanding (MoU) is being established between both organizations.

Furthermore, a Memorandum of Understanding is established with EUMETNET, a network of 21 European national meteorological services, with the purpose to create the conditions to facilitate the data exchange and to promote the increase in the cooperation between the two parties, for the benefit of both the meteorological and geodetic communities.

Publications

The proceedings of the EUREF symposia are the main source of information concerning the EUREF activities. In the period covered by this report were published:

- EUREF Publication No. 12, 2003,
- Report on the Symposium of the IAG Sub-Commission for Europe (EUREF), Ponta Delgada, 5 - 8 June 2002,
- Reports of the EUREF Technical Working Group. Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 29, Frankfurt am Main; ISBN 3-89888- 873-8, 425 pages,
- EUREF Publication No. 13, 2004,
- Report on the Symposium of IAG Sub-commission for Europe (EUREF), Toledo, 4 - 7 June 2003,
- Reports of the EUREF Technical Working Group. Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 33, Frankfurt am Main; ISBN 3-89888- 885-1, 451 pages.
- EUREF Publication No. 14, 2005.
- Report on the Symposium of IAG Sub-commission for Europe (EUREF), Bratislava, 2 - 5 June 2004.
- Reports of the EUREF Technical Working Group (TWG). Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 35, Frankfurt am Main; ISBN 3-89888- 795-2, 413 pages.

The proceedings of the symposia held in Vienna, 2005 and Riga, 2006, are under preparation. For enabling the early access to the contributions presented to symposia and TWG meetings, the original presentations are also pre-published in the EUREF homepage.

Sub-Commission 1.3b
Reference Frame for South and Central America (SIRGAS)

Report for the Period 2003 – 2007

LUIZ P. FORTES, EDUARDO LAURÍA, CLAUDIO BRUNINI, ANTONIO HERNANDEZ, LAURA SÁNCHEZ

Sub-commission 1.3b (South and Central America) encompasses the activities developed by the "Geocentric Reference System for the Americas" project (SIRGAS). As such, it is concerned with the definition and realization of a unified reference frame for South and Central America, consistent with ITRF, besides promoting the definition and establishment of a unique vertical reference system in this region.

During the 2003-2007 term many activities have been carried out in the scope of the SC 1.3b, i.e., the SIRGAS project. The official coordinates, along with their covariance information, of 184 GPS stations observed in the SIRGAS 2000 GPS campaign, covering the entire Americas, were released in February 2003. These coordinates are referred to ITRF2000, epoch 2000.4. A velocity field for South America was published in November 2003, after combining least-squares collocation and finite elements solutions.

The Executive Committee of project met in three opportunities to discuss the project activities: Aguascalientes, Mexico (December 2004), Caracas, Venezuela (December 2005), and Heredia, Costa Rica (November 2006). In addition to those meetings, a Workshop of the SC1.3b-WG1 on Continuous GNSS stations in Latin America was held in Rio de Janeiro, Brazil, in August 2006.

SC1.3b-WG1 "Reference System"

In this Working Group, dealing with the continental reference system, the SIRGAS Analysis Centers project was created in order to establish processing, comparison and combination centers in Latin America and the Caribbean countries. Therefore, since October 1st, 2006, the following processing centers are experimentally processing the continuous GNSS stations in the region:

- IGM and UNLP, Argentina,
- IBGE, Brazil,
- IGAC, Colombia, and
- INEGI, Mexico.

With this respect, DGFI continues to be in charge of the official processing of the entire network as the IGS Regional Network Associate Analysis Center for SIRGAS (RNAAC SIR).
In addition to that, the Atmospheric Studies for SIRGAS project was created with the objective of establishing a SIRGAS service based on continuous GNSS stations in Latin America and the Caribbean. Under this project, two types of service have been proposed: a production one, oriented towards the computation and dissemination of vertical TEC maps in a routine basis; and another one for researching ionospheric models that best fit the Latin America and the Caribbean region.

SC1.3b-WG2 "Geocentric Datum"

WG2 deals with the installation of the reference frames in the individual countries. Almost all South American countries have adopted or are in the process of adopting an official geodetic reference system based on SIRGAS. During the past four years a great successful effort has been carried out in terms of integrating the Central America countries to the project. As a consequence, a GPS campaign is planned to be held during the second semester of 2007 in this region.

SC1.3b-WG3 "Vertical Datum"

Efforts in WG3 concentrated on the determination of a reliable geopotential value W_0 within a global realization, i.e. a W_0 value applicable worldwide. Although the reference W_0 value of a vertical datum can arbitrarily be selected, it is preferred to introduce a quantity, which agrees with the precision of the latest observing techniques of the Earth's gravity field. In this way, W_0 was determined by applying different approaches (mean value of the geopotential values at the sea surface following the Gauss-Listing geoid definition, solution of the fixed gravimetric geodetic boundary value problem, etc.), different global gravity models (EGM96, TEG4, GGM02S, EIGEN-CG03C, EIGEN-GL04S), and different mean sea surface models (CLS01, KMS04, GFSC00.1). This study is required, since the new vertical reference system for SIRGAS is based on geopotential quantities, i.e., a global W_0 value as a reference and geopotential numbers as coordinates. In this way, a unified reference level is guaranteed for the different physical height types (orthometric and normal heights) and it allows the different countries to keep the physical heights they prefer.
Regarding the unification of the existing vertical datums in South America, the countries have continued the 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 reference frame stations. 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 data analysis, 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.

The SIRGAS activities related to the definition and realization of a new vertical reference system are integrated in the IAG Inter Commission Project 1.2: Vertical Reference Frames.

The project was represented in many international meetings with presentations. It can be cited: IUGG General Assembly, Sapporo, Japan (July 2003), XXII Reunión Científica de Geofísica e Geodésia, Buenos Aires, Argentina (September 2004), 8th United Nations Regional Cartographic Conference for the Americas. New York (July 2005), IAG Scientific Assembly, Cairns, Australia (August 2005), African Reference Frame Technical Workshop, Cape Town, South Africa (July 2006), Geodetic Reference Frames 2006, Munich, Germany (October 2006), etc.

Public Relations

A new project website (http://sirgas.igm.gov.ar) was developed in 2006, where all information related to the project can be found.

Many documents, papers, reports related to the project were published during this period. The most important are listed below:

Drewes, H., Heidbach, O. (2005): Deformation of the South American crust estimated from finite element and collocation methods. In: A Window on the Future of Geodesy, International Association of Geodesy Symposia, Vol. 128, 544-549, Springer.

Drewes, H., Kaniuth, K., Völksen, C., Costa, S. M. A., Fortes, L. P. S. (2005): "Results of the SIRGAS campaign 2000 and coordinates variations with respect to the 1995 South American Geocentric Reference Frame". In: A Window on the Future of Geodesy, International Association of Geodesy Symposia, Vol. 128, 32-37, Springer.

Fortes, L. P. S., Lauría, E., Brunini, C., Navarro, A. H., Sanchez, L., Drewes, H., Seemüller, W. (2005): “El Proyecto Internacional SIRGAS: estado actual y objetivos futuros”. Proceedings of the 8th United Nations Regional Cartographic Conference for the Americas. New York.

Fortes, L. P., Lauría, E., Brunini, C., Amaya, W., Sánchez, L., Drewes, H., Seemüller, W. (2006): Current status and future developments of the SIRGAS Project. Festschrift dedicated to Prof. Dr.-Ing. h.c. Günter Seeber on the occasion of his 65th birthday and his retirement. Scientific work in the field of Geodesy and Geoinformatic of the University of Hanover, Vol. 258, 59-70.

Fortes, L. P., Lauría, E., Brunini, C., Amaya, W., Sánchez, L., Drewes, H., Seemüller, W. (2006). “SIRGAS – A geodetic enterprise”. Coordinates Magazine, Volume II, 5th edition, May of 2006.

Sánchez, L.; Krügel, M. (2006). The role of the TIGA project in the unification of classical heigt systems. Presented at the IAG Symposium GRF2006 (Geodetic Reference Frames 2006). Munich, Germany. October 9 to 13, 2006. (In press).

Sánchez, L. (2006). Strategy to establish a Global Vertical Reference System. Presented at the IAG Symposium GRF2006 (Geodetic Reference Frames 2006). Munich, Germany. October 9 to 13, 2006. (In press).

Sánchez, L., C. Brunini (2006). Achievments and chalenges of SIRGAS. Presented at the IAG Symposium GRF2006 (Geodetic Reference Frames 2006). Munich, Germany. October 9 to 13, 2006. (In press).

Sánchez, L (2006). Approach for the establishment of a global vertical reference system. Presented at the VI Hotine-Marussi Symposium. Wuhan, China. May 29 to Juny 02, 2006. (In press).

Sánchez, L (2007). Definition and Realization of the SIRGAS Vertical Reference System within a Globally Unified Height System. IAG Symposia, Vol. 130: 638-645, Springer.

SIRGAS Newsletters #8 (February 2005), #9 (April 2006), #10 (September 2006), #11 (December 2006), all available at (http://sirgas.igm.gov.ar).

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

Report for the Period 2003 – 2007

MICHAEL CRAYMER, RICHARD SNAY

This sub-commission has 3 active working groups. The following summarizes the activities of each.

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. Work continued on the production of weekly GPS coordinate solutions for nearly 800 continuously operating ITRF/IGS densification stations in North America. These solutions are a combination of six different regional solutions using four different GPS processing software. The combined solutions are being submitted to the IGS, together with weekly processing reports, with a latency of approximately 4 weeks. Most recent improvements since 2003 have been the incorporation of a weekly regional solutions for over 560 US CORS stations using the PAGES processing software, and for over 180 stations from MIT's official daily combinations of the Plate Boundary Observatory solution. The preliminary Plate Boundary Observatory solution from Scripps was also expanded from 50 to 75 points with plans to include all primary US CORS and all CGPS sites in Canada beginning with GPS week 1400. Currently, submissions have been delayed since GPS week 1400 while some regional processing centers update their software and processing procedures for the new IGS processing strategy, including precise orbits based on absolute phase centers. Cumulative solutions have also been computed based on the weekly combinations up to week 1399 to provide velocity estimates for all sites with a data span of at least one year. This solution is being contributed to the ITRF2005 densification effort.

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

Significant efforts began under this newly created joint working group with UNAVCO, Inc. in support of the Earth Scope project. The goal is to define a plate-fixed regional reference frame for North America stable at the mm-level to provide a standardized and consistent reference frame in support of geodynamics studies throughout the continent. Seven workshops to define the reference frame been held since 2004. The 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 frame based on improved GPS velocity solutions and ITRF2005 is expected by the end of 2007. Reference frame products includes coordinates and velocities (with uncertainties) for all frame sites, a model for glacial isostatic adjustment, and rotation rates with respect to ITRF2000. Further versions will follow as the reference frame is improved. More information about the working group is available from the UNAVCO web site (follow the links at <http://www.naref.org/>).

SC1.3c-WG3: Reference Frame Transformations

This WG 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 (in Canada and the U.S.) relationship between ITRF and NAD83. The later 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.

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

Report for the Period 2003 – 2007

RICHARD WONNACOTT

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 assist in establishing in-country expertise for implementation, operation, processing and analysis of modern geodetic techniques, primarily GNSS.

These objectives are to be carried 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, a great deal of organizational development and promotional effort among various organizations has taken place.

Progress During the Review Period

Progress on the AFREF project has been slow but steady with a number of meetings and workshops being held. It is important to note that, although progress has been slow, the National Mapping Organizations and relevant University departments in Africa are aware of AFREF and are showing keen interest in the project. Added to this is awareness and support which organizations outside of Africa are offering the project. The support shown for the project from within Africa and by International agencies is reflected in an increased activity with the installation of permanent GNSS receivers particularly in the latter half of 2006 and early part of 2007. The exact number and location of new installations is uncertain at this stage but the United Nations Economic Commission for Africa's (UNECA) Committee On Development Information – Geo-information (CODI-Geo) has embarked on an audit of installations through its AFREF Steering Committee. It is hoped that the first results of this audit will be available by the middle of 2007.

The following are some of the highlight AFREF related meetings held between 2003 and 2007.

2004 August:

UNECA CODI met in Addis Ababa and accepted the Windhoek Declaration and established an AFREF Working Group and nominated a Steering Committee thus giving the project some official status within CODI. In broad terms, the Windhoek Declaration was a commitment by the 8 signatory countries to:

- Support the AFREF project;
- Publicize & promote the project within their respective Governments and international organizations; and that
- The UNECA should accept the principles and concepts of AFREF and these be accepted and implemented by UNECA CODI;
- UNOOSA be requested to support the project; and
- The IAG and the IGS be requested to continue to support the project and assist with it's implementation.

2004 October:

The African Association of Remote Sensing of the Environment met in Nairobi and at the same time the CODI – Geo AFREF Steering Committee met for the first time. At this meeting a structure and terms of reference for the committee and working group was agreed upon.

2004 November:

The United Nations Office for Outer Space Affairs (UNOOSA) group of GNSS experts met in Vienna and endorsed and gave support to the AFREF project largely as the outcome of one of 4 regional workshops on the "Use and Application of Global Navigation Satellite Systems (GNSS)" held in Lusaka in July 2002.

2005 April and 2006 March:

Dedicated sessions or workshops were held during the FIG Working Week in Cairo, Egypt in April 2005 and the FIG Regional Conference held in Accra, Ghana in March 2006. A Call for Participation in the project was prepared in Cairo and has subsequently been distributed to International agencies and NMOs in Africa.

2006 July:

A very successful technical workshop was held in Cape Town, South Africa which was attended by approximately 40 delegates from 19 African countries. 15 representatives from a number of International Organizations including the IGS, UNAVCO, IGN, BKG, NGS and HartRAO gave excellent presentations. The workshop was sponsored by IAG, UNAVCO, UNOOSA, University of Cape Town, Department of Land Affairs, the National Research Foundation in South Africa and GNSS equipment vendors.

Publicity

Apart from the various meetings and workshops that have been held during the past four years, numerous articles and reports on AFREF have been published in industry journals and on the internet. Such articles have generated a great deal of interest and support for the project among surveyors, cartographers and GIS practitioners.

Conclusion

Progress with the AFREF project has been slow but has reached a stage of high level awareness among international organizations and NMOs in Africa. The IAG and IGS are among the international organizations that have committed their support for the project. It is believed that the next four-year period will see many new permanent GNSS receivers being installed throughout Africa and possibly the first results of the GNSS data processing from these stations being published.

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

Report for the Period 2003 – 2007

JOHN MANNING

The work of the Sub-commission on the Asia Pacific Reference Frame for this period has been carried out in conjunction with the Regional Geodesy Working Group of the Permanent Committee for GIS Infrastructure in the Asia and the Pacific region (PCGIAP). The role of this working group has been to coordinate regional cooperation in Geodesy amongst national agencies and to build a regional geodetic infrastructure. This group has the dual function to report on relevant activities to the UNRCC-AP and to the IAG Sub-commission to the Asia Pacific Reference Frame. Members of this working group are nominees from national surveying and mapping organizations rather then being drawn from academic institutes.

The inaugural business meeting of the PCGIAP Working Group was held in Sydney, Australia in 1996. The initial goal of the Geodesy Working Group was to establish a precise regional geodetic reference framework from Central Asia to the Pacific. A primary achievement of the working group has been to establish a single regional horizontal geodetic datum and provide linkages for individual country datums to this regional datum through densification of the International Terrestrial Reference Frame .

The 16th United Nations Regional Cartographic Conference for Asia and the Pacific (UNRCC-AP) held in Okinawa in July 2003, acknowledged the achievements of the PCGIAP Regional Geodesy Working Group and endorsed a resolution in relation to the ongoing activities of the Geodesy working group to:

- The enhancement of a regional geodetic infrastructure through annual cooperative campaigns, including ties to vertical datum origin points,
- Review the status of the regional geoid in relation to current and improved global gravity models available from satellite gravity, and the application of absolute gravity as a means of developing a regional gravity reference frame,
- Promote the application of new geodetic adjustment techniques and datum change transformation parameters for regional spatial data integration and for geo-referencing cadastral and statistical information,
- Encourage the transfer of GPS technology to Pacific Island nations and other developing countries through regional and local geodesy workshop activities,
- Development of a catalogue of regional tide gauges for monitoring sea level changes and placement of GPS at key sites, and
- Review the status of geodetic networks in individual countries and upgrade the PCGIAP web site information.

All activities during this period 2003 –2006 were guided by a work plan through to the 17th UNRCCC-AP which was held in United Nations Regional Office in Bangkok in September 2006. However unexpected tectonic events have had a significant impact on Geodesy in this period with Indonesian earthquakes and devastating tsunami aftermaths of the December 2004 events, requiring more detailed attention to reference frameworks related to these events.

There were a number of recent face-to-face meetings held to maintain contact between working group members and to assist progress on projects. These included the following:

- An informal meeting of the working group was held during the 10th PCGIAP meeting in Bangalore, India in January 2004,
- A regional Geodesy workshop was held in Chengdu, China in September 2004 in conjunction with IAG Commission 2,
- A special Tsunami workshop was hosted by Indonesia in Bali in May 2005,
- A regional Geodesy workshop was hosted by Geoscience Australia immediately before the IAG General Assembly in Cairns, Australia, August 2005,
- An associated meeting on regional gravity was hosted by Mongolia in Ulan Baatar in June 2006

A full report of the 11th PCGIAP meeting in Bali is available on the PCGIAP web site http://www.gsi.go.jp/PCGIAP/bali/bali_rep.htm and presentations for the Cairns meeting are available on CD from.

Annual, week long GPS regional campaigns were observed in 2004,2005 and 2006. Geoff Luton from Geoscience Australia continued to be the coordinator for annual GPS observation campaigns for ten years in a row. Participation in the campaigns typically included:

2003: 25 countries & 112 sites
2004: 15 countries & 62 sites
2005: 16 countries & 38 sites

Data from these campaigns is collated and available to countries requesting the observational data. Combined solutions have been compiled by Geoscience Australia and submitted for use in ITRF determinations (through geoff.Luton@ga.gov.au). Near concurrent regional geodetic VLBI projects, have been arranged each year with the Asia Pacific Space Geodynamics group, as:

SESSION	DATE
APSG-12	08 OCTOBER 2003
APSG-13	21 OCTOBER 2003
APSG-14	15 SEPTEMBER 2004
APSG-15	27 SEPTEMBER 2004
APSG-16	11 OCTOBER 2005
APSG-17	06 DECEMBER 2005
APSG-18	OCTOBER 2006

Whilst the GPS campaigns have been undertaken for ten years, it is apparent that with the increase in continuous stations it is no longer technically essential to hold specific date campaigns to disseminate the precise global coordinates for infrastructure points through the region. Some agencies such, as Geoscience Australia (GA) now compute regular weekly solutions. This was evident in computing the events of the December 2004 earthquakes. Observation campaigns can be observed at the individual country's convenience as GA offers to include these in their weekly regional solutions. Changes to technology now enable observations made at any time throughout the year to be included in regular regional computations, which in turn are forwarded to global peak Global geodesy bodies for inclusion in the densification of the International Terrestrial Frame. The general tectonic movements in the South East Asian area are shown in the figure 1.

Work on the regional geoid project saw good cooperation between Japan and China to establish a high precision gravity network by successfully carrying out FG5 absolute gravity observations in remote locations, in China (Lhasa); in Malaysia (Sabah, Kuala Lumpur), in Indonesia (Bogor and Yogyacarta) and in the Phillipines with 28 sites observed. Other instrumental comparisons had been made at Wuhan in China between three FG5 units. China is looking to take an FG5 to nearby countries for observations in Vietnam. This absolute gravity framework underpins the national gravity networks, which in turn are essential for coordination and computation in an upgraded regional geoid. This project is complex with volume of space gravity observations becoming available and release of new global gravity models from Champ and Grace Satellite missions remains a huge but unfunded task. A number of absolute gravity points were observed across Australia the country as a framework for relative gravity. There was also cooperation with Japan for FG5 precision absolute gravity occupation of a site in Perth when en route to Syowa Antarctica and also in Canberra during its return to Japan. Further cooperative interaction has been discussed with IAG Commission 2, Sub-Commission on the SE Asia Geoid.

The transfer of Geodetic and GPS technology projects were taken forward in the Pacific considerably by Australia, which now has a continuous GPS tracking system associated with tide gauges for monitoring global change purposes in the South Pacific. The sites are located in the following countries: Samoa, Cook Islands, Tuvalu, Tonga, Nauru, PNG, Kiribati, Micronesia, Fiji, Vanuatu, Palau. Data from these GPS sites are available from Geoscience Australia for local and global scientific research and local applications.

The project for the development of a catalogue of regional tide gauges with nearby GPS placements is ongoing Geodesy activity in the region, which requires responses from individual countries. The project was overtaken in the immediate short term by the Banda Aceh and associated Indonesian earthquakes and resultant regional tidal waves. This event triggered a new priority approach for near real time monitoring of the land surface movement using positional data from continuous GPS trackers and a reassessment of tide gauge installations. This remains a priority for consideration, as there have been major earthquakes in the area in 2005 and 2006 with loss of very many lives in Yogyakarta and Pangandaran Beach regions.

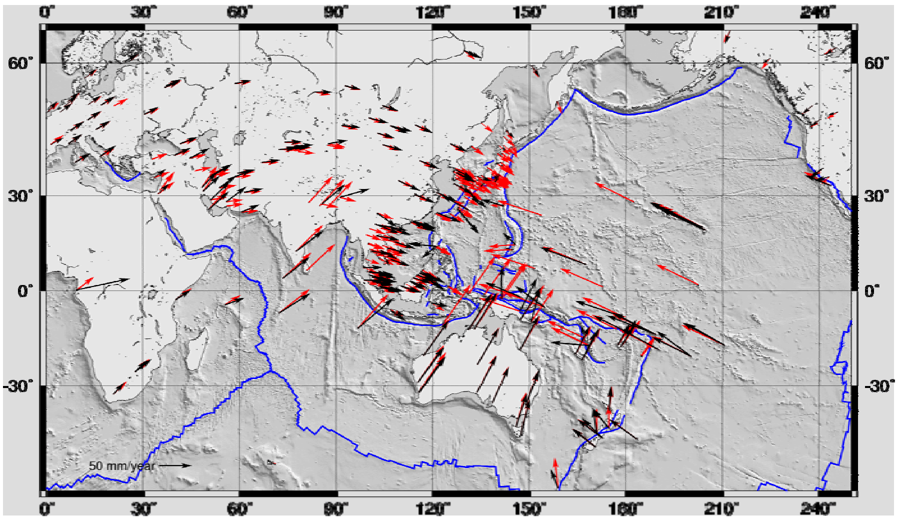

Figure 1: Plate velocities from repeated GPS observations

The Banda Aceh and Nias earthquakes focused world attention on the impact of tectonic crust motion occurring as surface events or as submarine events. These earthquakes have unsettled the earth's crust in the region and other major earthquakes and volcanic eruptions continue to cause havoc and loss of human life and infrastructure devastation. Geodetic technology offers a means of early detection and measurement of the result of land movements. Indonesia bears the brunt of these events, current technology is not able to predict only to warn vulnerable areas of imminent impact in the short term, A number of countries such as Germany and Japan are working on measures to enable better warning systems for Tsunami waves to be installed, but the application of available technology is costly and technically difficult. Dr Surabaya from Indonesia presented a comprehensive report on the situation at the Cairns regional workshop, which included a graphic of details of the Banda Aceh event, see figure 2:

Workshop outcomes from the open Regional geodesy meeting held in association with the IAG conference in Cairns Australia discussed the impact of the Banda Aceh tsunami and subsequent geodetic and geophysical activity in the establishment of monitoring systems both in individual countries and in overall regional Tsunami warning systems was the subject of continued discussion following the Bali meeting. Shigeru Matsuzaka presented the comprehensive Japanese Daphne project on earthquake monitoring in the region on behalf on Dr Imakire from GSI.. Presentations are included on the CD Rom of the Regional Geodesy workshop in Cairns in August 2005, which is available from Geoscience Australia. Future activity requires close cooperation throughout the South East Asian region with the placement of receivers with data being quickly available for warnings, and as a basis for reconstruction planning. This imitative deserves IAG support in the monitoring of earthquakes events and surface movements by GPS technology.

The status of the geodetic networks in individual countries was updated on the PCGIAP web site by Japan but needs constant attention as geodetic datums in the region are continually being updated as the countries move to introduce Geocentric based coordinates. Australia is moving to a vastly upgraded national network which is being coordinated by Geoscience Australia (contact gary.Johnston@ga.gov.au) whilst Malaysia is introducing a real-time precise GPS network for land and sea applications.

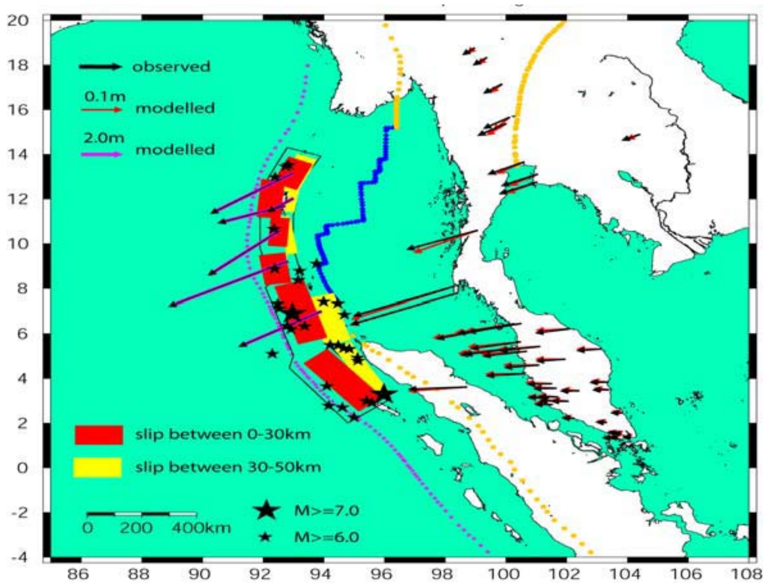

Figure 2: Analysis of the Banda Aceh earthquake slips

Australia has computed all observations for the first six campaigns and forwarded the solution to the IERS for inclusion as regional densification in the new global reference frame being computed.

The Regional Geodesy group also supports the TIGA sea level monitoring project with GPS data from sites near tide gauges. Geoscience Australia recently delivered initial regional solutions to the TIGA project of the International GNNS Service, which monitors the vertical motion of continuous GPS base stations collocated with precision tide gauges. All data and solutions are available from Geoscience Australia.

The 17th UNRCC-AP was held in September 2006 and the meeting recommended the continuation of Regional Working Group activities and its interface with IAG commissions. The next meeting of the regional geodesy working group will be held in south Korea later this year and a meeting is planned for Fiji at the tiem of the propose PCGIAP meeting during GSDI conference in 2008. The Chairman of the PCGIAP working group is Dr Matsuzaka shigeru@gsi.go.jp<>from GSI and Dr Pengfei Cheng chengpf@casm.ac.cn from China is the vice chair.

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

Report for the Period 2003 – 2007

REINHARD DIETRICH

1. Observation Campaigns

The SCAR GPS Campaigns 2006 and 2007 were carried out in the austral summers 2006 and 2007. All together, the data of 34 Antarctic sites are now collected in the SCAR GPS database beginning with the year 1995.

2. 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 XXVIV SCAR Meeting in Hobart/Australia in July 2006 and at the GRF2006 Symposium in Munich in October 2006.

3. Meetings

During the XXVIV SCAR Meeting in Hobart in July 2006 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 2006-2008. R. Dietrich (Germany) was endorsed as the chairman of GIANT. The members of GIANT represent the SC1.3f.

4. The International Polar Year 2007/2008

The International Polar Year 2007/2008 started at 1st of March 2007 and will continue until 28th of February 2009. It is organized jointly by ICSU and WMO, and provides the frame for a broad range of coordinated, international projects.

The SC1.3f actively participates in the frame of the project POLENET (Polar Earth Observing Network). In October 2006 a POLENET workshop was organized in Dresden, where also issues of the reference system realization in Antarctica were discussed.

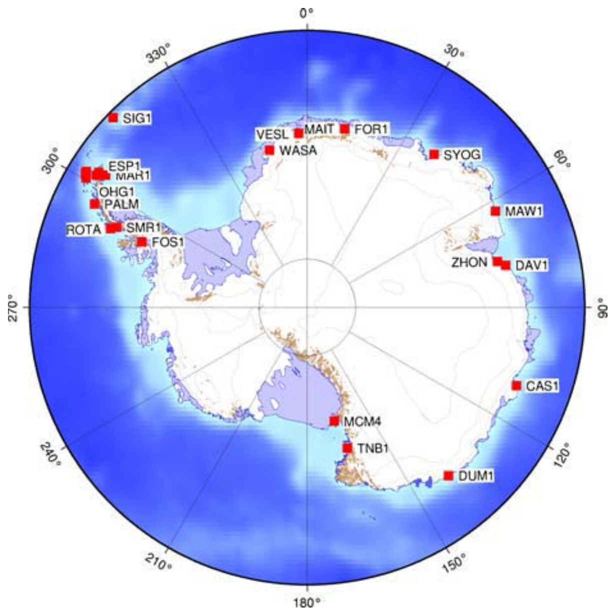

Figure 1: Distribution of GPS sites in Antarctica.

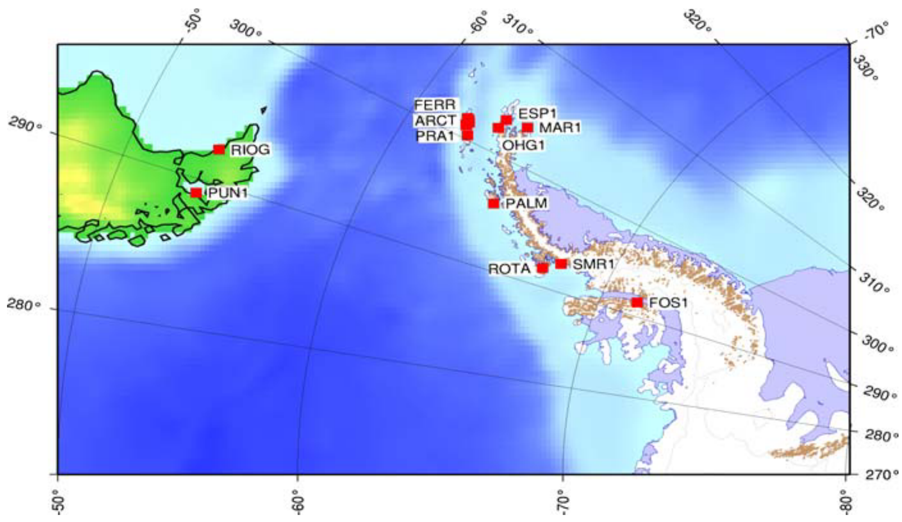

Figure 2: Distribution of GPS sites in Antarctica: Peninsula in detail

Sub-Commission 1.4
Interaction of Celestial and Terrestrial Reference Frames

Report for the Period 2003 – 2007

H. SCHUH, R. HEINKELMANN, J. SOKOLOVA, V. TESMER

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 was focusing during the report period on the consistency between the various reference frames.

The retirement of the former president S.Y. ZHU in 2005 caused a kind of break of the activities of SC 1.4 as the new president (H. Schuh) could only chair the Sub-Commission since summer 2006, i.e. during the last 9 months of the period to be reported here. Thus, this report will give a general overview only and will concentrate on the research and studies carried our since the Mid-Term Report 2005 (Zhu et al., 2005). Concerning the research done within the four Working Groups of Sub-Commission 1.4 only some examples can be given below.

WG1.4.1: Theoretical Aspects of the Celestial Reference System

Scheduled activities were:
– Study the effects of the new IAU definitions, the relation between the barycentric system (as realized by VLBI) and the geocentric system.

The celestial and terrestrial ephemeris origin replaced in 2003 the vernal equinox and the traditional first axis of the terrestrial intermediate frame. Consequently, the Earth rotation angle replaced the apparent sidereal time. The Earth orientation parameters consisting of the difference between UTC and UT, the polar motion parameters, and the nutation residuals, connect the CRF and the TRF. That makes it possible to represent each of these frames by the other one plus the Earth orientation parameters. A change or error in one of the two frames must therefore be compensated by a corresponding change in the other frame and/or the Earth orientation parameters, and any error in the orientation parameters must be reflected by a change in at least one of the two reference frames. In 2006 new IAU definitions were adopted with relevance for WG 1.4.1:

IAU Resolution B1 (http://www.iau.org/fileadmin/content/pdfs/IAU2006_Resol1.pdf) deals with the adoption of the P03 Precession Theory and Definition of the Ecliptic and recommends that, beginning on 1 January 2009, the precession component of the IAU 2000A precession-nutation model be replaced by the P03 precession theory of Capitaine et al. (2003).

IAU Resolution B2 (http://www.iau.org/fileadmin/content/pdfs/IAU2006_Resol2.pdf) is a supplement to the IAU 2000 Resolutions on reference systems. Recommendation 1 deals with harmonizing the name of the pole and origin to “intermediate”. According to its main recommendation the terminology “Celestial Intermediate Origin” (CIO) and “Terrestrial Intermediate Origin” (TIO) will be used in place of the previously introduced “Celestial Ephemeris Origin” (CEO) and “Terrestrial Ephemeris Origin” (TEO). Recommendation 2 is on the default orientation of the Barycentric Celestial Reference System (BCRS) and the Geocentric Celestial Reference System (GCRS).

WG1.4.2: Realization of Celestial Reference Frames (CRF and Transformations)

Scheduled activities were:
– Survey of the current status of CRF realization;
– Review of implementation of IERS Conventions and IAG Fundamental Parameters.

To achieve further progress regarding the realization of celestial reference frames it is essential to review the current status, to identify deficiencies and to make proposals for improvements. This task was closely related to various components of the IERS (e.g., ICRF PC, CRCs) and the techniques analysis coordinators (in particular of the IVS), and required a close cooperation between the different groups. The activities included the survey of the current status of CRF realization, a review regarding the implementation of IERS Conventions and IAG Fundamental Parameters and different space techniques for CRF realization. Many aspects related to this WG were treated in the IERS Technical Note 34.

Concerning the barycentric CRF the International Celestial Reference Frame (ICRF) is realized by VLBI (Ma et al. 1998). The International Celestial Reference Frame (ICRF) is currently defined by the radio positions of 212 extragalactic objects. Since its inception there have been two extensions to the ICRF: ICRF-Ext.1 (IERS, 1999) and ICRF-Ext.2 (Fey et al. 2004). These extensions included revised positions of ICRF candidate and "other" sources, based on inclusion of additional observations, as well as positions of an additional 109 "new" sources. With continued applicable VLBI observations and improvements in analysis a better realization of the ICRF is now possible and an even better realization is feasible in the foreseeable future.

Planning for a second realization of the ICRF is currently underway with a projected completion date concurrent with the XXVII[th] IAU General Assembly in 2009. Two Working Groups (WG) were established on the second realization of the ICRF (ICRF2) as a joint project of the International Astronomical Union (IAU), the International Earth Rotation and Reference Systems Service (IERS) and the International VLBI Service for Geodesy and Astrometry (IVS).

Goal of the IAU WG: Oversee generation, validation and utility of ICRF2; engage in formulation of resolutions of adoption by IAU (http://rorf.usno.navy.mil/ICRF2/IAU/).
Goal of the IVS/IERS WG: Produce ICRF2 for IERS / IVS consideration and for submission to the IAU Working Group (http://www.iers.org/MainDisp.csl?pid=198-1100160).

Scientific contents of the WG chaired by Chopo Ma are:

- defining source selection,
- catalogue generation and comparison,
- time series generation, comparison and analysis,
- unstable source selection and position estimation,
- modelling effects comparisons,
- TRF and EOP comparisons,
- data selection testing.

Concerning highly precise optical celestial reference frames, the state of the art optical catalogue is the FK6 (Wielen et al. 1999). It includes the FK5 and the Hipparcos-Catalogue.Upcoming optical astrometry space missions such as GAIA (Global Astrometry Interferometer for Astrophysics) and SIM (Space Interferometer Mission) will significantly enhance the quality of the optical catalogues in terms of position precision and number of stars.
The primary reference to work of WG 1.4.2 is the IERS Technical Note 29.

WG 1.4.3: Systematic Effects in the CRF Determination

Scheduled activities were:

- Identify inconsistencies between different software regarding CRF determination.

It is well-known that the accuracy achieved today is mainly limited by technique- and/or solution-related systematic biases (effects), which are often poorly characterized or quantified. This issue was addressed regarding the determination of the celestial reference frame. The tasks included the identification and description of inconsistencies (systematic effects, refined models).

Here a lot of work has been performed by various groups. A rather complete quantification of systematic and statistic effects on the CRF determination has been done by Tesmer et al. (2006a, 2006b), and Tesmer (2007). MacMillan and Ma (2007) also investigated network effects and proper motions of sources on the CRF determination.

Comparison between various CRF realizations

Various VLBI CRF realizations were compared to each other which were submitted by the following eight IVS Analysis Centers: AUS (Geoscience Australia), BKG (Bundesamt für Kartographie und Geodäsie, Germany), DGFI (Deutsches Geodätisches Forschungsinstitut, Germany), GSFC (NASA Goddard Space Flight Center, USA), JPL (NASA Jet Propulsion Laboratory, USA), MAO (Main Astronomical Observatory of the National Academy of Sciences, Ukraine), SHAO (Shanghai Astronomical Observatory, China), USNO (U. S. Naval Observatory, USA). A brief description of the input catalogues is given in Table 1.

IVS Analysis Center	Software	Time span (month/year)	Number of delays	Number of sources (total sources/reference sources)
AUS,	OCCAM	11/1979 – 12/2004	3208197	737 / 207
BKG	Calc/Solve	01/1980 – 01/2005	4031453	748 / 212
DGFI	OCCAM	01/1984 – 01/2005	3650771	686 / 199*
GSFC	Calc/Solve	08/1979 – 01/2005	4574189	954 / 212
JPL	MODEST	10/1978 – 01/2005	3575847	734 / 2
MAO	SteelBreeze	10/1980 – 01/2005	3773765	685 / 25
SHAN	Calc/Solve	04/1980 – 01/2005	4431503	813 / 212
USNO	Calc/Solve	09/1979 – 01/2005	4252684	943 / 207

Table 1. VLBI CRF realizations submitted for the next ICRF by eight IVS Analysis Centres. The last column shows the number of sources in the catalogue and the number of reference sources used to tie the orientation of the catalogue to the ICRF. (* - 199 stable sources from M. Feissel-Vernier stable list).

Weighted root-mean-square (WRMS) differences of the radio source coordinates between the CRF catalogues calculated by the eight IVS Analysis Centers and the ICRF are shown in figure 1. One can see that the WRMS differences get the least values for catalogues computed with the Calc/Solve software, both for mutual comparison of these catalogues and their comparison with the ICRF. The latter is most probably caused by the fact that the ICRF was constructed using Calc/Solve. Large WRMS differences between JPL and other catalogues may be caused by its orientation which was defined by only two reference sources, unlike other catalogues, for which a much longer list of reference sources was used. Catalogue AUS shows the greatest differences with the other catalogues, probably because it is the only catalogue which was constructed using the Least Squares Collocation method, while the other Analysis Centers used conventional Least Squares. One can see that the DGFI catalogue, which was also constructed using the OCCAM software but with its Least Squares version, does not stand out against other catalogues. The WRMS differences between the input catalogues in itself may not be very valuable, especially if they are caused by differences in the orientation of their axes, more interesting is the fact that all the input catalogues demonstrate rather large differences with the ICRF, which may indicate significant systematic errors in the ICRF (Sokolova and Malkin, 2007).

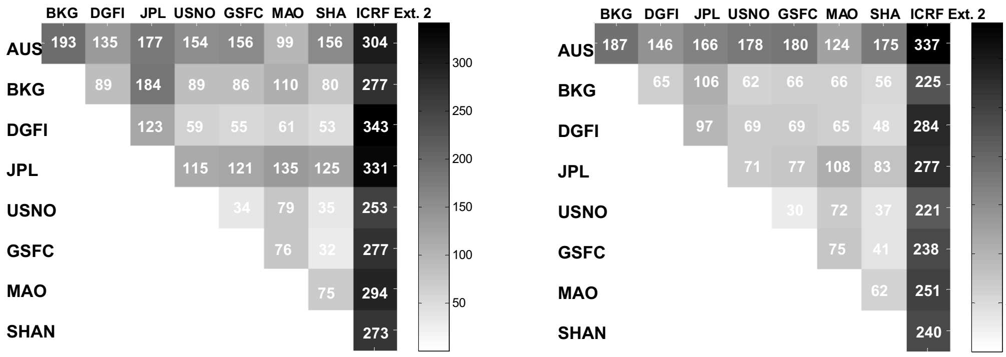

Fig. 1: WRMS differences of the radio source coordinates between CRF catalogues calculated by eight IVS Analysis Centres, μas (Δα - left figure, Δδ - right figure).

Effects of geodetic datum definition on VLBI-determined CRF

An important issue for the CRF determination is the choice of sources used for the NNR constraints. The external reliability is an appropriate measure for the quality of a datum (see e.g. Kutterer, 2004). In the absence of errors any arbitrary subset of datum points which satisfies minimal conditions by removing the datum deficiency of the equation system, yields identical results. The optimal datum in terms of external reliability is that one which includes all points. However, when analyzing ‘real’ data the optimal subset of datum points has to be selected by considering quantity, stability, and geometry.

In order to quantify the effects of the datum on the CRF determination, various subsets of celestial datum points were used for the NNR constraints:

– 199 ‘stable’ sources (Feissel, 2003),
– 71 sources with structure index 1 in both X-, and S-band (Fey, 1997),
– 212 sources of category ‘defining’ of the ICRF (Ma et al., 1998),
– 121 sources with both components tested for normal distribution w.r.t. constant position (Engelhardt and Thorandt, 2006).

These subsets were used for the NNR constraints w.r.t. ICRF-Ext.2 and applied to the same accumulated normal equation system of solution IGG05R01 (Heinkelmann et al., 2006) including more than 2600 24-hour sessions and 466 sources. The results of the CRF realizations for the various subsets differ by very small rotations. Maximal rotations are found between the subsets of Feissel’s stable sources and Fey’s structure index categorization. They reach ω_1 = 13.4 μas, ω_2 = 9.4 μas, and ω_3 = 0.2 μas.

Effects of meteorological data on VLBI-determined CRF

For the analyses of space-geodetic techniques various series and models of meteorological data are in use. The meteorological quantities atmospheric pressure and surface temperature are of main importance. The atmospheric pressure is needed for the hydrostatic zenith delay, atmospheric loading and mapping functions, whereas the surface temperature is mainly relevant for antenna thermal deformations. Heinkelmann et al. (2007) investigated various meteorological data and their impact on TRF and CRF determination:

– in-situ meteorological records (IVS),
– meteorological series derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) numerical weather model (NWM),
– empirical global pressure and temperature (GPT) model (Böhm et al., 2007),
– Berg’s model of the atmosphere (BERG).

The meteorological series were used as input to the same solution IGG05R01 (Heinkelmann et al., 2006) using identical settings. The effects of meteorological quantities on the determination of CRF show no significant systematics. Maximal variations of right ascension and declination reach ±100 as. They appear between BERG and IVS series.

Effect of various analysis options on VLBI-determined CRF

The effect of various analysis options on VLBI-determined CRF was investigated by Tesmer et al. (2006a, 2006b) and Tesmer (2007):

- different troposphere mapping functions and gradient models,
- choice of the data set (neglecting sessions before 1990 and 21 astrometric sessions),
- handling of sources that may not be assumed to have time-invariant positions,
- handling of the station network (estimate the station positions per session, as positions and velocities over 20 years, or fix them to a priori values).

The biggest, clearly systematic effects in the estimated source positions up to 0.5 mas were found to be due to different gradient models, the selection of the a priori values and the constraints (see figures 2, 3 and 4, grey stars indicate the differences between the declination estimates of the 2769 sources in the solution, the solid red lines are median values computed each 0.5° for all values inside a ±12.5° band). The choice of the data set does generally not have a significant influence (see figure 5). This holds also (with several exceptions) for different options how to treat sources which are assumed to have time-invariant positions. Furthermore it turned out that fixing station positions to values not consistent to the solution itself can noticeably affect CRF solutions (see figure 6).

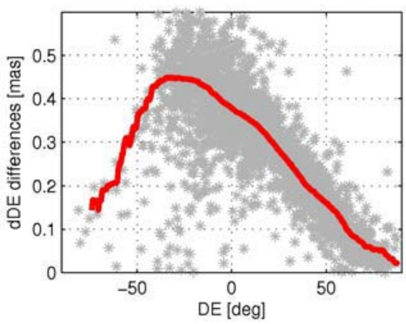

Fig 2. Differences between 2769 declination estimates of two CRF solutions: with no gradients estimated – with gradients estimated slightly constrained.

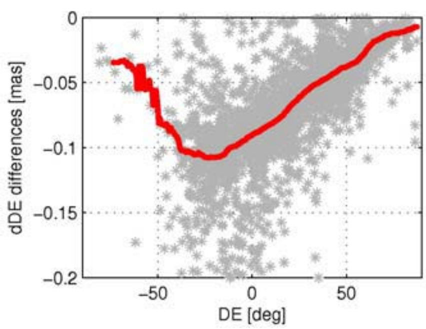

Fig 3. Differences between 2769 declination estimates of two CRF solutions: with gradients estimated fully unconstrained – with gradients estimated slightly constrained.

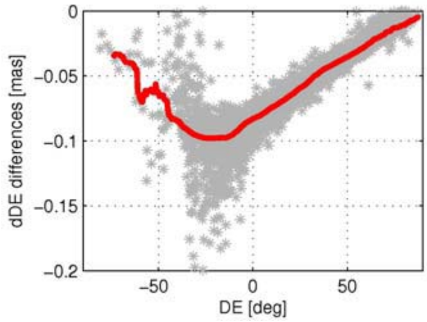

Fig 4. Differences between 2769 declination estimates of two CRF solutions: using constant a priori gradient values (mean of 1990-1995 from DAO weather model) – using 0 a priori gradient values.

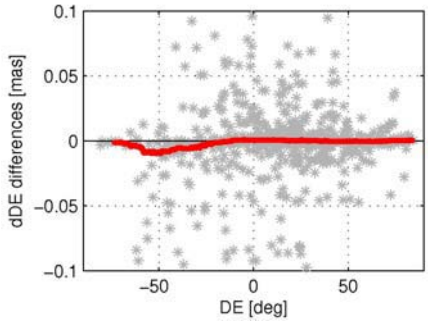

Fig 5. Differences between 669 declination estimates of two CRF solutions: without using the 21 sessions of the VCS (VLBI Calibrator Surveys) – with using the VCS sessions.

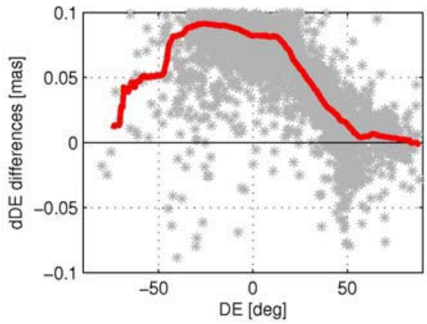

Fig 6. Differences between 2769 declination estimates of two CRF solutions: all stations fixed to a preliminary solution of ITRF2005 – estimating positions and velocities for all stations.

WG 1.4.4: Interaction Between Celestial and Terrestrial Reference Frames

Scheduled activities were:

- Identify effects of errors in the CRF on the TRF and related products (e.g. EOP) and vice versa.
- Compare the EOP with geophysical models and identify the effect of Earth deformation on the EOP determination.

A major goal of this WG was to investigate the interaction between the celestial and terrestrial reference frame and the transformation between both (precession, nutation, EOP), and to improve the consistency between ICRF, ITRF and EOP. The major tasks included the effect of errors in the CRF on the terrestrial reference frame and other related products, and vise versa, the realization of the NNR-condition for the ITRF (e.g. deformations) and its interaction with EOP determination, comparison with geophysical models, and the interaction with the gravity field.

Terrestrial points of various space-geodetic techniques are often co-located and thus transformations between corresponding reference frames can be improved using local tie measurements. It is common practice to apply GNSS receivers on LEO or other satellites used for SLR, for tying the celestial reference systems.

Interaction between CRF and TRF

By Tesmer et al. (2004), a VLBI solution with a TRF, the EOP and a CRF being estimated simultaneously was established applying a non-biasing NNR and NNT datum for the TRF and NNR for the CRF. Using such minimum datum conditions, biases were avoided which are due to fixed reference frames or other relevant parameters of the observation equations. Heinkelmann et al. (2006) present a similar solution and give more technical details.

Tesmer (2006) summarizes investigations regarding the connection between TRF and CRF as realized by VLBI. In this context, most interesting is: (1) The sparse southern VLBI observing network implicates a not sufficiently redundant observing geometry. This is why some parameters of southern sources and stations are significantly correlated in CRF and TRF solutions (like O'Higgins, Antarctica or Hobart, Australia). (2) This also holds for sources and stations, which were not observed in varying network constellations (like Crimea, Ukraine or Saint-Croix, Virgin Islands, USA).

GPS satellite orbits used as quasi celestial reference frame for satellites in Low Earth Orbit

Rothacher and Svehla (2003) sketch how Low Earth Orbiters (LEOs, such as CHAMP, JASON, GRACE etc.), equipped with GPS receivers can be interconnected with global GPS solutions. Today, it is common habit to use the high flying GPS satellites as quasi celestial reference frame for the LEOs. As GPS observations from LEO on-board receivers are not subject to tropospheric delay, they can be used very well to estimate the position of the satellite in the orbit, e.g. with very high time resolution by means of kinematic approaches (Svehla and Rothacher, 2005).

Satellite and receiver antenna phase center variations

In recent years, the effect of absolute instead of relative antenna phase patterns on geodetic GPS results was investigated in detail. Both, the receiver and the satellite antennas (which are part of the quasi celestial GPS reference frame) are subject to phase patterns. Schmid and Rothacher (2003) estimated GPS satellite antenna phase center offsets and variations in nadir direction, azimuth-dependent phase center variations were demonstrated by Schmid et al. (2005). Steigenberger et al. (2007) compared different antenna phase center models, including the relative model used by the IGS so far, and the latest absolute IGS model igs05.atx (Schmid et al., 2007): Terrestrial reference frames showed significant station displacements, e.g. horizontally by up to 5 mm and 1 cm in height.

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Inter-Commission Project 1.1
Satellite Altimetry

Report for the Period 2003 – 2007

WOLFGANG BOSCH

Introduction

The Inter-commission Project 1.1 ‘Satellite Altimetry’ was created in August 2003 at the IUGG General Assembly in Sapporo, Japan. Due to the interdisciplinary relevance of satellite altimetry and overlap of research areas this project is joined between IAG commission 1, 2 and 3.

Terms of Reference

Satellite Altimetry has evolved to an operational remote sensing technique with important interdisciplinary applications to many geosciences. For geodesy, the potential operational, precise and near global mapping and monitoring of the Earth surface is of particular importance. The construction of high-resolution global mean sea surface and potentially its variability will help to globally unify height reference systems. Altimetry contributes to essential improvements of the Earth gravity field. Even with the new dedicated gravity field missions CHAMP, GRACE and GOCE, satellite altimetry will be needed for the determination of the high resolution gravity field. Mapping and monitoring of seasonal and secular changes of the mean sea level helps to understand fundamental processes of the System Earth: the ocean water mass redistribution, one component of the global hydrological cycle, has impact to the Earth centre-of-gravity, to Earth rotation by the ocean angular momentum functions, the temporal variations of the Earth gravity field, as well as studies of sea level rise and its impact on environment. The multiple applications suggest that satellite altimetry will become a core element of a global observing system. This includes, but is not limited to, the following scientific and organisational aspects:

– the combination of multiple altimeter mission data with different space-time sampling and the adaptation and cross calibration of new technologies like laser altimetry (GLAS on ICESat), interferometric altimetry (Cryosat), delay-doppler altimetry (proposed by ABYSS), wide swath-altimetry (proposed on Jason-2), and potentially airborne and spcaeborne LIDARs. A reliable vertical reference system for altimetry is one of the most crucial prerequisite
– a coordination among space agencies, processing centres, data providers, value-adding entities and the users together with a scientific feedback to ensure data and product quality and improvements for orbits and geophysical parameters. A scientific service appears to provide a most convenient platform.

The interdisciplinary relevance of satellite altimetry with overlaps between research areas of various IAG commissions justify to establish the project as a joint project of commissions 1, 2, and 3 of IAG.

Objectives

The primary objective of the joined commission project is to identify the scientific requirements to ensure a long and precise time series of utmost consistent altimeter observations with up-to-date geophysical corrections, consolidated geocentric reference and long-term stability. It has to be elaborated, how satellite altimetry is going to contribute to a global observing system, how the data of different missions is to be harmonized and how fast updates of orbits and geophysical parameters can be achieved in order to support scientific and operational applications. More specific, it is required to obtain precise knowledge about the inherent vertical reference system of altimetry and the long-term stability of the altimeter sensors itself, and of auxiliary sensors (radiometer). It is also envisioned that this project will provide a forum to foster innovative ideas for research and applications of satellite altimetry relevant to strengthening of the realisation of vertical component of the ITRF and to diverse areas of geosciences.

Program of Activities

– Study the contribution of satellite altimetry to the realisation and stability of the vertical component of the ITRF implied by precise orbit determination, geocenter variations, miscentering of reference frame, as well as long-term performance of altimeter - and auxiliary sensors.
– Investigate by an interdisciplinary working group the rationale, feasibility and scope of an International Altimeter Service in order to serve scientific and operational applications of satellite altimetry. The group shall strive for a broad support by other scientific entities. (see IAS-PG)

Membership of IAS-PG

Aarup, Thorkild	UNESCO/IOC
Anderson, Ole	KMS
Beckley, Brian	NASA/GSFC
Benada, Robert	NASA/JPL
Benveniste, Jerome	ESA
Bosch, Wolfgang	DGFI
Brenner, Anita	GSFC
Callahan, Phil	JPL
Challenor, Peter	SOC
Cotton, Dave	SOC
Femenias, Pierre	ESA, ESRIN
Imawaki, Shiro	RIAM
LeTraon, Pierre-Yves	CLS, AVISO
Lillibridge, John	NOAA
Lindstrom, Eric	NASA
Mitchum, Gary	USF
Naeije, Marc	DEOS
Nerem, Steve	CCAR
Plag, Hans-Peter	UNR
Scharroo, Remko	NOAA/LSA
Schöne, Tilo	GFZ
Shum, C.K.	OSU
Urban, Timothy	CSR
Vincent, Patrick	CNES
Woodworth, Phil	POL

Web-Page and Mailing List

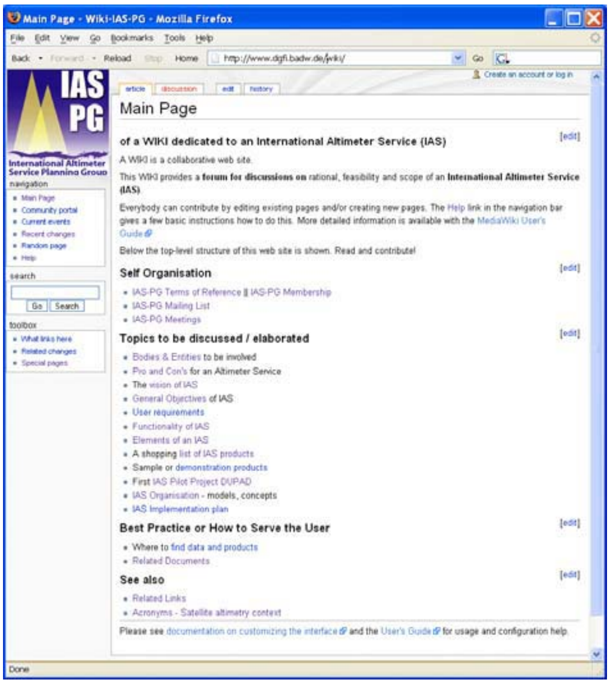

Fig. 1 Screenshot of the Wiki web site for the IAS-PG

As the Inter Commission Project did not have any means business meetings were attached to International Symposia and Workshops. In order to provide a forum for discussions outside of working meetings an IAS-PG mailing list was setup first. Several E-mail with request for comments (RFC) were used by the chair to push forward discussions on particular topics. Later on the mailing list was heavily used for spam mail and had to be closed. In addition, a web site was created in terms of a collaborative „Wiki", a simple content management system allowing everyone to edit existing pages or to create new content. A screenshot of the entry page of the Wiki is shown in figure 1.

Endorsements

The IAS-PG got official endorsements by the

- Global Sea Level Observing System GLOSS (IOC)
- International Association of Geodesy, IAG
- International Association of the Physical Sciences of the Oceans, IAPSO

First Business Meetings

Initial Meeting during 8th Meeting of GLOSS Experts at IOC, Paris, 13-17 October 2003

The idea of an International Altimeter Service was introduced, followed by a general discussion on the rational of an International Altimeter Service. There is a general accepted requirement to serve users with a long and precise time series of utmost consistent altimeter observations. This is an international, multi-disciplinary, mission overlapping and agency independent task, providing the general rational for an International Altimeter Service. Additional rationales are based on more technical issues (different data format, data with increasing size and complexity, delayed update of corrections ...). Several suggestions for the realisation of the IAS were given: the organization of ESEAS and OCCC were recommended as examples. It was emphasized that any altimeter service has to rely on the space agencies. On the other hand the envisaged service should address and support scientist working with the altimeter data. Later on the GLOSS Experts passed a letter of endorsement for the IAS Planning Group.

Business Meeting

at EGU2004 General Assembly, NICE, 27 April 2004

The Terms of References were presented and discussed. It was suggested to extend the list of products and to include explicitly products over land and lakes as well as over ice surfaces. An introduction to the mailing list was given and it was decided to create in addition a 'WIKI' web site. Request for comments were discussed for i) the compilation of contact data on space agencies, processing centres, other existing or emerging observing systems as well as scientific organizations and expert groups that work on satellite altimetry. The second work statement was on the general objectives and the functionality of the altimeter service. Results of these discussions were compiled to the Wiki web site. For the assessment of user categories and user requirements it was referred to previous studies, in particular the final reports of the GAMBLE (Global Altimeter Measurements by Leading Europeans) project. The meeting was supplemented by status reports on the re-processing of ERS-1 data, the Pathfinder project and information about ESA's Oxygen O_2 programme.

Business Meeting
at EGU General Assembly, Vienna, 27 April 2005

This meeting focused on the organisation of the envisaged altimeter service, on first IAS demonstration products and the GRID technology. For the future IAS organization it was suggested to use the already existing services of IGS, ILRS, and IVS as an example. It has to be recognized, however, that the data delivery situation in altimetry is different from the situation in these space techniques. Altimeter data is provided by the space agencies which operate altimeter satellites. They have their own data policy – fortunately in most cases completely open. For IGS, ILRS and IVS data is taken by the services itself. Therefore, IAS cannot be built without essential contribution and support of the space agencies.

JPL supports a project dedicated to the “re-tracking” (the re-analysis of the radar echo’s) of the TOPEX/Poseidon data – a rather demanded processing task. Resources to update simultaneously orbits, ocean tide corrections, to replace the geoid and the mean sea surface and to create a full GDR-product are missing. It was suggested that re-computation and merging of additional corrections could be performed by a first IAS pilot project. This pilot project could realise a distributed upgrade procedure and give an impressive demonstration of the IAS functionality.

Finally, a suggestion was made to consider GRID technology for the International Altimeter Service. GRID technology is a new but emerging and promising technique which allows coordinating resources (e.g. processing power or data storage) without a centralized control. The technology is based on standard, open, general-purpose protocols and interfaces and is capable to deliver a non-trivial quality of services. GRID technology seems to be extremely well suited to coordinate a virtual network of processing centres already providing service functions to altimeter users.

IAS-PG Conclusions

The most important results of the first business meetings can be summarized as follows:

- There is a general agreement that an International Altimeter Service (IAS) is necessary and should be created as soon as possible.
- The IAS shall integrate the envisaged altimetry services into the Global Earth Observing System of Systems (GEOSS) and let altimetry become an essential element of Global Ocean and Geodetic Observing Systems (GOOS, GGOS).
- IAS shall provide a unique point-of-contact for altimeter users and support all applications of satellite altimetry, including, for example, applications for oceanography, coastal zones, hydrology, geodesy, cryosphere.
- IAS shall support calibration and validation activities, assess data and product quality, and recommend improvements for generation and delivery of data and products.
- IAS will not replace but be based on the voluntary contribution of the many existing data, analysis, and product centres already providing service functions. Thus, IAS will have to coordinate a network of centres. User request are to be re-directed to and resolved by these centres, which keep desired data.
- IAS must ensure that intellectual property rights remain with and proper referencing is made to the generating node, whenever data, products or algorithms are provided or used in publications.
- A unification of data formats is neither feasible nor desirable. Instead, IAS shall provide generic tools, which keep the necessary metadata to inform about data content and allow extracting data with content and format upon user request.
- IAS shall integrate and share distributed resources (data bases) from multiple institutions, each with own policy and mechanism on the bases of standard, open, and general-purpose protocols and interfaces.

The IAS Terms of References (ToR)

According to the above conclusions the IAS-PG focused in the second half of its period on drafting Terms of References (ToR) for the envisaged IAS. This ToR should provide the basis for a Call of Participation to be submitted in order to seek proposals for data and analysis centres and for an organisation to operate the Central Bureau and an information service.

Organisation and structural elements of the other already existing services were carefully studied. Not everything could be taken over from other services. But like most of the other services, IAS can be realized only as voluntary collaboration of existing national and international organisations or legal entities.

A draft organization chart with the organisational elements is shown in figure 1. IAS elements will at least comprise

- an Executive Committee (decisions, policies, control and coordination, representation to external organisations),
- the Central Bureau (day-to-day operation, operating the Information Centre, publishing documents, organizing meetings),
- Working Groups on Data and on Analysis. Other working groups (ad-hoc or standing) can be created on demand.

The following permanent components were suggested for the IAS:

- Data Centres, (data and product generation, archiving and dissemination, compiling and provision of metadata),
- Analysis Centres (analysis of altimeter data and products, calibration and validation activities, model and algorithm development), and an
- Information Centre (user point-of-contact, summary information about data and products).

The IAS-ToR included also necessary rules for the collaboration. It was kept as lean as possible with the option that any rule can be customized by the Governing Board. The full text of the ToR is available at http://www.dgfi.badw.de/wiki/Documents/IAS-TOR-06-02-14.doc

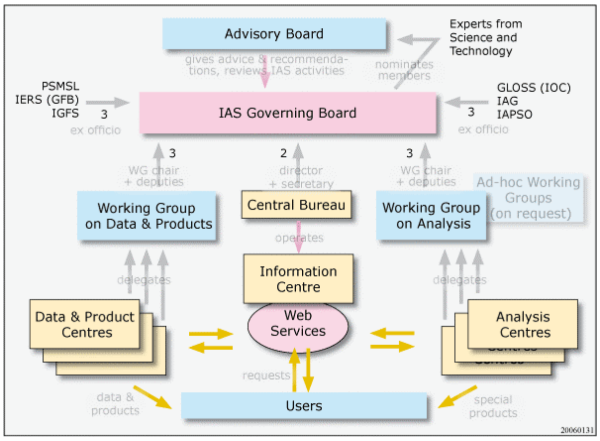

Fig. 2 Draft organigram showing the permanent components and organisational elements of the envisaged International Altimeter Service IAS.

Further Business Meetings

At IAG General Assembly at Cairns (Aug 2005)

A meeting with a first discussion on the draft ToR. It was emphasized that a contribution of – or control by scientific experts are to be considered. Therefore, the organisation was complemented by an Advisory Board, a group of experts from Science and Technology that are nominated by the IAS Governing Board (Figure 2).

At ESA Symposium Venice (March 2006)

The IAS ToR was distributed in advance to the meeting – together with the announcement of the envisaged Call for Participation. The suggested organisation of the IAS and its permanent component were introduced during the meeting. Before the Venice meeting there were a few groups who indicated their general interest. The discussion at the Venice splinter meeting, however, was controversial – partly positive, partly negative, but in essence with no perspective for an applicant who is able and willing to host the IAS Central Bureau. It was therefore meaningless to submit an IAS Call for Participation. The reasons for the failure to appoint an IAS:

– The general objective of IAS is widely accepted, but a specific and well-focussed work plan was not presented.
– Existing centres claim that a rather complete and gradually improved service to altimeter users is already provided.
– The existing centres are not willing to be organized or coordinated by an organization like the IAS Governing Board.

At OST Science Team Meeting Hobart (March 2007)

This business meeting was used to discuss again the vision of the altimeter service IAS with scientific experts from the Jason-1 Science Team. Again a very controversy discussion on deficiencies on the one hand and existing services on the other hand.

Call for an IAS-Integrating Office (IAS-IO)

In spite of the refusal of the ToR and the Venice failure to submit a Call for Participation IAG insisted in creating a service for satellite altimetry. The rationality for this request is founded by the fact that IAG focuses on the establishment of a Global Geodetic Observing system (GGOS) as part of a GEOSS, the Global Earth Observing System of Systems. Satellite altimetry will have to be an essential component of GEOSS and thus of GGOS.

The IAS-PG therefore set up another Call seeking proposals for the establishment of an IAS-Integrating Office (IAS-IO) with the general objectives

- to provide a platform (and single point of contact) for general information on satellite altimetry and its applications;
- to communicate with, and interface to, altimeter mission data providers, centres which process, archive, and analyse altimeter data, and other related services and organizations;
- to promote satellite altimetry as a core element of Global Earth Observing Systems; and
- to help compile and analyse data, and respond to altimeter user requirements.

At web-site http://www.dgfi.badw.de/fileadmin/DOC/2007/ call4IAS-office.pdf the full text of the Call can be found. It was distributed by E-mail exploder of IGS, ILRS, GGOS, IERS, and OST-ST. Moreover the Call was announced on the IAG web site. The deadline for proposals was set to March 1st, 2007. Unfortunately, not a single proposal was submitted for the establishment of the IAS Integrating Office.

Conclusions

The general need to establish an IAS is widely accepted, but up to now the deficits identified in Venice have not been solved: there is no precise description of a specific and well-focussed work plan for the IAS – which is very difficult because of the many interdisciplinary applications of satellite altimetry.

Also the role of the requested IAS-Integrating Office was somewhat clumsy: it is unconvincingly asking to establish a nucleus for an information centre on satellite altimetry in a situation where many, rather good web sites on altimetry are already available. For the outreach of satellite altimetry there are a few organisations investing since many years la lot of money and are being funded by the space agencies. It is not attractive trying to do something better than those organisations.

Whatever is suggested for the IAS, it must be

- attractive by solving some of the existing deficiencies or
- complementary, e.g. new, different or better than already existing services.

A realistic strategy to proceed towards an IAS is therefore to demonstrate such advantages by pilot projects clearly indicating what can be improved and by which mechanism. The work of the IAS-PG clearly identified some topics, suggesting itself as pilot projects: the online access of altimeter data and products with user defined content and format, the fast upgrade capability of altimeter mission data, and the application of GRID technology.

Inter-Commission Project 1.2
Vertical Reference Frames

Report for the Period 2003 – 2007

JOHANNES IHDE

Terms of Reference of ICP1.2

The Earth's surface may be described by its geometry and the potential of the Earth's gravity field. The determination of heights includes both of these aspects - the geometric part and the geopotential part. Presently, space geodetic techniques allow an accuracy in geometric positioning of about 10-9 of the Earth´s radius in global and continental scales. Gravity field parameters, including the physical height components, can at present be determined only 2 to 3 orders of magnitude less accurately than the geometric parameters. Moreover, the current height reference frames around the world differ in their vertical datums (e.g., the mean sea-level at the fundamental tide gauges) and in the theoretical foundations of the height systems. There is no global height reference system defined or realized, as with the International Terrestrial Reference System (ITRS). Considerable progress in the definition and realization of an unified, global vertical reference system will be achieved from the data of the new satellite gravity field and altimetry missions.

Based on the classical and modern observations, the ICP1.2 on Vertical Reference Frames shall study the consistent modelling of both, geometric and gravimetric parameters, and provide the fundamentals for the installation of a unified global vertical reference frame.

Objectives

- To elaborate a proposal for the definition and realization of a global vertical reference system (World Height System – WHS);
- To derive transformation parameters between regional vertical reference frames;
- To establish an information system describing the various regional vertical reference frames and their relation to a world height frame (WHF).

Program of Activities

- Harmonization of globally used height data sets;
- Study of combination procedures for height data sets from different techniques;
- Study of information on regional vertical systems and their relations to a global vertical reference system for practical applications;
- Unification of regional (continental) height systems.

Members

Alireza A. Ardalan (Iran), Carine Bruyninx (Belgium), Milan Bursa (Czech Republic), Tonie van Dam (Luxemburg), Gleb Demianov (Russia), Will Featherstone (Australia), Johannes Ihde (Germany), Christopher Jekeli (USA), Adolfientje Kasenda (Australia), Bill Kearsley (Australia), Roland Klees (Netherlands), Gunter Liebsch (Germany), Markku Poutanen (Finland), Laura Sanchez (Colombia), Tilo Schöne (Germany), Steve Shipman (UK), Jaroslav Simek (Czech Republic)

During the four years the ICP1.2 working group was extended by:

Matt Amos (New Zealand), Wolfgang Bosch (Germany), Alessandro Capra (Italy), Robert Cunderlik (Slovakia), Hermann Drewes (Germany), Bernhard Heck (Germany), Jan Krynski (Poland), Urs Marti (Switzerland), Jaakko Mäkinen (Finland), Marcel Mojzes (Slovakia), Dan Roman (USA), Zdislav Šima (Czech Republic), Viliam Vatrt (Czech Republic), Marc Véronneau (Canada), Marie Vojtiskova (Czech Republic), Herbert Wilmes (Germany).

During the four years the ICP1.2 working group was partly joint by:

Ruth Adams (UK), Jonas Ägren (Sweden), Susana Barbosa (Portugal),Matthias Becker (Germany), Dorota Brzezinska (USA), Francoise Duquenne (France), Henri Duquenne (France), Jan Ferko (Slovakia), Joana Fernandes (Portugal), Georgia Fotopoulos (Canada), Roger Hipkin (UK), Petr Holota (Czech Republic), Jianliang Huang (Canada), Karl Heinz Ilk (Germany), Michael Kuhn (Australia), Jan Kouba (Canada), Roberto Teixeira Luz (Brazil), Jan Marsa (Czech Republic), Jürgen Müller (Germany), Diethard Ruess (Austria), Eimuntas Parseliunas (Lithuania), Martin Vermeer (Finland), Franziska Wild-Pfeiffer (Germany).

Meetings and workshops

- European Vertical Reference System Workshop, 5-6 April 2004 in Frankfurt on Main, Germany (draft minutes);
- Business Meeting of ICP1.2, 31 August 2004, on GGSM2004 in Porto, Portugal (minutes);

- Business Meeting of ICP1.2, 22 August 2005, on the IAG Scientific Symposium in Cairns, Australia (minutes);
- ICP 1.2 Workshop, 11-12 April 2006 in Prague, Czech Republic (minutes);
- ICP1.2 Splinter/Business Meeting, 28 August 2006 at the 1st IGFS Symposium in Istanbul, Turkey

Status and Results

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)" - File VRS_conventions_3.0_2007-05-01. 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.

A global unified vertical reference system for an International Vertical Reference System (IVRS) can be realized by:

- A global network of stations with coordinates in ITRF and geopotential numbers referred to a conventional global reference level. This network should include co-location of permanent GNSS, tide gauges, permanent (SG) and periodical (AG) gravity stations.
- A global reference level derived from a conventional global gravity model (CGGM) from satellite gravity missions only in combination with a global sea level model from satellite altimetry.
- Both based on a set of consistent conventional numerical standards
- In addition local and regional gravity observations around the IVRS stations are required.

Regional and national height reference systems can be integrated into an IVRS by GNSS/levelling aligned to ITRF and using the CGGM and the numerical standards.

Changes of the solid and fluid Earth surface can be observed with respect to the conventional IVRF level by relevant observation techniques. The IVRS level is defined by a conventional W_0. The conventional IVRS level has to be related to the instantaneous mean sea surface level (MSSL).

Deficiencies

In view to a planned ISO registry for geodetic parameters, the establishment of an information system describing the various regional vertical reference frames and their relation to an IVRS was not realized. This includes the determination of transformation parameters between regional vertical reference frames and the unified global height system.

Further open topics are the relationships between an IVRS and the International Terrestrial Reference System (ITRS) (Basic relations between ITRS and IVRS conventions, parameters, realization, models).

Proposed continuation

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 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 associations.

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), the International Hydrographic Organisation (IHO), the International Federation of Surveyors (FIG), and. the Inter-service Geospatial Working Group (IGeoWG) of NATO.

Annex: Numerical Standards

The Geodetic Reference System 1980 (GRS 80, 1980) defines major parameters for geodetic reference systems related to a level ellipsoid. It is agreed by the International Union of Geodesy and Geophysics (IUGG), International Association of Geodesy (IAG) and International Astronomical Union (IAU). The GRS80 parameters are recommended by IAG for the conversion of ITRF Cartesian coordinates to ellipsoidal coordinates. It is used worldwide for many map projections and million of coordinates are related to it.

At the IUGG General Assembly 1991 in Vienna new values for the geocentric gravitational constant GM and the semi-major axis a of the level ellipsoid were recommended. Since this time these parameters have been used in global gravity models e.g. EGM96. The two other defining parameters were not changed.

In the IERS 2003 conventions (Mc Carthy and Petit, 2004) numerical standards are listed (Table 1.1). These conventions have the effect of standards and when read with chapters 4.1.4 and 4.2.5 recommended the use of

GRS80 for transformations. The value of the geocentric gravitational constant (GM) has not changed since 1991. The parameters in Table 1.1 have the status of standards. In parallel in chapters 4.1.4 and 4.2.5 the GRS80 is recommended for transformations.

Table 1 contains parameters of different level ellipsoids. The gravitational constants GM of GRS80 and IERS 2003 conventions differ in the metric system by about 0.9 m. The semi-major axis of both standards differs by 0.4 m. It has to be stated, that the IERS 2003 conventions recommends different level ellipsoid parameters for different applications.

GRS80 is recommended (and generally used) for geometrical applications. For global gravity models, various inconsistent values are used in practice.

The IAG needs to remove this inconsistency to enable the development of integrated geodetic applications (cf., Hipkin, 2002). The geoid potential parameter W_0 of a Global Vertical Reference System defines the relationship of the physical heights to the Earth body. The parameter W_0 must be consistent between systems to ensure the relations to be reproducible.

Table 1: Level ellipsoid parameters

Ellipsoid	Semi-major axis a [m]	Flattening f^{-1}	Geocentric gravitational constant GM [$10^8 m^3 s^{-2}$]	U_0/W_0 [$m^2 \cdot s^{-2}$]	γ_e [$m \cdot s^{-2}$]
International 1930 (Hayford)	6 378 388	297	3 986 329		
GRS 67	6 378 160	298.247	3 986 030		
GRS 80	6 378 137	298.2572221	3 986 005	62 636 860.850	9.78032677
IUGG 91	6378136.3 ± 0.5		3 986 004.41 ± 0.01		
IERS 2003 Conventions (zero tide)	6378136.6 ± 0.1	298.25642 ± 0.00001	3986004.418 ± 0.008	62 636 856.0 ± 0.5	(9.78032666)*

Angular velocity of the Earth rotation ω		10^{-11} rad s^{-1}	7 292 115

In addition to the existing IERS numerical standards other parameters shall be calculated and included in the IERS conventions e.g.

γ_e normal gravity at equator
γ_p normal gravity at pole
* not consistent with IERS 2003 Conventions

(Remark: The numerical value of W_0 has to be revised in view of recent work done at the DGFI)

Acknowledgement: The review of this report by Bill Kearsley, Matt Amos, Bernhard Heck, and Laura Sanchez is gratefully acknowledged.

Inter-Commission Study Group 1.1
Ionosphere Modelling and Analysis

Report for the Period 2003 – 2007

M. SCHMIDT

Generally, the ionosphere is defined as a thick shell of electrons and ions, which envelopes the Earth from about 60 to 1200 km height. The knowledge of the electron density is the key point in correcting electromagnetic measurements for ionospheric disturbances. Hence, for many disciplines of geo-sciences ionosphere modelling means a very important task at present and in the future. In order to benefit from different disciplines this study group aimed on the establishment of a scientific link between geodetic and aeronomy experts. Ionospheric information, e.g., provided by Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) and other space techniques has been analyzed for possible improvements of existing ionosphere products. To be more specific, this study group works on the derivation of ionosphere models based on physics and mathematics by incorporating statistical approaches.

Several members of the study group dealt with existing ionosphere models like the International Reference Ionosphere (IRI) (e.g. Bilitza 2004) or the NeQuick model. The latter is developed by the Aeronomy and Radio Propagation Laboratory of the International Centre of Theoretical Physics (ARPL-ICTP) in Trieste/Italy and by the Institute for Geophysics, Astro-physics and Meteorology (IGAM) of the University of Graz in Austria. These physical and/or empirical models can be analyzed and represented by different mathematical approaches, e.g., spherical harmonic expansions, B-spline representations or wavelet models. Any of these representations can be related to geodetic observations in order to improve dominant model parameters, e.g., by least-squares estimation. This procedure, known as ionospheric imaging, means simply the attempt to estimate the 4-D (spatio-temporal) electron density within the ionosphere. Ionospheric imaging can be used to investigate the structured response of the electron density to underlying physical drivers on a large number of spatial and temporal scales.

Basically, ionosphere models can be separated into two- or three-dimensional models of the vertical total electron content (VTEC) and three- or four-dimensional models of the electron density (ED). Both quantities are related to each other by the slant total electron content (STEC), which means the integral of the ED along the ray-path between the transmitting satellite S and the receiver R as can be seen n from the sketch in Fig. 1.

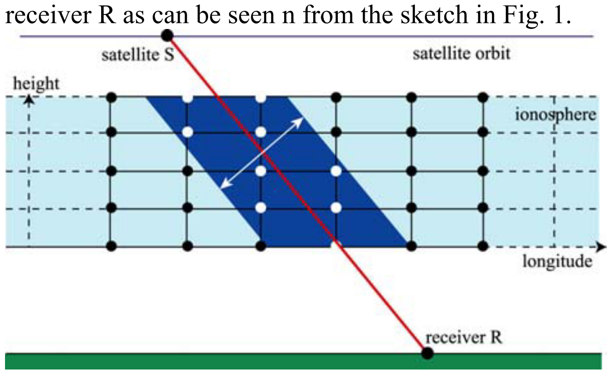

Fig. 1: Relation between a GNSS measurement and the distribution of B-spline functions. The dots indicate the centres of the base functions; the width of the band (dark-blue) along the ray-path depends on compactness.

More than 30 years ago computerized tomography techniques were proposed for reconstruction of the ED distribution. Since that time many different approaches, e.g., based on 3D volume elements (voxels) (e.g., Cilliers et al. 2004, 2005), spherical harmonics in com-bination with empirical orthogonal functions (EOFs) (e.g. Liu and Gao 2004) or B-splines in combination with wavelets (e.g. Schmidt 2006, Schmidt et al. 2007a); a comprehensive overview about techniques for ED modelling is given by Garcia-Fernandez (2004).

Schmidt et al. (2007a) present a variety of multi-dimensional models of the ED distribution mathematic-ally based on wavelet and EOF strategies and physically controlled by IRI. To be more specific, in one of these approaches the authors describe the ED by means of three-dimensional (3-D) wavelet expansions with respect to space considering time-dependent series coefficients. As 3-D spatial base functions tensor-product endpoint-interpolating quadratic B-splines were chosen, i.e. products of three 1-D B-splines depending on longitude, latitude and height; cf. Fig.2.

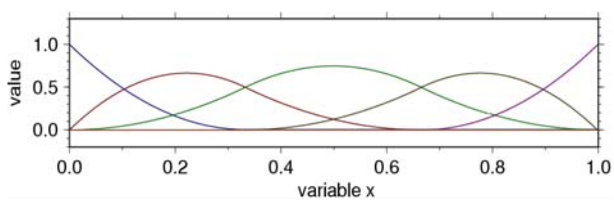

Fig. 2: Quadratic B-spline functions of the lowest resolution level. Just the three functions in the middle are not modified by the endpoint interpolating procedure; for more details see Schmidt (2007a).

Since STEC is defined as the integral of the ED along the ray-path geometry-free GNSS observations can be used to determine the series coefficients of the 3-D B-spline expansion. As a matter of fact each series coefficient of this 3-D expansion is related to a specific grid point within the unit cube, i.e., the peak of the corresponding 3-D B-spline function. However, since the coverage of GNSS observations is very inhomogeneous, an unknown series coefficient can be computed only if observations are given close to this peak. For simplification Fig. 1 shows a 2-D problem by neglecting the latitude-dependency. The white and black dots indicate the centres of the B-spline functions in the longitude-height plane. Due to their compact support only 2-D B-splines related to the white dots, have non-zero entries in the observation equations. Hence, in case of large data gaps many coefficients are not calculable and the corresponding addends can be excluded from the observation equation. If only a few observations support the computation of a coefficient, prior information could be introduced in order to stabilize the estimation process. With the estimated series coefficients the decomposition of the electron density into detail signals using wavelet techniques can be started; the related approximations are low-pass filtered versions of the electron density. The different steps of the procedure, i.e. the adjustment based on variance component estimation and the decomposition into detail signals, are visualized in Fig. 3. Numerically, the series coefficients of the detail signal expansions, i.e., the wavelet coefficients are usually very small and may be neglected. Thus, the wavelet decomposition into detail signals, i.e., the establishment of a multi-resolution representation (MRR) is also a very advantageous method for data compression.

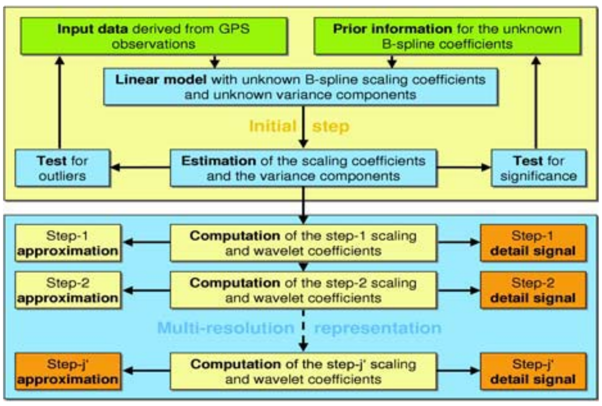

Fig. 3: Flowchart of the multi-dimensional model of the electron density; the two boxes at the top are the input data (GNSS measurements and prior information), the orange colored boxes represent the output components of the multi-resolution representation; for more details see Schmidt (2006) and Schmidt et al. (2007a).

The insensitivity of ground-based observations to the radial geometry can be overcome by introducing other base function for the height-dependency, e.g., EOFs. Consequently, as an alternative approach Schmidt et al. (2007a) replace the B-spline expansion with respect to the height by a series expansion in terms of the dominant EOFs, which are calculated by applying the method of principal component analysis (PCA) to the reference model, i.e. IRI, in a pre-processing step. Approximately 98% of the electron density is considered by the first two modes of the PCA. Figure 4 shows exemplified the corresponding eigenvectors. As further approaches for modelling the height-dependency of the ED we want to mention the Chapman function and the Epstein function, which are both widely used in ionosphere research (e.g. Zhang et al. 2002 or Garcia-Fernandez 2004).

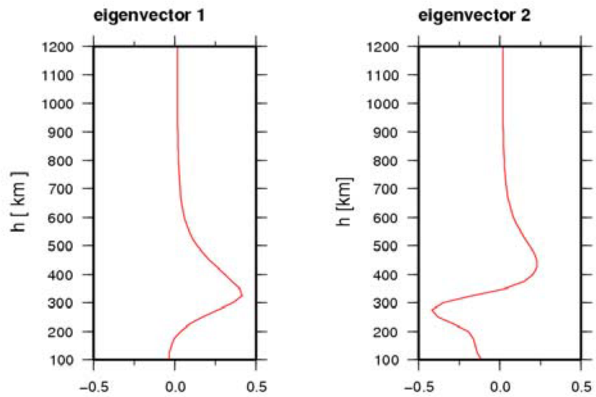

Fig. 4: The first and the second eigenvector consider about 88% and 10% of the total energy of the electron density, respectively. The shape of the first eigenvector defines mainly the height profile of the electron density.

Besides these 3-D series expansions Schmidt et al. (2007a) also derived a 4-D model by considering a fourth 1-D B-spline function related to the time. The main advantage of this approach is that the observations do not need a temporal discretization any more. On the other hand large linear equation systems have to be solved, but fortunately, due to the compact support of the B-splines the resulting normal equation system is of block-diagonal structure and can be solved efficiently.

Typically, the primary data source used in ionospheric imaging are STEC observations obtained from the worldwide International GNSS Service (IGS) network. However, as will be discussed in the following many other data sources are available that increase the fidelity of the ionospheric reconstructions. The insensitivity of ground-based observations to the radial geometry, as mentioned before, can also be treated by considering measurements from space-borne receivers flying on low-Earth-orbiting (LEO) satellites, e.g., the Constellation Observing System for Meteorology, Ionosphere and Climate and Taiwan's FORMOsa SATellite Mission #3 (COSMIC/FORMOSAT-3), the CHAllenging Minisatellite Payload (CHAMP) mission or the Gravity Recovery And Climate Experiment (GRACE). The six COSMIC satellites, e.g., were successfully launched on April 14th, 2006. Over the first year, these satellites will be gradually boosted from their initial orbit of 400 km to the final orbit of 800 km. Each spacecraft is equipped with three instruments, namely a GPS (occultation) receiver (GOX), a tiny ionospheric photometer (TIP) and a tri-band beacon (TBB). The GOX can be used to evaluate directly the COSMIC STEC measurements or ED profiles, respectively. The latter are derived from the occultation measurements applying the Abel inversion. The TIP provides nadir observations of radiative recombination emission at 135.6 nm for characterizing the Earth's nightside ionosphere. The TBB is capable of measuring integrated plasma density parameters for the F-region. Altimetry satellites like Topex/Poseidon, Jason or ENVISAT provide a huge number of VTEC data. Figure 5 is an extended version of Fig. 1 considering also other geodetic space-borne measurement techniques besides GNSS.

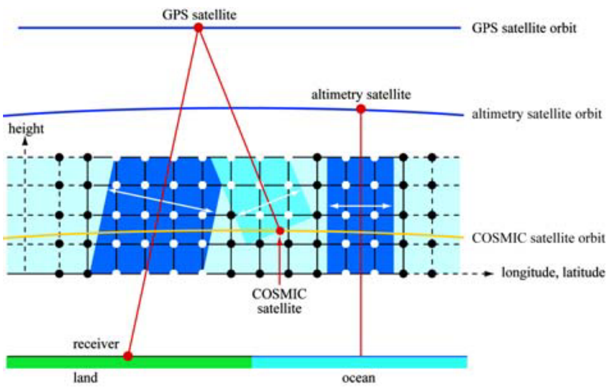

Fig. 5: Combination of different geodetic space-borne measurement techniques. As in Fig. 1 the dots indicate the centres of the B-spline base functions The GPS receivers and the COSMIC satellites measure STEC, altimetry satellites measure VTEC. In addition the COSMIC mission provides data directly related to ED.

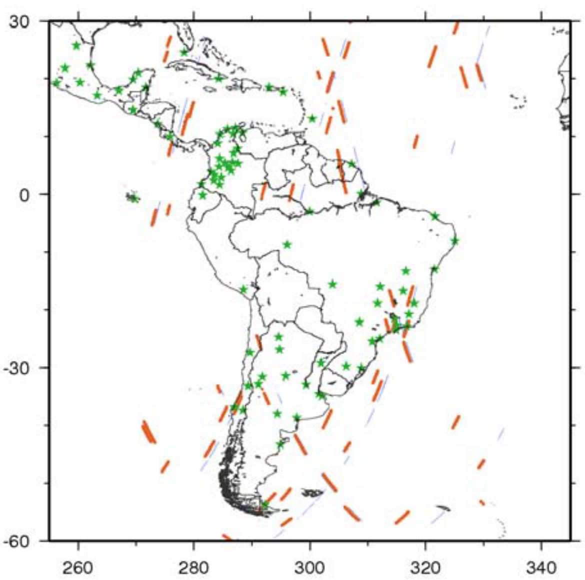

Fig. 6: Blue dots indicate the positions of six COSMIC satellites at the time of STEC measurements on January 7, 2007; red dots mean the piercing points of the ray-paths to the corresponding GPS satellites located at the upper boundary of the ionosphere at a height of around 1200 km. This way there exist around 2,200 COSMIC measurements. Green stars indicate IGS stations as well as regional GPS stations in Central and South America.

Figure 6 shows the distribution of STEC measurements from the six COSMIC satellites during a specific day. Note, that according to Fig. 5 in case of a regional 3-D or 4-D B-spline modelling only the data with ray-paths complete within the 3-D region of interest can be used. For each of the different observation techniques mentioned before and possibly including terrestrial measurements an observation equation can be derived for estimating the unknown series coefficients of the B-spline ED expansion within a specific 3-D spatial region or a specific 4-D spatio-temporal region. This way a Gauss-Markov model can be established merging the different techniques. The relative weighting between the techniques can be achieved by the method of variance component estimation; for more details see Schmidt et al. (2007b). After estimating the ED wavelet decomposition methods can be applied in order to establish a multi-resolution representation of the ED and to reduce the data; see Fig. 3. As shown by Schmidt (2006) even simple reduction strategies provide a large data compression rate.

Since the B-spline representation is restricted to regional areas, high-frequency features like the equatorial anomaly can be handled appropriately. Finally, the presented methods can be used to perform an update of climatological parameters of the applied reference model, i.e., IRI by adjusting local equivalent solar indices.

A group at METU (Middle East Technical University) in Civil Engineering Department, Geodesy and Photogrammetry Division, works to establish a regional model for the ionosphere over Turkey on the basis of real GPS observations within a PhD project funded by the TÜBİTAK (The Scientific and Technological Research Council of Turkey). As an important step we can now generate TEC by making use of the carrier phase smoothed pseudo range observations processed by Bernese GPS Software Version 5.0, so that pseudo range observations can be used for the determination of ionospheric delay differences. Besides that, biases for receivers are also produced with Bernese v5.0 and Differential Code Biases (DCB) for the satellites are taken from IGS internet page. After having generated the ionospheric delay differences, the STEC between the satellites and receivers can be estimated. Approximate receiver positions are obtained from the header of the GPS observation files and satellite positions for observation epochs can be interpolated from IGS precise orbit files (SP3). The routines have been developed in MATLAB 7.0. In the following stages of the project, related codes will be prepared for pseudo range smoothing and DCB determination. Thus, external software, such as Bernese, will not be needed for TEC determination.

Besides these projects many work was done during the past years in order to improve IRI directly. The following paragraphs present a summary on the most important items.

A data base of Alouette/ISIS topside sounder electron density profiles (~500,000 data points) was made available online based on the data records stored at the National Space Science Data Center (NSSDC) (Bilitza et al., 2003, 2004a). This data base has stimulated new efforts to accurately represent the topside in ionospheric models (Bilitza et al., 2006) and has led to a correction of the IRI topside formula (Bilitza, 2004). The latest version of the IRI model, IRI-2007, was developed including many improvements (e.g., new model options for the topside electron density and ion composition) and several new parameters (e.g., the spread-F occurrence probability) (Bilitza, 2006). IRI-2007 will also be the first version with a special model for auroral altitudes. The IMAZ model is a Neural-Net model that was trained with data from the EISCAT incoherent scatter radar facility and from many auroral rocket flights.

Work continues on a variability model for the ionosphere (Araujo-Pradere et al., 2004, 2005, Bilitza et al., 2004b). This will include a specification of quartiles and deciles in addition to the monthly median given by IRI. The current focus is on the F-2 peak using the large data base of worldwide ionosonde data.

Data from ionosonde stations in Korhogo (Ivory Coast) and Ilorin (Nigeria) have been used to investigate shortcomings of the IRI model in the African longitude sector (Adeniyi et al., 2003; Obrou et al., 2003).

As seen before ionospheric imaging is defined as estimating a 4-D regional or global grid of ED values, by using ground- and space-based data sources. Vertical GPS TEC maps, while similar to ionospheric imaging, provide 2-D horizontal spatial structure.

At the University of La Plata, the so-called La Plata Ionospheric Model (LPIM) has be developed, which is based on a spherical harmonic expansion (Azpilicueta et al. 2005). Nowadays, there is a variety of approaches for processing dual-frequency GPS observations to produce Global Ionospheric Maps (GIMs) of VTEC with a temporal resolution of two hours or less. For a better modelling of the variability of the VTEC, a solar-fixed coordinate system and the geomagnetic latitude are usually adopted. Early investigations by Rawer demonstrated the benefit of using the modified dip latitude (modip) to describe the free electron distribution on the F2 layer at mid and low latitude. The LPIM was updated to use modip latitude instead of the geomagnetic one. Exhaustive comparisons against Topex VTEC measurements provided by Aviso – performed for 90 days of 1999 – have demonstrated that the use of modip significantly improved the agreement between GPS and Topex. It could be confirmed that especially for low-latitudes the VTEC structures of Topex were validated better by using the modip approach instead of the geomagnateic latitude. The use of modip smoothes out the VTEC variability and facilitates its mathematical representation (Azpilicueta and Brunini, 2006).

Dual-frequency carrier phase and code-delay GPS observations can be combined to obtain ionospheric observables related to the STEC along the satellite-receiver line-of-sight (LoS). This observable is affected by inter-frequency biases (IFBs; often also called differential code biases (DCBs)) due to the transmitting and the receiving hardware. As mentioned above these biases must be estimated and eliminated from the data in order to calibrate the STEC values obtained from GPS observations. Based on the analysis of single differences of the ionospheric observations obtained from pairs of co-located dual-frequency GPS receivers, this research (Ciraolo et al. 2006) addresses two major issues: (1) assessing the errors translated from the code-delay to the carrier-phase ionospheric observable by the so-called levelling process, applied to reduce carrier-phase ambiguities from the data; and (2) assessing the short-term stability of receiver IFBs. The conclusions achieved are: (1) the levelled carrier-phase ionospheric observable is affected by a systematic error, produced by code-delay multi-path effects through the levelling procedure; and (2) receiver IFBs may experience significant changes during one day. The magnitude of both effects depends on the receiver/antenna configuration. Levelling errors found in this research vary from 1.4 to 5.3 TECU. In addition, intra-day variations of code-delay receiver IFBs ranging from 1.4 to 8.8 TECU were detected.

The Institute of Communications and Navigation of the German Aerospace Center (DLR) continued the regional TEC monitoring activities over the European (http://www.kn.nz.dlr.de/ daily/tec-eu/) and Northern polar area (http://www.kn.nz.dlr.de/daily/tec-np/).

Within the frame of the space weather pilot project of ESA an operational ionosphere data service (SWIPPA) was established at DLR (http://www.kn.nz.dlr.de/swippa/) that provides a warning message and various TEC derived ionospheric data products for European users with update rates of five minutes. The 1Hz sampled GPS data are provided by the Bundesamt für Karthographie und Geodäsie (BKG).

Furthermore, as another interesting topic earthquake signatures seen in the ionosphere were studied. For that purpose ground- and space-based GPS measurements have been analyzed (Jakowski et al. 2006).

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Inter-Commission Study Group 1.2
Use of GNSS for Reference Frames

Report for the Period 2003 – 2007

R. WEBER, C.BRUYNINX

Introduction

Recognizing the importance of the upcoming new European satellite navigation system (GALILEO) and of the modernization programs planned for GPS and GLONASS, the IGS (International GPS Service) decided to set up a GNSS-Working Group begin of 2003. A major goal of this WG is to prepare a consolidated feedback to GNSS system engineering based on relevant IGS experience of providing highest accuracy products for the existing systems. Special emphasis should be laid on calibration characterization issues such as the role of SLR for orbit determination of GNSS satellites, estimation of inter-system and inter-frequency biases, clock and orbit prediction as well as reference frame definition and realization.

After the past IUGG Meeting in Sapporo 2003 the president of IAG Commission I on 'Reference Frames' decided to set up a Study Group entitled 'Use of GNSS for Reference Frames'. Goal is to evaluate and support the use of Global Navigation Satellite Systems for the definition and densification of the International Terrestrial Reference Frame (ITRF). According to the new statutes of IAG it has been agreed by the IAG president, the Commission I president and the IGS Governing Board that the IGS-GNSS WG and IAG IC-SG1.2 should be closely coordinated. Furthermore the group is closely linked to IAG Commission IV on 'Positioning and Applications'.

The membership list has been broadened according to the new topics. One of the overlapping goals clearly was how to take advantage of the IGS product suite for the definition and densification of the International Terrestrial Reference Frame (ITRF).

Members

R. Weber (Chair)	C. Bruyninx (Co-Chair)
Y. Bar Sever	N. Beck
C. Boucher	R. Galas
W. Gurtner	G. Hein
L. Hothem	J. Johansson
R. Langley	J. Manning
H. van der Marel	V. Mitrikas
F. Perosanz	H.P. Plag
R. Zandbergen	

The revised Terms of Reference of both sub-groups, meeting reports as well as technical papers were made available to the public via the Working Groups web-links http://mars.hg.tuwien.ac.at/Research/Satellite Techniques/GNSS_WG_IGS/gnss_wg_igs.html and http://www.gps.oma.be/IAG-study-group/workprogram.php

General Activities

A major goal of the WG was to identy synergies using a real GNSS observation network covering three satellite navigation systems for reference frame maintenance. In 2004 the WG compiled a list of Recommendations to GNSS system design entities with a special focus on the upcoming GALILEO system. In order to collocate the GALILEO Reference Frame (GRF) to ITRF the IGS asks for a proper calibration of GRF Reference Station antennas and for providing that data to the scientific community.

In order to improve the quality of the contribution of the global GNSS station network to the ITRF2005, a discontinuity table containing the epochs with discontinuities in the IGS station coordinates, has been created. In addition, regional sub-commission chairs of commission 1 have been asked to review and complete this discontinuity table. EGNOS RIMS station data has been offered via IGS to analysts, providing data of about 15 additional stations in Africa which will improve the stability of the GNSS reference frame. Based on a preliminary reference network design the quality of the tie and anticipated time evolution of the GALILEO Reference Frame with the ITRF has been investigated.

Members of the Working Group are part of the consortium that was chosen by the European Commission to carry out the project "Galileo Geodesy Service Provider (GGSP)". The GGSP will be responsible for providing the Galileo terrestrial reference frame and also for the links between the Galileo ground segment and the IAG services (IGS, ILRS, IERS). Since the Galileo project does not want to deal with the individual services, the GGSP will be the intermediary.

The WG supported attempts to equip future GPSIII satellites with retroreflectors by providing technical background information. In this context the interaction with entities involved in the technical set up of modernized GPS (GPS III) and modernized GLONASS has been intensified, unfortunately not to a level similar to the current interaction with the Galileo project team.

The major activity of the WG in 2006/2007 was the preparation of a 'White Paper on IGS requirements for new GNSS signals'. This paper takes into account expected upgrades of the GNSS space and ground segments and explores potentially optimal sets of GNSS-signals to be tracked by future geodetic GNSS receivers. In this context the paper deals with future TCAR and MCAR techniques, with error mitigation and with inter- and intrasystem biases.

WG Meetings (Sep. 2003 – Apr. 2007)

- Open WG-Meeting during ION2003, Portland (Sept 2003)
  Topics: Galileo/GPS Frequency Overlay, Tie of Galileo Reference Frame to ITRF
- Open WG/SG-Meeting during the IGS Workshop and Symposium, Bern (March 2004)
  Topics: Formal Organisation of the Joint IAG/IGS Study Group; Recommendations to GALILEO Systems Design, GPS and GLONASS Modernization
- Meeting SC-,WG- and SG-chairs of Commission IV during ION 2004 (Sept 2004)
  Topics: Organisational Issues and Relation of IGS GNSS WG / IAG IC-SG 1.2 to Commission IV
- First Meeting of WG/SG members with Galileo Project Team at ESOC, Darmstadt (June 2004)
  Topics: Satellite Phase Center Definition, on-board retro-reflector arrays, GSTB-V1
- Second Meeting of WG/SG members with Galileo Project Team at ESOC, Darmstadt (March 2005)
  Topics: Laser Ranging on-going activities, GNSS Biases (intra- and intersystem), Relation Galileo Reference Frame Provider – IGS, GSTB-V2 Mission Status
- Meeting , IKK GALILEO Austria, Vienna (June 2006)
  Topics: Galileo Concession, Supervisory Authority, GalileoSat Programme
- Open WG-Meeting during AGU Fall meeting, San Francisco (December 2006)
  Topics: Status GNSS / IGLOS-PP / Satellite Antenna Phase-Pattern / DCBs
- Meeting of WG during IGS-AC meeting, ESOC ,Darmstadt (May 2006)

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Inter-Commission Working Group 1
Quality Measures, Quality Control and Quality Improvement

Report for the Period 2003 – 2007

H. KUTTERER

Introduction

There are various notions of quality in Geodesy and related fields. The measures in use are typically referring to the uncertainty of observed or derived quantities. They are mainly defined for results or products, respectively. Precision and accuracy measures such as standard deviations or RMS values may serve as examples. However, their use in practice is neither unique nor precise nor even complete. In many cases their derivation is not transparent as the observation frame is not documented or reported. Moreover, only a few measures in use are related to the underlying processes which actually have to be modeled and understood for a thorough quality improvement. In, e.g., the cases of reliability or integrity the observation or system configurations are taken into account in order to check the data or the system performance for errors.

In industrial production and other fields new standards such as the ISO 9000 family on quality management are common since one or two decades. These standards could serve as a basis also in geodetic applications. As they are not concrete enough for a direct application in geodetic theory and practice they have to be elaborated and adopted in a sufficient way. In metrology there has been some advance due to the “Guide to the expression of Uncertainty in Measurement” which is used increasingly. Its benefit is the description of a clear, complete and unique documentation of all quantities with influence on the derivation of the measurement results. There is some ongoing discussion as the chosen distinction between random and systematic effects shows some shortcomings. Actually, the presentation is restricted to the very special case of measurement results of one-dimensional quantities.

There has been a long and good tradition of quality in Geodesy. Today, a multitude of new sensors and sensor systems has to be handled which yield huge amounts of data in a very short time span. The observation and analysis processes become more and more important. At present, there is no final convention on quality measures and quality control or even on the definition of uncertainty measures which can be used in most fields of geodesy. In addition there are also many problems of technical character such as the optimal functional and stochastic modeling in space geodesy. For all these reasons it is still hard to compare and to combine processing results which are derived at different institutes for the, e.g., derivation of terrestrial or celestial reference frames. Hence, it is very likely that the quality of geodetic products is not optimal today.

Adequate quality measures and models are the indispensable basis for a quality control and quality improvement in Geodesy. They have to be in maximum accordance with analogue developments in related field. They need to be defined and modeled in a precise and unique way using a strong mathematical theory. There must not be any restriction concerning their consistent use in Geodesy, in particular regarding their propagation through all relevant geodetic processes and regarding their optimization based on proper objective functions. Finally, procedures are needed for the derivation of the actual numerical values of the measures.

This has been the setting where the work of the IC-WG 1 took place. Its main goal was the development of a mathematical-statistical quality model with extended features and measures for use in Geodesy. Such a quality model could be a basis for quality control and quality improvement. Although only parts of this goal were actually reached due to various reasons there have been many studies and results which are of broader interest in this field. This report is organized as follows. The contributions of the WG members are divided into three categories which are described below:

(i) advances in modeling (including quality control in the applications),
(ii) advances in estimation and filtering,
(iii) extended uncertainty budget.

All information on published contributions which were submitted to the chairman can be found in the list of references. Some references with major relevance from colleagues outside the WG are added. Due to the limited space not all publications are cited in the text.

Advances in modeling

From a more practical point of view of quality in Geodesy it is hard to distinguish between pure modeling issues and respective quality control elements and functions. For this reason contributions to both aspects are treated in this section in parallel. There have been advances in the extension of well-established models, in the adaption of models which are used outside Geodesy, and in the application of established methods to new fields.

Modeling in Geodesy comprises both the relation between observed and derived parameters such as in adjustment models and the functional description or causal explanation of the characteristics of dynamic systems. Both issues are addressed in this section. Progress in observation modeling could be achieved for some space-geodetic techniques and in different fields of application. The stochastic models of VLBI has been extended for various variance and covariance components (Tesmer, 2004; Tesmer and Kutterer, 2004). A more refined stochastic model of GPS phase observations was developed by Schön and Brunner (2006) based on turbulence theory. Wieser et al. (2005) and Wieser (2007a ,b) used the measured carrier-to-noise density ratio as the main input to a proper variance model. Jin et al. (2004, 2005), Wang et al. (2004) and Zhang et al. studied various aspects of the stochastic model in GPS modeling and data analysis such as, e.g., online modeling issues. Outside the WG progress was achieved, also in the meaning of quality control procedures, by Bischoff et al. (2005, 2006).

The combination of different results or products, respectively, which have been derived by different operators or software packages using identical observation data is a task which is routinely performed in the processing of space-geodetic technique and the so called intra-technique combination. Some publications on TRF combination are given in the list of references; see, e.g., Krügel and Angermann (2007). Up to now this procedure is not rigorous from a mathematical point of view as neither the identity of the original observation values nor the individual impact of the operators and software packages is considered by quantification and proper modeling. However, as the weights for the following inter-technique combination with the results of other space-geodetic techniques are based on the results of the intra-technique combinations, there are some shortcomings in the determination of the ITRF or other reference frames – at least from a theoretical point of view. This problem is also known from typical GPS processing software.

Kutterer et al. (2007) showed that a correct variance propagation for intra-technique combination can be obtained approximately by proper correction factors which take both the identity of the observed values and the quantified operator-software impact into account. Further developments (which are unpublished up to now) outline a clear procedure for a statistically founded combination which is based on an adequate functional model and variance and covariance component estimation.

As indicated above, quality control can be understood in the context of modeling. It is often based on well-established techniques which are applied in a meaningful way. Kutterer (2003) studied the role of non-datum parameter constraints in the processing of VLBI data which are typically reduced before further processing and thus have the potential to bias the final results. Kutterer et al. (2003) considered outlier detection in VLBI data analysis. They identified the robust BIBER estimator by Wicki as the most useful one in this context as it is both effective concerning the smallest number of misidentifications and efficient regarding computer run-time and work-space requirements. Kutterer (2004) adapted well-known elements of reliability theory to the analysis of VLBI data. Tanir et al. (2007) studied the use of regularization methods for the intra-technique combination of VLBI data.

Wieser (2004) studied statistical tests of one-way GPS observations when processing double-differenced observations. Wieser et al. (2004) investigated algorithms for the differentiation of outlier scenarios possibly affecting Kalman filter based kinematic GPS. Kuusniemi et al. (2007) developed a forward-backward algorithm for efficient real-time outlier detection in GPS-based pedestrian navigation. Akyilmaz and Kutterer (2003a) studied the use of fuzzy logic for the derivation of a reasonable multidimensional outlier model as a basis for multivariate outlier tests based on the theory of the general linear hypothesis test.

Several studies have been carried out regarding the modeling of unknown functional relations in the context of multivariate analysis in descriptive and causal models. Akyilmaz and Kutterer (2003b, 2004, 2005) developed a Neuro-Fuzzy model for the prediction of Earth orientation parameters which showed a good performance concerning approximation quality and efficiency. Akyilmaz et al. (2003, 2005) and Akyilmaz and Arslan (2007) studied various applications of fuzzy inference systems for, e.g., geoid surface approximation, map projections, and TEC prediction. Boehm and Kutterer (2006) and Martin and Kutterer (2007) used fuzzy inference systems for both the descriptive and causal modeling of structural deformations of a lock. This technique has also been applied outside the WG by Miima and Niemeier (2004). All this work has been embedded in the field of Soft Computing which is intensely studied in many technical disciplines.

Quality control in the context of engineering geodesy, e.g. for sensor calibration, has been studied by Neitzel and Petrovic (2004a, b). Neitzel (2006) presented a rigorous estimation of instrument errors of sensor systems of polar type such as tachymeters and terrestrial laser scanners. Lehmann (2004, 2005) and Lehmann and Scheffler (2006) discussed quality control issues in the context of geodetic monitoring and geo-kinematics. The work of Hewitson and Wang (2006a, b, 2007) focused on quality issues of GNSS Receiver Autonomous Integrity Monitoring (RAIM).

Advances in estimation and filtering

The search for outliers in the observed data has a long and strong tradition in Geodesy. There has been some work on robust estimation. Neitzel (2003, 2004) developed a combinatorial algorithm based on the maximum correlation adjustment principle for the determination of a maximum subset of congruent points in similarity transformations of geodetic networks. Yang published a significant number of studies on robust estimation and filtering, mainly for Kalman filters; see the corresponding references at the end of this report such as Yang (2005a, b) and Yang and Gao (2005, 2006). Snow and Schaffrin (2004, 2007) presented the BLIMPBE which is an estimator for bias control. Xu (2006) presented a new approach for mixed integer linear models which uses Voronoi cells.

The Total Least-Squares estimation principle (TLS) has gained some interest during the last four years. It is expected that the respective studies will be continued; additional studies are foreseeable. There has been a significant number of publications by Schaffrin and co-authors; see, e.g., Schaffrin and Felus (2005, 2007) or Schaffrin and Wieser (2006, 2007). Besides, Acar et al. (2006) and Akyilmaz (2007) contributed in this field. The idea behind TLS is the same as for the errors-in-variables model in multivariate regression analysis. Hence it can be classified either as an extension of the functional and stochastic model or as an extension of the least-squares objective function since the configuration matrix of the adjustment model is considered as erroneous in addition to the classical observation errors. As the TLS principle can be identified as a special case of the least-squares adjustment in the Gauss-Helmert model (condition equations with unknown parameters) several analogies can be identified. The geodetic applications can be found in several fields. The main discussion has been on coordinate transformations and related issues where direct estimation equations are found which are based on a singular value decomposition. Besides, also deformation analysis was considered.

Extended uncertainty budget

All practical experiences in geodetic observations indicate the presence (or even dominance) of systematic effects in the data in addition to the random effects which are due to non-controllable influences. One approach to handle systematic effects is based on the modeling of physical correlations in the data and its adequate consideration in least-squares adjustment and other analyses. A second approach was studied within the frame of the WG. The idea behind is that the lacking or insufficient knowledge of systematic effects yields a new type of uncertainty in addition to the one which is due to random effects. Whereas this second type is modeled in terms of random variables and hence treated by means of techniques from stochastics, the origin of the first type is rigorously considered as a non-random bias. The corresponding uncertainty is called imprecision. It is modeled in terms of intervals or fuzzy intervals, respectively. Hence, the mathematical background is interval mathematics or fuzzy theory. Actually, the fuzzy case is more general than the interval case.

In order to provide mathematical tools which are meaningful in Geodesy, techniques like least-squares estimation, hypothesis testing, Kalman filtering and others have to be extended in order to take data into account which is uncertain due to both random and unknown systematic effects. The mathematical basis for the extensions is the extension principle which was introduced by L. Zadeh who is considered as the “father” of fuzzy theory. In this field there has been significant progress.

On the one hand there have been a number of mathematical developments such as (i) the derivation of zonotopes which represent the general result of a linear mapping of multidimensional intervals and which are independent of the chosen parameter basis, (ii) the consistent formulation of multi-dimensional hypothesis tests together with generalized probabilities of type I and type II errors. The corresponding extension of the Kalman filter algorithm which is used for navigation and monitoring purposes has to be mentioned. There is some ongoing work in this field. On the other hand some typical geodetic observations were considered such as leveling, tachymetry and GPS. Extended error models are discussed in detail in order to better understand the dominance of the systematic type of uncertainty on longer distances. The obtained results are very plausible. It could be shown that – regarding the underlying mathematical mechanisms – they are superior to be purely stochastic modeling in terms of physical correlations.

There has been comparable work in related engineering disciplines and in applied mathematics. Nevertheless it must be noted that in Geodesy the acceptance of such extensions could be improved. Although the mathematics of fuzzy theory is not familiar to the typical geodetic scientist it can be understood on the basis of a Master’s degree. Open questions refer to the corresponding extension of the object models, the application of the theory to differential equations, the optimality of extended estimators and tests and the practical derivation of meaningful numerical values for the fuzzy quantities.

For further reading on interval and fuzzy extensions of geodetic data analysis techniques see, e.g., Kutterer (2004, 2006), Kutterer and Neumann (2007), Kutterer and Schön (2004), Lehmann (2004), Neumann and Kutterer (2006, 2007), Neumann et al. (2006), Schön (2003), Schön and Kutterer (2005a, b, 2006a, b, 2007).

Some work was dedicated to the treatment of systematic errors in GPS coordinate time series. Although it is widely accepted that GPS time series contain periodic signatures that correspond to known geophysical effects there is some evidence that some of the power in the GPS time series spectrum, particularly in the height component, is an artifact of the analysis process. Unfortunately, it is somewhat difficult to separate 'real' geophysical signals from these artifacts. Therefore it is important to theoretically understand the mechanisms in standard GPS processing methodology which result in periodic artifacts manifesting themselves in coordinate time series. Furthermore, it is desirable to ascertain the frequencies at which such artifacts will appear and, additionally, experiments should be conducted which can demonstrate, identify and quantify such artifacts in coordinate time series derived from real GPS data, as opposed to simulated data. Finally, it is desirable to find algorithms and processing techniques that can mitigate or, preferably, eliminate, these artifacts.

Work to date has focused on understanding the impact of errors in tidal loading models on GPS coordinate time series. The effects were first identified in Penna and Stewart (2003), whilst in Stewart et al. (2005) a theoretical explanation using a simplified but analogous simulated model was developed. The respective predictions were demonstrated for real data in Penna et al. (2007) whilst Stewart and Penna (2007) extends the simplified theoretical model to demonstrate how solving for additional parameters can change the properties of systematic errors in the final coordinate time series. There is still much work left which should focus both on the derivation of specific error functions for, e.g., multipath propagation into GPS time series and on error mitigation techniques.

Conclusions

As shown before, there are several results of the WG members on quality which are without doubt of particular interest for the geodetic community. The refinement of the functional and stochastic modeling, e.g., for space-geodetic techniques and the TRF combination, the non-standard modeling using soft computing techniques as well as the consideration of other principles such as Total Least Squares or robust estimation have to be mentioned. Several metrological aspects in Geodesy have been taken into account in terms of mathematically founded calibration models and numerical measures. The rigorous distinction of different types of uncertainty has been elaborated in a mathematically consistent way. All these results are valuable elements towards a more general understanding of quality in Geodesy as they provide important information and new ideas.

However, the treatment of quality in Geodesy has still various shortcomings which could not be overcome during the last four years. Actually, the WG did not succeed in deriving the intended quality model for general use in Geodesy what may be due to two reasons. First, it turned out that the main interests in Geodesy (and in the WG) did not focus on sophisticated quality measures on a sound theoretical basis. The importance of the observation and analysis processes is not (yet) recognized. The broad awareness for quality modeling of processes and products as a scientific field of its own right with strong mathematical challenges is (still) lacking. In contrast to other fields such as robotics or geoinformatics the group of respectively interested colleagues in Geodesy can still be neglected. It is not clear when (or if) this situation will change.

Second, based on the experience of the last four years, an inductive ("bottom-up") approach seems to be more promising than the deductive ("top-down") approach which has been tried within the WG. Even if quality is considered as a topic of common interest in Geodesy, the actual notions and requirements may differ significantly. However, it is very likely to obtain a complete and consistent quality model in a sharply defined field of application. This could be the total process of reference frame derivation if there is a significant support by the technique and analysis centers. This may also hold for complex multi-sensor systems in engineering geodesy for documentation or monitoring purposes.

Actually, an extended quality model has already been derived outside the WG by Wiltschko (2004) for use in telematics. It is based on a probabilistic background and is fully compatible with the scope of the original WG Terms of References. Hence, it serves as a proof of concept in the present report. Therefore, it is – without doubt – worthwhile to intensify the research on quality in the suggested way keeping in mind that there are sister communities to IAG in Geodesy which share common interests in this field.

The successful work of a WG over a four years period strongly depends on the continuous coordination of the group by the chair person and on dedicated contributions of the WG members. From an ideal point of view it has to be admitted that this was not achieved in an optimal and satisfactory way what is to some part definitely due to the chair person's move from Munich to Hannover and the challenging new tasks. However, even if – from a more pragmatic (and today's) point of view – the WG's objectives turned out to be suboptimal due to a too fuzzy focus as discussed above there has been significant progress which can be understood as a solid basis for further work on quality issues. This is clearly underlined by the following long list of references which is definitely of particular interest for a considerable number of colleagues in Geodesy and related disciplines.

The chairman of the WG is gratefully and without reservation deeply indebted to the WG members for their dedicated studies and their contributions to the preparation of this final report.

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Final Activity Report for IAG Commission 2, The Gravity Field

by

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Commission President

June 2007

Executive Summary

Commission 2 consists of four sub-commissions, seven projects, and five study groups organized in the following structure:

1. Sub-Commission SC2.1: Gravimetry and Gravity Networks (president: Shuhei Okubo)
   a) Inter-Commission Study Group IC-SG2.1 (Joint with IGFS): Comparison of Absolute Gravimeters (Chair: Leonid Vitushkin) (changed to a joint study group with IGFS, from previous status as a study group solely in the Commission)
   b) Commission Project CP2.7: Gravity in South America (Chair: María Cristina Pacino)

2. Sub-Commission SC2.2: Spatial and Temporal Gravity Field and Geoid Modeling (president: Martin Vermeer)
   a) Study Group SG2.2: Forward Gravity Field Modeling Using Global Databases (Chair: Michael Kuhn)
   b) Study Group SG2.3: Satellite altimetry: data quality improvement and coastal applications (Chair: Cheinway Hwang)
   c) Inter-Commission Study Group IC-SG2.6 (Joint with ICCT): Multiscale Modeling of the Gravity Field (Chair: Willi Freeden)
   d) Inter-Commission Study Group IC-SG2.7 (Joint with ICCT): Towards cm-accurate Geoid - Theories, Computational methods and Validation (Chair: Yan Ming Wang) (This study group was formed just recently in 2006-2007.)

3. Sub-Commission SC2.3: Dedicated Satellite Gravity Mapping Missions (president: Pieter Visser)

4. Sub-Commission SC2.4: Regional Geoid Determination (president: Urs Marti)
   a) Commission Project CP2.1: European Gravity and Geoid (Chair: Heiner Denker)
   b) Commission Project CP2.2: North American Geoid (Chair: Marc Véronneau)
   c) Commission Project CP2.3: African Geoid (Chair: Charles Merry)
   d) Commission Project CP2.4: Antarctic Geoid (Chair: Mirko Scheinert)
   e) Commission Project CP2.5: South American Geoid (Chair: Denizar Blitzkow)
   f) Commission Project CP2.6: Southeast Asian Geoid (Chair: Bill Kearsley)

In addition, there are various Inter-Commission working groups and projects, as follows.

a) Inter-Commission Working Group IC-WG1 (Joint with ICCT & Commission 1): Quality Measures, Quality Control, and Quality Improvement (Chair: H. Kutterer)
b) Inter-Commission Working Group IC-WG2 (Joint with IGFS): Evaluation of Global Earth Gravity Models (Chair: Jianliang Huang)
c) Inter-Commission Working Group IC-WG3 (Joint with ICCT & Commission 1): Satellite Gravity Theory (Chair; Nico Sneeuw)
d) Inter-Commission Project IC-P1.1: (Joint with Commissions 1 & 3): Satellite Altimetry (Chair: Wolfgang Bosch)
e) Inter-Commission Project IC-P1.2: (Joint with Commission 1) Vertical Reference Frames: (Chair: Johannes Ihde)
f) Inter-Commission Project IC-P3.1: (Joint with Commissions 1 & 3): Global Geodynamics Project (Chair: David Crossley)

These entities have their primary affiliation in other Commissions or Services (in parentheses), and the reporting of their activities is contained in other corresponding documents (available reports from some of these are also attached as Appendices 15-17).

This report covers the period of activity of the primary entities in Commission 2 for the period May 2006 – April 2007. Each of the chairs of the entities was asked to summarize activities in six general areas:

1) publications of members, including journal papers, conference papers and presentations, and bulletin reports;
2) organizations of workshops, conference sessions, group meetings;
3) participation in observation campaigns and major computational efforts;
4) other noteworthy accomplishments, including significant interaction with groups outside the Commission;
5) future plans and activities;
6) issues and concerns, and recommended improvements in the Commission.

Reporting for the Commission was organized by Sub-Commission, with entities submitting activity summaries to their corresponding Sub-Commission. Each president of a Sub-Commission then collected and submitted a brief report to the Commission President. This report then summarizes these for the Executive Committee of the IAG.

Almost all entities of the Commission achieved significant progress in their stated objectives during the past year. Besides the highlights of the Commission mentioned here, further details may be found on the web sites of individual sub-commissions (see http://www.geology.osu.edu/~jekeli.1/iag-commission2) and in the Appendices to this report.

Finally, recommendations are made with regard to the continuation for the next four years not only of the sub-commissions but various study groups and projects under each one.

1. A significant event for the Commission during the past year was the First International Symposium of the International Gravity Field Service, held in Istanbul, Turkey, 28 August – 1 September 2006. This symposium brought together scientists in many areas of gravity field measurement and modeling, and related research activities. All components of the Commission were well represented and they actively participated among the ten symposium sessions that attracted a total of 228 papers. The symposium represented an excellent launch of the newly formed International Gravity Field Service and demonstrated a strong cooperative relationship with the Commission. A Springer volume with many of the presented papers is in progress of being published.

The Proceedings of the IAG Scientific Assembly, Dynamic Planet 2005, held in Cairns, Australia, in August 2005 was also released this year and contains, among many other contributions authored by members of the Commission, 28 papers from the Session titled, "Gravity field determination from a synthesis of terrestrial, airborne and altimetry measurements".

Finally, the Commission is also involved in the upcoming Symposium on Terrestrial Gravimetry – Static and Mobile Measurements, to be held in St. Petersburg, Russia, 20-23 August 2007. More information about this and previous symposia can be found on the internet through links provided on the Commission web pages.

2. Sub-Commission 2.1 (Gravimetry and Gravity Networks) reported (Appendix 1) continued progress in establishing absolute gravity networks in East and South-East Asia. Following the successful creation in 2005 of the Absolute Gravity Standard Station Network in East Asia and South-East Asia (AGSSN-ESEA), additional complementary measurements have been carried out in 2006 to provide calibration data for superconducting gravimeters. Absolute gravimetry in the Pacific Rim countries is particularly important as population growth continues and depends on sustainable groundwater supplies. Several campaigns to monitor groundwater using precise portable absolute meters are planned for the next several years (2008-2010). The accuracy assessment of absolute gravimeters and particularly the specification of the measurement strategy, data processing, calculation of the uncertainties and presentation of results are among several continuing efforts of the study group, IC-SG2.1, on Comparison of Absolute Gravimeters (which was elevated to an Inter-Commission Study Group to provide a closer tie to the International Gravity Field Service that has a key interest in global absolute gravity networks). The work of this Study Group is also closely aligned with the BIPM Consultative Committee on Mass – Working Group on Gravimetry (CCM-WGG) and plans the next major international comparison of absolute gravimeters in 2009. Other significant gravity network studies reported under this sub-commission include the activities in South America in conjunction with the new geoid for South America. New campaigns are planned for 2007-2008 for absolute and relative gravity networks aiming to tie together and strengthen various national networks and also occupy tide gauge and permanent GPS stations.

Because of the continuing importance that absolute (and relative) terrestrial gravity plays in understanding and monitoring crust dynamics and subsurface hydrology, it is recommended that the sub-commission on gravimetry and gravity networks continue during the next quadrennium of the Commission. In particular, the work of the existing commission project CP2.7 should continue to facilitate collaboration among South American countries in developing international gravity networks. However, it may be considered that this project be combined with the geoid project CP2.5 (see below in Section 5.). The IC-SG2.1 (Comparison of Absolute Gravimeters) may be transitioned to the project level with the aim of contributing to the efforts of the IGFS as well as various regional absolute gravimetry campaigns. It is hoped that airborne gravimetry, and especially airborne gravity gradiometry, find renewed active interest within the Commission, either through study groups or projects, since these systems are becoming more prevalent as the instrumentation technology advances and the successes of various campaigns increase. There is then definitely also a need to interface more closely with the satellite gravity missions to enable a seamless gravity modeling from the longer-wavelength satellite-derived components to the short-wavelength components obtained with airborne systems.

3. The work of Sub-Commission 2.2 (Spatial and Temporal Gravity Field and Geoid Modeling) during the past year may be fairly well summarized by the numerous papers and posters presented at the IGFS Symposium in Istanbul, Turkey. See also Appendix 2 for a complete four-year summary. Of particular importance is the tremendous advancement in both global and regional gravity modeling. The satellite mission GRACE has had a seminal impact on successfully correlating temporal variations in global precision gravity models with mass transport on the Earth's surface, e.g., the hydrology of the Amazon River basin. More such studies have been done (e.g., with respect to earthquakes and ice mass balance) and will undoubtedly increase in number as the GRACE mission continues to yield global models on a prolonged temporal basis. On the regional front, a new geoid model was derived for Mongolia almost entirely from airborne gravimetry, showing again the importance of this system in providing high-resolution gravity models at the regional and local level. Similar campaigns over Malaysia, the Gulf of Mexico, and the Arctic Ocean also yielded to varying degrees significant new data. Satellite altimetry is being pushed to its limits for coastal applications where data quality is poorest. However, this is where an understanding of the ocean surface is most important for societal concerns regarding sea level rise, coastal erosion, and marine ecosystems. New methods in data processing (re-tracking) have yielded impressive results, as demonstrated at an international workshop on altimetry with emphasis on coastal applications that was organized by SG2.3 in Beijing in July 2006. It is also noted that forward modeling of the Earth's gravity field is being vigorously pursued as new data bases describing surface topography, ocean bathymetry and internal density variations are increasing in resolution and accuracy.

Clearly, gravity field modeling continues to be a mainstay of the Commission and it is recommended that this sub-commission continue into the next quadrennium of the Commission. Due to the increasing emphasis on temporal modeling and its tremendous applications in geodynamics (which may be defined as including all temporal aspects of the Earth), it may be advantageous from an organizational viewpoint to restrict the sub-commission to temporal modeling and include static modeling in another sub-commission (SC4). This may provide a cleaner separation between the terms of reference between these two sub-commissions. With the temporal emphasis, there will need to be strong ties to Commission 3 on Earth Rotation and Geodynamics. The Study Group SG2.3 on satellite altimetry and coastal applications has been very active and strong (Appendix 6) and should continue in some fashion, perhaps as a new study group that could contribute to both this and the sub-commission that deals mostly with (quasi-static) geoid models. Likewise, the study group on forward modeling has made great progress and has laid the foundation for additional significant work. It is recommended that this study group also be followed with a new study group that addresses these new objectives (Appendix 5).

The Inter-Commission study group, IC-SG2.6, on multi-scale gravity modeling also reports (Appendix 7) wide-ranging collaborative work with the space-gravimetric, geodetic theory (inverse problems), geodynamics, and oceanographic groups. This demonstrates the effective applicability of multiresolution methods in many areas of geodesy and geophysics and research in these areas will undoubtedly continue to advance the methods and theory. A new study group that addresses a particular application with high level research potential may be considered for the next four years.

Finally, the Inter-Commission study group, IC-SG2.7, on analyzing the theory and practice toward the cm-accurate geoid commenced just recently (January 2007) and it is recommended that it be continued without further justification for the next four years. A preliminary report is provided as Appendix 8.

4. Sub-Commission 2.3 (Dedicated Satellite Gravity Mapping Missions) again reports (Appendix 3) tremendous progress in the acquisition and analysis of new gravity data from the satellite mission, GRACE, and the recently launched FORMOSAT-3/COSMIC mission. Analysis of these data, as well as data provided by CHAMP, continues to demonstrate the vast potential to extract useful geodynamic information from these global gravity mapping systems, particularly the temporal variations. The complexity of data processing and modeling (inverse problem) for these satellite missions has stimulated growth in theoretical and mathematical aspects which are needed also for planned future satellite missions, such as GOCE and GRACE/GOCE follow-on missions, as well as satellite cluster systems. A special issue of the Journal of Geodesy (January 2007) was devoted to the inverse problem for satellite gravimetry.

The report from the newly formed Inter-Commission Working Group (IC-WG2) informs us that global gravity models from different current solutions are not consistently accurate in various regions of the world. This and the anticipated abundance of research activity surrounding the release of the upcoming GOCE mission data provide more than sufficient motivation to continue this sub-commission, SC2.3, as well as the working group, IC-WG2. The analysis of satellite gravity data at many different levels, from raw data processing to geophysical interpretation to simulation studies of future missions forms a particularly important part of the Commission. Probably more than any other component, this sub-commission has formed and should continue to nurture very close ties to the Inter-Commission Committee on Theory (ICCT) because the satellite missions provide new and pressing challenges to assimilate different data types both spatially and temporally and at many different scales. The formation of additional study groups and projects in this active area of multidisciplinary research is strongly encouraged.

5. During the past year, as for the entire first quadrennium of the Commission 2, the various geoid projects under Sub-Commission 2.4 (Regional Geoid Determination) have progressed with different levels of success. The European geoid, the Antarctic geoid, and South American geoid projects are most actively engaged in model improvements due to both geopolitical and scientific impetuses. The African geoid project is hampered by a lack of data and the Southeast Asian geoid project by a lack of international agreements to move forward. The North American geoid project seems to continue only at a low level of activity. The report of the sub-commission (Appendix 4) provides a concise review of accomplishments and future plans; see also Appendices 9-14.

It is expected that in many areas where only poor geoid models are currently available, the responsible organizations are eagerly awaiting the results from the GOCE mission, which may deliver a model of sufficient accuracy/resolution for these areas in the near term. However, in most areas regional geoids of higher accuracy (cm-accuracy or better) and resolution (1-10 km) will be required in the future and this can only be achieved with high-accuracy regional gravity surveys. Therefore, regional geoid projects should continue to be supported by the Commission. In particular the active European, South American, and Antarctic projects deserve continuation for the next four years without further justification. One may consider combining projects CP2.5 and CP2.7 since they have been active and reporting essentially as one unit during the past four years. This would be analogous to the European project CP2.1 that naturally combines both gravity and geoid modeling. The other three geoid projects (North America, Africa, Southeast Asia) should be renewed only if there are viable plans (new proposals) that have a reasonable chance for success, including significant activity by their members.

It is also recommended that this Sub-Commission continue with a broader base of interest that includes besides specific regional and global geoid modeling, static gravity field modeling from a more general standpoint, as well as terrain (bathymetry) data applications in gravity field and geoid modeling.

6. In summary, Commission 2 has established a strong agenda for IAG in the area of gravity field measurement and modeling with significant links to a number of sister commissions and services. The Commission has been active at all the major IAG conferences and has played key or leading roles in several symposia during the past four years. Its significance is again demonstrated by the response of IAG contributors to the IUGG general assembly, having submitted more than two fifths of their papers to the

IAG session GS002 (216 out of 507 for sessions GS001-004). The Commission is carrying on the traditions of the IAG by fostering individual and group activities in gravity research, as well as encouraging collaborations with cross-disciplinary entities. The next four years promise to be important ones for the Commission as a new satellite gravity mission (GOCE) is launched and corresponding data in the form of a new type (gradiometry) are analyzed; as the temporal domain of the Earth's gravity field is further exploited to understand mass transports, particularly with respect to the ice-mass balance problems; and as new instrument technologies, particularly gravity gradiometry, are utilized for terrestrial applications using airborne surveys.

The Appendices are reports provided by the sub-commission presidents and chairs of individual entities and form a part of this report. They provide the details of activities within the sub-structure of the Commission.

Appendix 1: Report of **Sub-Commission SC2.1**, by S. Okubo (includes reports for SG2.1 and CP2.7)
Appendix 2: Report of **Sub-Commission SC2.2**, by M. Vermeer
Appendix 3: Report of **Sub-Commission SC2.3**, by P. Visser
Appendix 4: Report of **Sub-Commission SC2.4**, by U. Marti
Appendix 5: Report of **Study Group SG2.2**, by M. Kuhn
Appendix 6: Report of **Study Group SG2.3**, by C. Hwang
Appendix 7: Report of Inter-Commission Study Group IC-SG2.6, by W. Freeden
Appendix 8: Report of Inter-Commission Study Group IC-SG2.7, by Y.M. Wang
Appendix 9: Report of **Commission Project CP2.1**, by H. Denker
Appendix 10: Report of **Commission Project CP2.2**, by M. Véronneau
Appendix 11: Report of **Commission Project CP2.3**, by C. Merry
Appendix 12: Report of **Commission Project CP2.4**, by M. Scheinert
Appendix 13: Report of **Commission Projects CP2.5&CP2.7**, by D. Blitzkow
Appendix 14: Report of **Commission Project CP2.6** by B. Kearsley
Appendix 15: Report of Inter-Commission Working Group IC-WG2, by J. Huang
Appendix 16: Report of Inter-Commission Project IC-P1.2: by J. Ihde
Appendix 17: Report of Inter-Commission Project IC-P3.1: by D. Crossley

Appendix 1

Activity Report of Sub-Commission 2.1

(Gravimetry and Gravity Networks)

Compiled by S. Okubo, President of SC 2.1

Absolute Gravity Network in East Asia and Western Pacific:
Reported by Y. Fukuda, Member of SC2.1.

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.

During the period from 2002 to 2006, Kyoto University and the Geographical Survey Institute of Japan have collaborated to establish the Absolute Gravity Standard Station Network in East Asia and South-East Asia (AGSSN-ESEA) as a part of the Asia-Pacific Space Geodynamics Project cooperation campaigns in the International Association of Geodesy and the Permanent Committee on GIS Infrastructure for Asia & the Pacific using FG-5 absolute gravimeters. These are summarized in Takemoto et al. (2006). As complementary measurements especially aiming at the calibration of the superconducting gravimeters, absolute gravity measurements were carried out in 2006 at Esashi and Kamioka of the AGSSN-ESEA.

Research Institute for Humanity and Nature (RIHN) launched a new project which assesses the effect of human activities on the urban subsurface environment in Asian coastal cities where population numbers and density have expanded rapidly and uses of subsurface environment have increased. The project will address the evaluation of the ground water flow systems and sustainable use of groundwater. In this concern, for monitoring the groundwater changes in Bangkok and Jakarta, precise gravity measurements is planned during 2008 to 2010 by mean of a portable type absolute gravimeter.

Publications

Takemoto, S., Y. Fukuda, T. Higashi, I. Kimura, Y. Hiraoka, Y. Hiyama, H. Nakagawa, M. Honda, H. Aoki, M. Hashizume, H. Amemiya, A. Suzuki, He-Ping Sun, Yong Wang, Houze Xu, Yaozhong Zhu, Weimin Zhang, Jeff. J. F. Hunang, Ta-kang Yeh, Hui-Chin Yu, Cheinway Hwang, S. Dwipa, D. S. Kusuma, A. Andan, P. Manurung, T.-C. Hua, M. Yosof Bin Abu Bakar, Sanudin Hj. Tahir, K. Wattananikorn, R. M. Agaton and E. Macasppac : Establishment of an Absolute Gravity Network in East- and South-East Asia (2006): J. Geod. Soc. Japan, 52, 51-95 (in Japanese with English Abstract).

Hiraoka, Y., I. Kimura, Y. Hiyama, M. Honda, H. Amemiya, A. Suzuki, S. Takemoto, Y. Fukuda and T. Higashi (2006): Collaboration in Establishment of Absolute Gravity Standard Station Network in East Asia (Ⅱ), J. Geogr. Surv. Inst., 110, 19-25. (in Japanese)

Study Group 2.1.1: Study Group on Comparisons of Absolute Gravimeters
Reported by Leonid Vitushkin (Chairperson of SG 2.1.1 and CCM WGG).

The SG2.1.1 works in the collaboration with the Working Group on Gravimetry of the Consultative Committee on Mass and Related Quantities (CCM WGG).

1. A preliminary evaluation of the results of the 7th International Comparison of Absolute Gravimetrs (ICAG-2005) at the BIPM in September 2005 was performed.
All the operators have presented their results of the absolute measurements (97 in-the-night measurements in the period from 3 to 25 September 2005 using 19 absolute gravimeters from countries and the BIPM) and it made it possible to evaluate the preliminary unweighted mean value at the reference site of the gravity network of the BIPM. The main difficulties arose in the evaluation of the budgets of the uncertainties for the individual gravimeters (mainly of the type FG5). A Discussion Group (moderator A.Germak, INRiM, Italy) was organized to develop the recommendations on the evaluation of the uncertainties in the measurements using the absolute ballistic gravimeters according to the requirements for the comparisons organized by metrology community.
The budgets of the uncertainties are necessary for the calculation of the weighted mean result of the comparison.
Further work on the improvement of the technical protocol is also in progress.

2. The requirements to the sites for the regional comparisons of the absolute gravimeters are developed and placed on the website of the CCM WGG (http://www.bipm.org). The access to working documents is restricted to the members of SG2.1.1 and CCM WGG.

3. The sites in Czech Republic, Finland, Luxembourg, Poland and Russia are proposed for the regional comparisons of absolute gravimeters.

4. The second regional comparison of absolute gravimeters will be held in Walferdange in November 2007 (coordinator Olivier Francis). The decision was taken that this comparison will be organized according the rules for a pilot study with the appropriate technical protocol and, on the other hand, it will be open for the participants from geophysical institutes, universities and other organizations not yet related to metrology organizations.

5. The 2nd Joint Meeting of the SG2.1.1 and CCM WGG was organized at METAS (Switzerland) 7-8 June 2006. 27 participants from 16 countries and the BIPM attended this meeting. The agenda and some documents of the meeting are on the website of the CCM WGG.

6. The 2nd Joint Meeting recommended organizing the next 8th ICAG at the BIPM in September 2009.

7. The chairman of the SG2.1.1 and CCM WGG Leonid Vitushkin with the President of Commission 2 Chris Jekeli took part in the organization of the symposium “Terrestrial Gravimetry. Static and Mobile Measurements.TG-SMM-2007” on 20-22 August 2007 in (see: http://www.elektropribor.spb.ru/cnf/tg-smm2007/enfrset.html).

8. The third Joint Meeting of the SG2.1.1 and CCM WGG will be held on 24 August 2007 at the D.I.Mendeleyev Institute for Metrology, St Petersburg, Russia.

Project CP2-7: Gravity in South America.
Reported by M. C. Pacino (Chair of Commission Project 2.7)

This is part of the Joint Report “Gravity and Geoid in South America”. The members of CP2-7 and CP2-5 Projects are organized in a coordinated effort to develop activities related to both projects. The two projects were established as part of the Commission II: Gravity Field, in order to organize the activities of gravity measurements in the continent and to provide the necessary information for the height system in association with the geoid determination.

The first joint meeting of CP2-7 and CP2-5 Projects took place in 2006:

REPORT OF MEETING “GRAVITY AND GEOID IN SOUTH AMERICA”

VENUE: *INSTITUTO GEOGRAFICO MILITAR - BUENOS AIRES (ARGENTINA)*
DATES: *25 – 29 SEPTEMBER 2006*
SPONSORS:
Instituto Geográfico Militar de Argentina
Facultad de Cs. Exactas, Ingeniería y Agrimensura (Universidad Nacional de Rosario)
Facultad de Ciencias Astronómicas y Geofísicas (Universidad Nacional de La Plata)
Escola Politécnica (Universidade de Sao Paulo)
Agencia Nacional de Promoción Científica y Tecnológica de Argentina
Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina
International Gravity Field Service (IGFS – IAG)

The Geoid School, sponsored by the IAG that took place in Rio de Janeiro (Brazil) in 1997, meant an important step forward for the integration of South American scientists into the international geodetic community. Since them, new developments and models have greatly varied the calculation methodology of geoid models, and thus allowing to get other results with the chance of applying them in several scientific disciplines.

In this sense, this symposium was organized in a joint effort of the IAG Projects CP2-7 (Gravity in South America) and CP2-5 (South American Geoid), and sponsored by IGFS together with several Argentine and Brazilian associations. Its aim was to update and deepen the knowledge about the terrestrial gravity field which leads to an adequate handling of the vertical reference.

The main intention of this symposium was bringing up a real possibility for South American colleagues to update the knowledge in this subject as well as to give a place to exchange opinions, experiences and common problems. It means the possibility of a meeting in a city in South America, where money and language inconveniences could be minimized in order to get the widest participation and to strengthen the relationships with the IAG community.

The activities were arranged in the following way:

- *Two workshop days for updating of the new methodologies and current models as well as the practical use of these concepts.*
- *Two days to inform about the activities, achievements and future prospects in several South American countries through speeches and murals.*

- *The last day for discussion and planning of joint activities.*

The event was very welcome by professionals of related activities from several countries of South America (Argentina, Brazil, Chile, Ecuador, Uruguay, Venezuela) as well as students from different universities.
The participants taking part in the workshop gave great attention to the lectures, which were focused on the main concepts and computing procedures.
Thirty presentations were attended by more than fifty participants. This fact is further evidence of the necessity of this kind of events at these latitudes.
On the last day, several recommendations and suggestions were discussed. Users of geoid models could set out their needs and, at the same time, they became aware of the possibilities of bringing their help in many ways. South American Scientist were able to share experiences and initiate conversations for joint projects. Students could have a picture of the latest projects, what meant an important step forward for them and for the whole geodetic community.

Future plans: Measuring campaigns

The budget for a new absolute gravity measurement campaign has been approved.
It will be developed in two steps:

- 2007: The reoccupation and densification of absolute gravity stations in Argentina, Brazil, Uruguay and Ecuador using FG5 – 223 of National Observatory (Rio de Janeiro – Brazil). Besides, a relative gravity campaign to connect the nationals networks will be also done.
- 2008: Absolute gravity measuring campaign using A10-011 of National Observatory (Rio de Janeiro – Brazil) at tide gauges and permanent GPS stations.

Appendix 2

Activities of IAG Subcommission 2.2: Spatial and Temporal Gravity Field and Geoid Modelling

Martin Vermeer

February 28, 2007

Abstract

The Subcommission's work over the last four years is summarized. The subjects of study are global and regional gravity modelling including topographic/isostatic modelling and the problems of upward and downward continuation, BVP and spectral approaches; tides, geodynamics, gravity changes due to air and water movement, and related subjects.

Highlights of the reporting period were the symposia in Porto, Cairns and Istanbul. Technology wise, the most reportable developments are undoubtedly

1. the GRACE mission results, which are still being added to, giving an unprecedented picture of the static global Earth gravity field as well as seasonal and other temporal variations; and
2. the extensive use of airborne gravimetry, facilitated by real-time GPS positioning, for regional and national gravimetric survey especially in heretofore unsurveyed areas.

The report refers to the Subcommission web site for a compilation of relevant publications by Subcommission members and others over the reporting period.

1 Reporting period

This report to the IUGG General Assembly in Perugia, Italy, covers the Subcommission's history from its official creation in Sapporo, Japan in 2003, up to the beginning of 2007.

2 Terms of Reference

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

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

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

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

3 Steering Committee and membership

Martin Vermeer (Chair) – Finland	marti.vermeer@hut.fi
Bernard Ducarme – Belgium	bernard@ksb-orb.oma.be
Michael Kuhn – Australia	kuhnm@vesta.curtin.edu.au
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Zdenek Martinec – Germany	zdenek@gfz-potsdam.de
Christopher Kotsakis – Canada	kotsakis@geomatics.ucalgary.ca

As for the Subcommission's members, we have a mailing list of interested people in which no distinction is being made between full and corresponding members. These are almost 40 people that your chairman knows to be or have been active in the field of the Subcommission. During the reporting period only part of these people actually responded to the initial invitation or otherwise participated in the work.

4 Activities

4.1 Subcommission

4.1.1 Porto

The main activity was undoubtedly our participation in the Porto International IAG Symposium GGSM "Gravity, Geoid and Space Missions" in 2004 (`http://www.fc.up.pt/ggsm2004/`). At this meeting, we organized a splinter meeting of the Subcommission, which was well attended. The meeting produced a number of relavant presentations which found their way to the symposium Proceedings. See our reference list.

4.1.2 Cairns

At the IAG Scientific Assembly "Dynamic Planet 2005" in Cairns, Australia, August 22-26, 2005 (`http://www.dynamicplanet2005.com/`), the Subcommission organized a splinter meeting, which was reasonably well attended. A report on this meeting can be found on the Subcommission website.

4.1.3 Istanbul

This meeting (`http://www.igfs2006.org/`), the first symposium of the International Gravity Field Service, included a Session 10 on geodynamics and gravity change chaired by Martin Vermeer. However, all sessions were more or less relevant:

- Session 1: Gravity field modelling from combination of local and satellite data
- Session 2: Regional geoid projects
- Session 3: Vertical datum and height systems
- Session 4: New global high-resolution gravitational models
- Session 6: Satellite altimetry
- Session 7: Airborne gravity
- Session 8: Terrain data and geopotential forward modelling
- Session 9: Absolute gravity and gravimetric networks.

Publication of Proceedings is in preparation; part of the presentations were submitted as manuscripts to a peer review process, that has now been completed.

4.1.4 Website

A Subcommission website has been functional: `http://www.hut.fi/~mvermeer/IAGSC2.2.html`, which is continually under construction.

4.1.5 Contributions

The current report includes contributions by Michael KUHN, Dan ROMAN, Dimitris TSOULIS, Heiner DENKER, Hussein ABDELMOTAAL and Artu ELLMANN and Frank LEMOINE.

- Dan ROMAN of the National Geodetic Survey, Washington DC, reported on the national geoid determination effort [RWHH04], which includes airborne gravity missions in collaboration with Naval Research Lab in the seas surrounding the country.

  He and others (John BROZENA) reported on airborne gravimetry work in the Gulf Coast region: the coastal regions of the Florida panhandle, Alabama, Mississippi, and some of Louisiana. Profiles were at above 10 km elevation and spaced 10 km part, which should mitigate aliasing. There were 41 north-south trending tracks, each about 500 km long. The total spatial coverage is then 400 km x 500 km.

  The expectation is that these data will be used to

  1. test various EGM's based on GRACE data to find the most optimal (400-500 km correlates to degree 90-100, where GRACE is thought to be valid) and
  2. locate and possibly fix any systematic errors in terrestrial and shipborne data.

- Michael KUHN of Curtin University, Perth, Australia, reported on the free availability of the Australian Earth Gravity Model; three publications related to it are [KS05, KF05, BKC+05].

- Dimitris TSOULIS, who is involved with a number of colleagues in finding ways of assessing available gravity field models by connecting them with known structures in the Earth's interior. This work relates to IAG Study Group 2.2, but also the the new satellite gravity missions.

- Heiner DENKER, who reported [?] on the European Gravity and Geoid Project, a regional application in practice of the subject area of our Subcommission. The ambitious effort is envisaged to exploit many different data types and several different techniques, but with a focus on gravimetric-topographic geoid determination using remove-restore.

  For the first time, also satellite mission data is included: already improvements by up to 60% are seen when using GRACE data compared to the previous European geoid model EGG97, while also systematic errors are substantially less. Accurate determination of W_0will make it possible to contribute to the establishment of a new, globally defined European vertical datum.

  The project is progressing well, and final geoid/quasigeoid computations are planned for 2007.

- Artu ELLMANN reported on ongoing work of the Vancouver group, on subjects like gravity field studies, e.g., the STOKES-HELMERT method of solving the geodetic BVP, and the rigorous determination of orthometric heights.

- Hussein ABD-ELMOTAAL has been active in Egyptian geod determination.

- Frank LEMOINE referred to a first article ([RLK+05]) on the GRACE work, showing that seasonal ground water variations in the Amazone and similar tropical river basins can be monitored gravimetrically from space.

4.2 Scientific results

One major development in the field of study covered by the Subcommission was the explosion of scientific studies prompted by the becoming available, during the reporting period, of CHAMP and especially GRACE mission results. Currently superior models are available both for the static gravity field of the Earth – which already are finding their way into regional and national geoid models – and the temporal variations, on land mostly related to hydrography.

We should mention (references in the on-line bibliography):

- The determination of ever more precise global geopotential and geoid models, especially from GRACE
- Their validation against, e.g., GPS and DORIS results
- The successful monitoring by GRACE satellite gravimetry of ground and ocean water level variations of various kinds, including the wet and dry monsoons in various tropical river basins
- The validation of these measurements against hydrological and ocean circulation models and satellite altimetry
- Other methodogical studies.

Today we have proven techniques to robustly determine global geoid models at cm-level accuracy up to harmonic degree 150, and study seasonal ground water variations on the several-mm level on subcontinental (river basin) scales.

4.3 IAG Study Group 2.2

This study group, "Forward Gravity Field Modelling Using Global Databases", chairman Michael Kuhn, reports separately. This section presents the abstract of his report, slightly edited.

"Today an increasing number of databases with ever increasing resolution are available that describe the Earth's shape and internal structure. These databases include high resolution digital elevation models (DEM) such as the latest release of SRTM-derived DEMs, bathymetric models of the world's oceans and models describing the geological and geophysical structure (e.g. density distribution) of the Earth's crust and mantle. The increasing number of these data allows for the use of forward gravity field model techniques (direct application of Newton's integral) being of great significance to gravity field modeling and interpretation. Furthermore, the comparison of the forward modeling results with existing gravity field models reveals useful information on the Earth's interior as well as the validity of the forward gravity modeling techniques.

The International Association of Geodesy (IAG) Study Group 2.2 is concerned with the employment of forward gravity modelling techniques to recently released global digital databases for gravity field recovery and interpretation. The key points the study group were focusing at are (i) the construction of forward gravity field models, (ii) the interpretation and application of forward modelling results, and (iii) the studying of forward modelling techniques. This contribution summarizes the activities of the study group over the last four years since its creation at the IUGG General Assembly at Sapporo in 2003. "

5 Publications

Lists of publications were provided by many members of the Subcommission.

At the Subcommission's web site, at `http://www.hut.fi/~mvermeer/bib2html/index.html`, can be found a richly cross-refererenced list of publications by members of the Subcommission (and others) that are relevant to the field of the Subcommission according to the Terms of Reference. The list includes the presentations at the various IAG symposia relevant to the work of the Subcommission (Porto, Cairns, Istanbul). This list will be updated before the General Assembly to reflect current status.

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Appendix 3

Sub-Commission 2.3 – Dedicated Satellite Gravity Mapping Missions
Commission 2 (Gravity Field)
International Association of Geodesy (IAG)

Report 2006

http:/www.deos.tudelft.nl/~pieter/IAG/sc23.htm

Pieter Visser (chair)

Members:

Pieter Visser (DEOS/Netherlands, chair) Srinivas Bettadpur (CSR/U.S.A.) Thomas Gruber (IAPG/Germany) Cheinway Hwang (NCKU/Taiwan) Radboud Koop (SRON/The Netherlands) Nico Sneeuw (GIS/Germany)	Pieter.Visser@lr.tudelft.nl srinivas@csr.utexas.edu Thomas.Gruber@bv.tu-muenchen.de hwang@geodesy.cv.nctu.edu.tw R.Koop@Sron.nl sneeuw@gis.uni-stuttgart.de

Activities/milestones:

- The sub-commission members have all been actively involved in further analysis of CHAMP and GRACE data. Highlights include strongly improved GRACE-based temporal gravity solutions, both on a regional and global scale. Especially, significant progress has been made in applying GRACE gravity field solutions for mass balance studies in for example the Arctic areas. The dedicated current (CHAMP, GRACE) and future (GOCE) gravity missions have stimulated new theoretical developments (inverse modeling, de-aliasing, etc.). This has been the focus of a special issue of the Journal of Geodesy.
- The GRACE project delivered new and improved (Release-04) gravity field products to the user community. In addition, GRACE and GOCE mission team members participated in each other's Science Team meetings at the end of 2006. The intention is to ensure that optimal quality data are collected from both missions to maximize science returns.
- The joint Taiwan-US mission FORMOSAT-3/COSMIC was launched successfully on April 17, 2006, deploying six micro-satellites at altitudes ranging from 525 to 800 km and at an inclination of 72^o in the final mission phase. Two patch antennae, mounted on the upper part of the main body, are for precise orbit determination (POD). Successful POD and gravity field retrievals have already been carried out. Information about the status and data acquisition is available at the web site of Taiwan's National Space Organization (NSPO): http://nspo.org.tw.
- A consortium of 9 European geodesy and geo-science groups, including 4 from the members of this sub-commission (IAPG, SRON, DEOS, GIS), have

been granted an ESA study on "Monitoring and modeling Individual Sources of mass Distribution and Transport in the Earth System by Means of Satellites", which focuses on future GRACE and GOCE follow-on Earth gravity missions. Gravity is playing more and more an important, if not crucial role in the earth sciences necessitating such follow-on missions.

- Most sub-commission members attended the 3rd International GOCE User Workshop in November 2006 in Frascati, Italy, and presented the latest results and status reports on preparations of the use of GOCE gravity field data.

Selected publications:

Gerlach C, and Visser PNAM (2006), Swarm and gravity: possibilities and expectations for gravity field recovery, First International Science Meeting, SWARM, 3-5 May 2006, Nantes, France, p. 7 pp., ESA WPP-261, July 2006

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Gruber Th, Rummel R and Koop R. (2006), The GOCE High Level Processing Facility; Proceedings of the Workshop: GOCINA - Improving Modelling of Ocean Transport and Climate Prediction in the North Atlantic Region using GOCE Gravimetry; Ed. Knudsen, Johanessen, Gruber, Stammer, van Dam; Cahiers du Centre Europeen de Geodynamique et de Seismologie, Volume 25, p. 45-55

Han S-C, Shum CK, Ditmar P, Visser PNAM, Beelen C van, and Schrama EJO (2006), Aliasing Effect of High-Frequency Mass Variations on GOCE Recovery of the Earth's Gravity Field, J. Geodyn., 40/(1-3), 69-76.

Hwang C, Tseng TP, Lin TJ, Fu CL, Svehla D and Schreiner B (2007) Precise orbit determination for FORMOSAT-3/COSMIC: preliminary result of gravity recovery, paper submitted to Journal of Geodesy

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Appendix 4

Activity Report of Sub-Commission 2.4 "Regional Geoid Determination" for the period: January 2006 - April 2007

General organization, overview

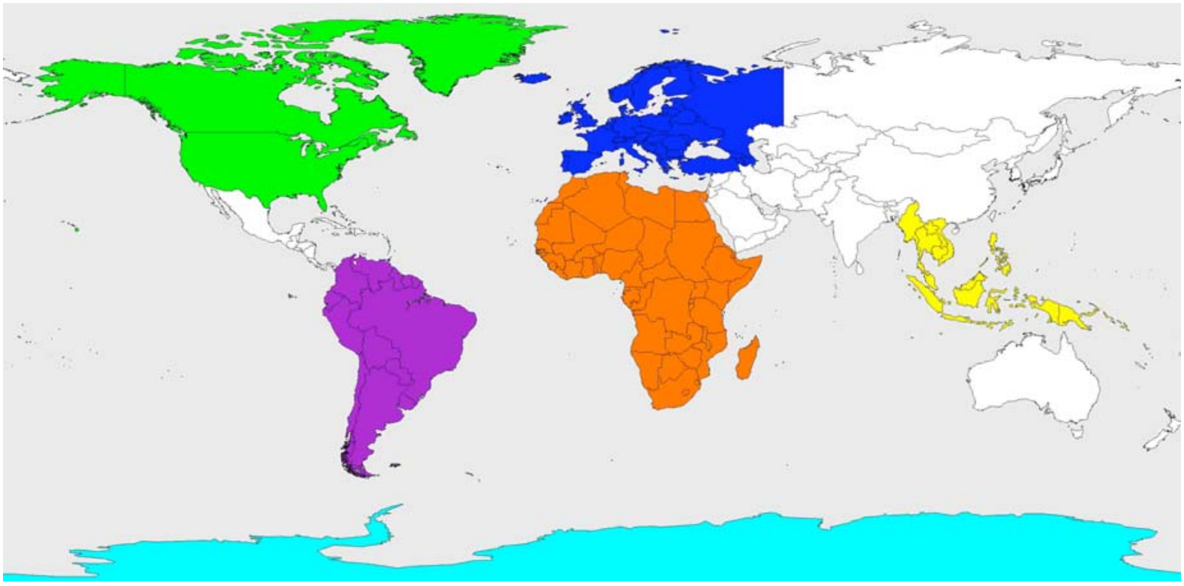
Sub-Commission 2.4 was initiated after the IUGG General Assembly in Sapporo (2003) and covers the following principal objectives:

- coordination of regional geoid projects
- comparison of methods and results, data exchange, comparison with global models
- gravimetric geoid modeling techniques and methods, available software
- GPS/leveling geoid determination:
- methods, comparisons, treating and interpretation of residuals
- common treatment of gravity and GPS/leveling for geoid determination
- geoid applications: GPS heights, sea surface topography, integration of geoid models in GPS receivers, vertical datums
- other topics: topographic effects, downward and upward continuation of terrestrial, airborne, satellite data specifically as applied to geoid modeling

The steering committee of SC 2.4 is formed by the chair and the leaders of the Sub-Commission projects:

Urs Marti	chair
Heiner Denker	CP 2.1: European Gravity and Geoid Project (EGGP)
Marc Véronneau	CP 2.2: North American Geoid Project
Charles Merry	CP 2.3: African Geoid Project
Mirko Scheinert	CP 2.4: Antarctic Geoid Project (AntGP)
Denizar Blitzkov	CP 2.5: Gravity in South America and South American Geoid
Bill Kearsley	CP 2.6: Southeast Asian Geoid

There has been no official meeting of the steering committee during the reporting period but there have been many informal contacts per e-mail and during the IGFS Symposium "Gravity Filed Of The Earth" (GGSM2004) in Istanbul (August 28 - September 1 2006). The web-site of SC2.4 can be found at http://www2.swisstopo.ch/um/sc24.htm, where the reports of the projects and several other information can be found.



Areas covered by the Commission 2 Projects

Meetings, Workshops

The principal meeting of SC2.4 during the reporting period (2006) was the IGFS Symposium in Istanbul (http://www.igfs2006.org/) where sessions 2 "Regional Geoid Projects" and session 1 "Gravity field modelling from combination of local and satellite data" covered many parts of the SC2.4 objectives.

Some special meetings of the Commission projects were the following:

CP2.1:	August 2006, Istanbul
CP2.2:	only e-mail contacts
CP2.3:	April 2006, Cairo
CP2.4:	July 2006, Hobart
	August 2006, Istanbul
	October 2006, Dresden
CP2.5:	September 2006, Buenos Aires
CP2.6:	August 2005, Cairns
	June 2006, Ulaanbaatar, Mongolia

Measuring Campaigns, computational efforts

The project CP2.1 (**European Gravity and Geoid**) invited national representatives to become members to the project. About 30 countries answered positively and a meeting with these national representatives was held at the IGFS meeting in Istanbul (August 2006) where possibilities to improve the data set (gravity and terrain models) were discussed. For many countries the gravity data set could be significantly improved and additional data from the arctic region and of ship gravimetry could be obtained. For many regions new DTMs became available and can be used in the project. Mainly for comparison reasons, a GPS-leveling data set from the EUVN-DA project can be used. It is planned to include this data set for a further improvement of the geoid in a future step. Several preliminary quasigeoid / geoid models with different data sets and global models have been produced. A test data set for comparing different geoid computation methods has been provided by H. Duquenne.

For the CP2.2 (**North American Geoid**) each partner (Canada and USA) continue their work on the National geoid model and height systems. A draft paper of the Canadian geoid model CGG2005 is available. Mexico showed some interest for a collaboration in a project for a common North American geoid and height system.

The **African Geoid** project collected SRTM terrain data and the new GRACE global models. National geoid models for Egypt, Algeria and South Africa have been computed, as well as a model for the whole continent with the improved terrain data set and the GRACE global models.

The project CP2.4 (**Antarctic Geoid**) is advancing well and many projects and activities are related with the International polar year (2007/2008). Planned aero-geophysical and aero-geodetic surveys will provide new data and allow to fill the existing data gaps. The project is now ready to start the build-up of a suitable data-base. Many coordination discussions at meetings between several active institutions could be held.

For the project CP2.5 (**Gravity and Geoid in South America**) a new gravity network in Ecuador has been established and evaluated and a new geoid model for Argentina and Brazil was determined. Absolute gravity measurements have been performed in several countries. A symposium on GRAVITY AND GEOID IN SOUTH AMERICA' was held in Buenos Aires.

In the period 2003-2007, it has been difficult, given the geopolitical, financial and other pressures, to arrange specific meetings of the parties interested the **Southeast Asian** Geoid project. A paper on the aims, objectives and problems of Commission 2, CP2.6 was presented at the meeting of the PCGIAP (United Nations Permanent Committee on Geographic Information Infrastructure for the Asia-Pacific) in Cairns. A further important meeting was held in Ulaanbaatar, where the focus was on the unification of height systems in Asia and geoid knowledge in this region.

Future plans

The **European** Geoid project advances well. A new solution will be presented at the IUGG general Assembly 2007. The project chair likes to continue the project after 2007 for another four years for further improvements of the model with new data and to integrate GPS/leveling measurements.

The chair of the **North American** geoid project does not want to continue this project in its present form. Either a new chairman has to be found or this IAG project has to be stopped in 2007. In any case, the discussions between the USA, Canada and Mexico for a common North American geoid and height system will continue.

In **Africa,** the main difficulty for an improvement of the geoid model is the lack of accurate data. This situation is unlikely to change unless major sponsors are able to support airborne gravity surveys in the worst-affected areas. The alternative is to wait and hope for the results of the GOCE mission.

The **Antarctic** Geoid Project is advancing well, especially with the activities of the International Polar Year 2007/2008. This long term project should be continued in the next 4 year period. Planned activities are already included in the actual terms of reference and include among others the promotion and realization of gravimetric surveys and the build-up of data bases.

In **South America,** the budget for new absolute gravity measurements for 2007 and 2008 has been approved. In 2007 the focus will be on the re-occupation of existing absolute stations and on the connection of national gravity networks. In 2008, observations at tide gauges and permanent GPS stations are planned.

One important outcome for the **South-East Asian** geoid project at the meeting in Ulaanbaatar was that it would be an important step to extend the geographical scope of the sub-commission into the whole of Asia, and to perhaps encompass the whole region covered by the PCGIAP. However it should be recognized that some national authorities are extremely cautious over sharing data etc. so this idea may not be practical.

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Appendix 5

Report of the IAG Study Group 2.2 on

Forward Gravity Field Modelling Using Global Databases

http://www.cage.curtin.edu.au/~kuhnm/IAG_SG2.2/index.html

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Aristotle University of Thessaloniki, Greece

Period Covered: 2003-2007

Important Note: This report has been prepared by the chair and vice-chair and is mostly based on information and feed-back obtained from members of the study group. Therefore, likely it will not cover the whole range of activities of all members, for this we would like to apologize. However, we hope that the most important aspects of the study groups activities and achievements are reflected by this report.

1. Introduction

This document presents the status report of the work undertaken by the IAG Study Group 2.2 since its creation in August 2003 after the IAG Executive Meeting during the XXIII General Assembly of the IUGG at Sapporo. The Study Group (SG) can be partly seen as a continuation of IAG Special Study Group 3.177 with special focus on forward modelling. During the period 2003 – 2007 the Study Group established its terms of references, organized its membership structure, created an internet website, held three official meetings, organized one conference session and its members were present at a number of different conferences and workshops. Apart from study group related activities it is acknowledged that there are noticeable activities accomplished by individuals outside of this study group showing the importance of the topic (see references not related to members of the study group).

A vast number of data describing the Earth's shape and internal structure (e.g. elevation, density and other geophysical parameters) are currently available. Several of these data are given globally with a continuously increasing resolution. For example the latest release of SRTM-derived terrain models (e.g. Farr et al. 2007) provide an almost continuous view of the global topography with the rather high resolution of 3-arc-sec by 3-arc-sec. Apart from many different Digital Elevation Models (DEMs) available there also exist global geological and geophysical data sets describing the Earth's interior with the 2-deg by 2-deg global crustal database CRUST 2.0 (Mooney et al. 1998) as a prominent model. The increasing number of these data allows the use of forward gravity modelling techniques (direct application of Newton's integral) in order to perform gravity field recovery and interpretation. Forward modelling results were and still are of great importance in geodetic as well as geophysical gravity field modelling (e.g. Tsoulis and Kuhn 2006). Furthermore, the comparison of forward gravity modelling results with existing gravity field models obtained from observations such as models obtained from the geodetic satellite missions CHAMP, GRACE and in future GOCE can reveal useful information on the dynamics of the Earth's interior as well as the validity of forward gravity modelling techniques.

2. Primary Objectives of the Study Group

The primary objective of this SG has been to investigate the use of different global datasets describing the Earth's shape and internal mass distribution for gravity field recovery and interpretation, using forward gravity modelling techniques (direct application of Newton's integral). Special focus of the SG was on the employment of high-resolution digital elevation models as well as datasets on the structure of crust and mantle to recover high-frequency information of the Earth's gravity field and to investigate whether these data can be used to study the behaviour of gravity inside the (topographic) masses. Furthermore, the SG tried to scrutinize existing and alternative approaches used in forward gravity modelling. Summarising, the SG's main generic objectives were as follows:

- Construction of forward gravity field models using geophysical data
- Interpretation of forward gravity field modelling results
- Application of forward modelling results in gravity field determination

3. Membership Structure

It is acknowledged that the SG's members have a wide ranging background from geodesy over geophysics to mathematics. Officially, the members have been divided into full or active members and corresponding members. However, no distinction has been done here as it is acknowledged that the same degree of activity has been demonstrated from both types of members.

Chair:	Michael Kuhn (Australia)	
Vice-chair:	Dimitrios Tsoulis (Greece)	
Full Members:	Hussein Abd-Elmotaal (Egypt)	Gabor Papp (Hungary)
	Giampietro Allasia (Italy)	Dan Roman (USA)
	Heiner Denker (Germany)	Kurt Seitz (Germany)
	Pavel Nóvak (Czech Republic)	Gyula Tóth (Hungary)
	Spiros Pagiatakis (Canada)	Yan Wang (USA)
	Nikolaos Pavlis (USA)	
Corresponding Members:	Irek Baran (Australia)	
	Miroslav Bielik (Slovak Republic)	Jon Kirby (Australia)
	William Featherstone (Australia)	Roland Pail (Austria)
	Jakob Flury (Germany)	Gabriel Strykowski (Denmark)
	Simon Holmes (USA)	Tony Watts (UK)
	Michael Kern (Austria)	K. Insa Wolf (Germany)

4. Activities of the Study Group

The material presented here has been mostly compiled from information and feed-back obtained from members of the study group throughout the period covered. In addition it also contains information of the most important activities of the SG such as the organization of session 8 on "Terrain data and geopotential forward modeling", held in 2006 at the 1st International Symposium of the International Gravity Field Service (IGFS), in Istanbul, Turkey.

4.1 Forward Gravity Modelling – Theory and Practical Application

Forward gravity modelling was and still is a central part of most techniques that model the Earth's gravity filed. In the past few years an increasing interest in forward gravity modelling could be recognized, which is partly due to the availability of results from the new geodetic satellite gravity missions (Champ, GRACE and in future GOCE) as well as the increasing availability of topography, density and other geophysical data describing the Earth's interior with ever increasing resolution. In Geodesy and geophysics, great part of forward modelling techniques are dedicated to the evaluation of terrain corrections or reductions (e.g. Takin and Talwani 1966, Zhou et al. 1990, LaFehr 1991, Parker 1995, 1996, Li and Chouteau 1998, Nowell 1999, Chakravarthi 2002,)

The evaluation of gravitational potential and/or attraction using methods different to the classical application of some sort of numerical integration has been investigated. In this regards analytical integration formulae can be regarded as an alternative to numerical integration techniques. These techniques usually have the advantage that the computational effort is much decreased with respect to classical numerical integration techniques. An analytical approach to approximate potential integrals has been presented by Allasia (2002) that can be applied to Newton's integral. Furthermore, Allasia (2004), Allasia and Besenghi (2004) and De Rossi (2004) developed and applied different algorithms for the approximation of surface data. Furthermore, analytical solutions of Newton's integral in terms of polar spherical coordinates have been presented by Tenzer et al. (2007).

A new space domain method for forward gravity modelling has been outlined by Strykowski (2003, 2006). Compared to classical forward modelling techniques such as the application of rectangular prisms the new method has considerable computational advantages as complicated mass density models of almost arbitrarily structure can be used without increased computational effect with respect to more simplified structures. This is achieved by a pre-computation and storage of the given mass density distribution, thus it is not necessary to calculate the source attraction for each field point separately. The mathematical formulation is based on power series expansions of the reciprocal distance function. The paper outlines the mathematical structure of the method and demonstrates that it can be used for gravity forward modelling. However, the method still lacks of an intelligent strategy to store the integrated mass density information and the brute-force implementation will not work because of the dimensionality of the problem is too big.

Different collaborative research between members of the SG took place over the last four years that explored aspects of forward gravity modelling techniques (Kuhn and Featherstone 2003a, Kuhn and Seitz 2005) and the application of regional and global data sets for gravity field recovery (Kuhn and Featherstone 2005, Tsoulis and Kuhn 2006). The optimal spatial resolution of crustal mass distributions for forward modelling has been discussed by Kuhn and Featherstone (2003a) while Kuhn and Seitz (2005) compare the solution of Newton's integral in the space and frequency domains. Wild-Pfeifer and Heck (2006) compared different methods for modelling mass density effects in the space and frequency domains in view of modelling topographic and isostatic effects in satellite gravity gradiometry observations. Both Kuhn and Seitz (2005) and Wild-Pfeifer and Heck (2006) use tesseroids in the space domain and a spherical harmonic representation of Newton's integral in the frequency domain. Tsoulis and Kuhn (2006) provide a review on recent developments in forward gravity modelling and its application for synthetic Earth gravity modelling and gravity recovery.

A review on the global evaluation of Newton integral in (Gauss) geodetic coordinates is given by Vajda et al. (2004). Using an exact formulation as well as spherical approximation various topographical corrections are addressed in terms of their definition, upper and lower topographic boundary and density used. Numerical aspects of the evaluation of the Newton integrals, such as the weak singularity treatment, split-up into spherical shell and terrain terms, and a requirement to integrate over the whole globe are adressed as well. Special attention is given to the so-called ellipsoidal topography of constant density. Furthermore, the ellipsoidal representation of the topographical potential and its vertical gradient has been studied by Novák and Grafarend (2005). Fast algorithms for the computation of the second order derivatives of the Disturbing Potential have been analysed by Abd-Elmotaal (2005a).

4.2. Gravity field modelling

Efforts have been put on the investigation of different modelling techniques for precise gravity field modelling (e.g. Kuhn 2003, Tsoulis 2003, Tsoulis and Tziavos 2003, Tsoulis et al. 2003). The application of polyhedron volume elements (PVEs) has been proven to provide a more precise geometrical description of the topographic surface than the description by rectangular parallelepiped (prism) models. The use of density models based on PVEs provides smoother and more realistic field structure for the second derivatives of the disturbing potential than the one provided by a prism model. An effort was made to compute synthetic vertical gravity gradients from a polyhedron model of the topography in a local area of Hungary (Benedek 2004). The resolution of the model used was 10 m x 10 m in a 20 km distance around the computation points. The results of simulation were compared to the data obtained from the prism model of the topography and the in situ VG measurements. Apart from a shift the field structure generated by the polyhedrons fit to the VG measurements sufficiently (±136 E in a range between 3800 E and 3200 E).

If the calculation level is close to the surface of topography, then the accuracy of gravity related quantities (e.g. gravity anomaly, gravity disturbance) can be improved significantly by a detailed description (e.g. by polyhedrons) of this surface in the vicinity of the calculation point. The improvement is in the range of a few cm in terms of geoid undulation and it shows a clear correlation with the height and its variability (e.g. Tsoulis 2003).

Gyula Tóth provided FORTRAN90 software routines for the computation of the gravitational effect of a polyhedral mesh. The software as well as a Power Point presentation can be downloaded form the SG's webpage (see section 4.7 below).

Rózsa and Tóth (2007) determine the effect of topographic masses on the second derivatives of gravity potential using rectangular prism and tesseroid bodies. Numerical results based on the global DEM ETOPO5 show that the effects can reach significant levels of 10 Eötvös in all gravity gradients at the altitude level of LEOs. Furthermore, Tóth and Völgyesi (2007) apply surface gravity gradient measurements in local gravity filed modelling over Hungary.

High frequency terrain effects over Germany based on a high resolution DEM (1-arc-sec by 1-arc-sec) have been studies in view of removing those effects from future GOCE data (Voigt and Denker 2006). The high frequency effects have been derived for gravity anomalies, deflections of the vertical and geoid heights. The major aim of the study was the derivation of optimal resolutions of terrain data for given accuracy levels. Another study used high resolution gravity and elevation data in order to look at their effect on local gravity parameters (Novák 2006)

A probabilistic inversion method was developed and tested in a mining area of Western Australia (Strykowski et al. 2005). It is based on the iterative statistical analysis of the misfit between the observed gravity field and the superimposed response of a number of elementary prismatic sources (rectangular parallelepipeds). The a priori model should rely on some geological information giving the approximate 3D extension of the source. The method is applicable if the gravitational effect of the source body to be determined can be isolated from the regional gravity signal and from the signals of other local sources. For this purpose a so-called multi-scale edge technique is used.

Looking forward to accessing the on board gradiometer data of GOCE the possibility of their geophysical inversion was investigated in the Alps-Pannonian-Carpathians region (Benedek and Papp, 2006). Here a detailed 3D model of the lithosphere is available and its improvement is desired. The spectral and space domain investigations show that a reliable estimation (±25-50 kg/m^3) of the density contrast on the Moho discontinuity will be possible even if planar (prism) approximation is used for the inversion. For this purpose the gravitational effect (the second derivatives of the disturbing potential T) of both the topographic masses and the well explored Neogene-Quaternary sediments have to be removed from the satellite observations. The amplitude of the gravitational signal generated by the Moho and the surface topography may reach 1 Eötvös unit at satellite altitude. The effect of the sedimentary complex is less by about one order of magnitude. The planar approximation however, may introduce about 10% systematic distortion of the simulated gravitational gradients in the region investigated. Therefore the forward computations have to be performed in a global Cartesian coordinate system utilizing the polyhedron approximation.

Some studies on the effect of topographical masses on airborne gravimetry (Novák et al. 2003) and space borne gravimetric and gradiometric data (Novák and Grafarend 2006) have been performed. The latter study also includes effects form atmospheric masses. Gravity reductions using a general method of Helmert's condensation method have been studied by (Novák 2007). Tenzer et al. (2003) studied the far-zone contribution to topographic effects used in athe Stokes-Helmert geoid determination method.

Some SG members were also active in gravity field modelling using different gravity data and geoid determination techniques, which is loosely associated to the aims of the group. Gruber (2003) looked into global gravity field modelling techniques and Gitlein et al. (2005) studied local geoid determination by the spectral combination technique. A comparison between Stokes integration and the application of wavelet techniques for regional geoid modelling has been performed by Roland and Denker (2005b). Kern (2004) made a comparison of data weighting methods for the combination of satellite and local gravity data while Roman et al. (2004) assessed the new U.S. National Geoid Height Model GEOID03. Long-period temporal variations of the gravity field have been modelled by Abd-Elmotaal (2005b) and an ideal combination of deflection of the vertical and gravity anomalies for precise geoid determination have been studied by Kühtreiber and Abd-Elmotaal (2005). A preliminary geoid model incorporating forward modelling results has been presented by Merry et al. (2005).

4.3 Crustal and lithospheric modelling and interpretation

Studies have been dedicated towards the determination of the lithosphere's elastic thickness and its anisotropic variations (Swain and Kirby 2003a, 2003b). This has largely been achieved through development of a new wavelet-based analysis and inversion method (Kirby and

Swain, 2004). A wavelet-coherence between Bouguer anomaly and topography/bathymetry data is formed, using rotated 2D Morlet wavelets arranged in a 'fan'-geometry. Both isotropic and anisotropic wavelet coefficients can be derived. These are then inverted against the predictions of a thin elastic plate model, for elastic thickness in the isotropic case, and weak rigidity direction and percentage anisotropy in the anisotropic case.

The method has been applied to synthetic data. These data are generated by loading an elastic plate (of known rigidity) with two random fractal surfaces that represent the initial topographic and Moho loads on the plate, and modelling the resultant deflections through a finite-difference solution of the flexure partial differential equation. The post-loading topography and Bouguer anomaly are then analysed with the wavelet method to give a recovered rigidity, which agrees with the input rigidity to approximately 8% in the isotropic case. For anisotropy, the recovered weak directions agree with the model to less than 1 degree (Kirby and Swain, 2006; Swain and Kirby, 2006). The method has also been applied to real data over Australia, Europe, and North and South America (Tassara et al, 2007).

A significant contribution to gravity field recovery can be provided by the development of so-called topographic / isostatic gravity models, which are the result of forward gravity modelling mass density information on the Earth's topography and crust. Several such models have been constructed and analysed using various data sources and/or different istostatic compensation models (e.g. Tsoulis 2005, Tsoulis and Stray 2005a,b). Forward gravity modelling of crustal mass density information provided by the CRUST 2.0 global database has been performed by Tsoulis (2004a, b), Kuhn and Featherstone (2005) and Tsoulis et al. (2006). In Tsoulis (2004a, b) the gravitational effect of crustal mass anomalies have been analysed in the frequency domain using a spherical harmonic representation of Newton's integral. The same approach has been used in Kuhn and Featherstone (2005) in the development of a global forward gravity filed model (see section 4.5 below). Tsoulis et al. (2006) apply CRUST 2.0 for gravity field modelling over the Hellenic area and results in terms of isostatic gravity anomalies have been compared to two other independent method of determining the Moho discontinuity. Other contributions look at the isostatic response of the Earth's crust derived from inverse isostasy (Abd-Elmotal 2004) and the use of Moho depths in geoid determination (Abd-Elmotaal 2003, Abd-Elmotaal and Kühtreiber 2003).

4.4 DTM Creation and Validation

Major contributions of SG members in the creation and validation of DTMs have been made. The development of a new global Digital Topographic Model (DTM2006.0), which incorporates the available SRTM data, as well as improved elevation data over Greenland and (parts of) Antarctica. DTM2006.0 was compiled in 30", 2', 5', 30', and 1° resolution. As with previous DTM compilations, this model provides information about terrain types, lake depths, and ice thickness (Pavlis et al. 2006a). A technique has been development and implemented that spectrally combines low degree gravity anomaly information, with high degree information implied by Residual Terrain Model (RTM) effects, to create "synthetic" gravity anomaly values over areas where gravity anomaly data are unavailable. These "synthetic" gravity anomaly values were necessary to develop gravitational model solutions complete to degree 2160, with proper spectral characteristics (Pavlis et al. 2006b).

A high resolution (1-arc-sec by 1-arc-sec, approx. 30 m by 30m) over Germany has been used to evaluate the currently released 3-arc-sec by 3-arc-sec SRTM terrain models (Denker 2005). Some considerable differences were found with a standard deviation of the differences of almost 8 m and maximum differences of up to 300 m. Further comparisons have been done with the global 30-arc-sec by 30-arc-sec GTOPO30.

4.5 Synthetic Earth gravity models: Derivation and validation

Two SEGMs have been developed at Curtin University of Technology since 2003 (Tsoulis and Kuhn 2006) of which one is a global model called CurtinSEGM (Kuhn and Featherstone 2003b, 2005) and one is a regional model called AusSEGM (Baran et al. 2006) defined over Australia only. The data for CurtinSEGM and AusSEGM are available via http://www.cage.curtin.edu.au/~kuhnm/CurtinSEGM/ and as electronic supplementary material from (Baran et al. 2006), respectively or from the corresponding authors of the models.

A synthetic [simulated] Earth gravity model (SEGM) generates exact and self-consistent gravity filed quantities and therefore is well suited to validate theories, algorithms and software used in gravity field modeling. A SEGM can be constructed using observations of the Earth's gravity field itself (source model), a reasonably realistic mass density distribution of the Earth's interior (source model) or a combination of both.

CurtinSEGM is a global source model SEGM using realistic parameters about the Earth's internal structure. The gravity field of CurtinSEGM is based on mass-density information of the topography, bathymetry, crust and mantle (Kuhn and Featherstone 2005), which have been forward modeled using a spherical harmonic representation of Newton's integral (e.g. Kuhn and Featherstone 2003a, Kuhn and Seitz 2005). The model is given by a spherical harmonic representation of the disturbing potential (up to and including degree an order 1440), which agrees reasonably well with empirical data such as given by EGM96.

AusSEGM is a regional SEGM over Australia using a combination of the source and effects model approach (Baran et al. 2006), which is specifically designed to validate regional gravimetric geoid determination theories, techniques and computer software. Currently AusSEGM is applied to test the geoid determination techniques used at Curtin University to construct the national geoid over Australia and at the University of New Brunswick to construct the geoid over Canada. AusSEGM provides synthetic gravity filed functionals (gravity, gravity anomaly and geoid height) on a regular 1-arc-min by 1-arc-min grid as well as arbitrary points with similar distribution as observed gravity stations. The long-wavelength effects part has been taken from an assumed errorless EGM96 (up to and including degree and order 360). The latter is a reasonable assumption in the context of the construction of a SEGM and ensures it replicates reasonably well the actual Earth's gravity field. A high-resolution (3-arc-sec. by 3-arc-sec) synthetic digital elevation model (SDEM), which is essentially a fractal surface based on the GLOBE v1 DEM has been constructed over Australia in order to model the short-wavelength source part of AusSEGM. Initial test have shown that AusSEGM is accurate to at least 30 _Gal for gravity and gravity anomaly and 3 mm for the geoid height. Furthermore, a comparison of AusSEGM gravity values with 330,929 measured gravity values over Australia provided by Geoscience Australia (http://www.ga.gov.au/oracle/index.jsp) show a rather good agreement with most of the differences being less than 20 mGal (99.3 % of all values).

The results from a combination of geopotential model with regional terrestrial gravity data was investigated in Wolf and Denker (2005), Wolf (2006) and Wolf and Kieler (2006) with help of synthetic data including noise. Second order derivatives of the gravitational potential were computed, two methods (spectral combination with integral formulas and least-squares collocation) were applied (Wolf and Denker, 2005; Wolf, 2006). In the context of quasigeoid computation the integration using kernel modifications and different dimensioning of the integration area were investigated in (Wolf and Kieler, 2006). Noise was generated for the geopotential model as well as for the terrestrial gravity data in a correlated and uncorrelated version. The closed-loop results were confirmed by statistical error assessment.

4.6. Conference Contributions of SG Members

It is important to mention that apart from the contributions mentioned above many members of the SG were very active through presentations at several national and international conferences and workshops. However, these contributions are too numerous to mention them in detail here but titles are generally available through the group members own personal webpages.

4.7 Study Group Webpage

A webpage of the group's activities has been created, which summarises the activities of the SG as well as a list of relevant publications. Two mirrored versions of the web-page are located at Curtin University of Technology, Perth, Western Australia, as well as Aristotle University of Thessaloniki, Greece.

See html addresses:
http://www.cage.curtin.edu.au/~kuhnm/IAG_SG2.2/intex.html
http://users.auth.gr/~tsoulis/IAG_SG2.2/index.html

4.8 Meetings of the Study Group

During the period covered the SG had three official meetings of which the minutes are available from the SG's webpage.

1. Gravity, Geoid and Space Missions - GGSM2004. Porto, Portugal, August 30th to September 3rd, 2004.
2. Dynamic Planet 2005 Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, Cairns, Australia, 22-26 August 2005
3. First International Symposium of the International Gravity Field Service (IGFS2006), August 28 - September 1, 2006, Istanbul, Turkey.

4.9 Conference Sessions

At the 1st International Symposium of the International Gravity Field Service (IGFS2006) the SG initiated session 8 on "*Terrain data and geopotential forward modelling*", which was convened by Michael Kuhn and Dimitrios Tsoulis. The session became an optimal platform for the group's members to present their current results, giving also the opportunity to other individuals to present their latest research in this field. The session attracted a total of 24 contributions (9 oral and 15 poster presentations). 11 authors responded positively to the call for submission of papers for inclusion to the Conference's Proceedings. All papers were led to a peer-reviewing process, after which 10 papers were accepted for publication. Our overall experience, judging from the quality and high standards of all presented papers, is that the SG's Session 8 has been receiver very well and was overall a success.

5. Future Work

The activity of the SG demonstrates that forward gravity modelling is a highly important topic in geodesy as well as other geo-sciences most notably geophysics. Obviously, this will not change in the foreseeable future. While the SG did not achieve all original aims manifested in its terms of references it contributed much to this topic warranting the recommendation of its continuation for another term of four years.

Some of the topics the SG could focus on during a second term could be:

- Evaluation of the high resolution SRTM terrain data in terms of forward gravity modelling. This includes the modelling or recovering of very high gravity signals or the detection of errors in the DTM.
- Global, regional and local gravity field recovery using forward gravity modelling results of the Earth's topography, crust and interior.
- Development and application of Synthetic Erath Gravity Models (SEGMs) based completely on forward gravity modelling. Applications could focus on the validation of techniques used to analyse data of the new geodetic satellite missions CHAMP, GRACE and in future GOCE, such as the derivation of mass changes from time varying gravity observations.
- Forward modelling of gravity inside the topographic masses.
- Overview/Summary/Collection of forward gravity modelling techniques including the comparison of forward gravity modelling software.

6. Publications

The following list of publication summarizes the ongoing activities of the SG members. It contains publications that were obtained by the chair up until the date of this report and demonstrates the increased activity of the members on the SG's core issues (publications of SG members are marked by an "*"). In addition the list contains some selected publications of individuals outside the group demonstrating the importance of the topic of forward modelling.

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Appendix 6

Final Report
IAG Special Group 2.3: Satellite altimetry: data quality improvement and coastal applications

Chair: Cheinway Hwang,
Department of Civil Engineering, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 300, Taiwan

1. Introduction

Coastal applications of satellite altimetry in geodesy, geophysics and oceanography have become increasingly important. However, shallow-water altimeter data are prone to errors in range itself, environmental and geophysical corrections. If shallow-water altimeter data are to be useful, the first problem on has to confront is data quality. For example, retracking waveforms of altimetry can produce improved results in altimetric applications. Retracked altimetry will be first used to improve tide modeling and in turn improve coastal gravity field modeling and determination of ocean dynamic topography. The densely distributed Geosat/GM and ERS-1/GM will be the biggest contributors to high frequency components of parameters extracted from altimeter data. Another dense data set, namely, Geosat/GM, has not been retracked for coastal applications. One of the objectives of this current SSG will be to freely provide a database of retracked ERS-1 and Geosat/GM for members interested in applications of these retracked altimeter data. Exchange of data and ideas are encouraged to maximize the use of improved shallow-water altimeter data.

2. International workshop of satellite altimetry, Beijing, China, July 21 to 22, 2006. (http://space.cv.nctu.edu.tw/altimetryworkshop/ALT2006.htm)

This workshop is dedicated to SG2.3 and to the problems and solutions of coast and land applications of satellite altimetry in such areas as coastal gravity field modeling, coastal circulations, river level and lake level monitoring and desert study using satellite altimetry.

The LOC is Chinese Academy of Surveying and Mapping, with Dr. PF Cheng and YM Dang being the chair and co-chair of the LOC. The presentations cover the following problems related to SG2.3

- methods for improving quality of coastal altimetry data
- waveform retracking for altimetry
- shallow-water tides from altimetry
- coastal gravity field modeling with altimetry
- vertical datum connection using altimetry
- land applications of altimetry
- altimetry applications and problems in polar seas
- lake level and river level changes from altimetry
- coastal circulations from altimetry
- Applications of altimetry to desert study

Participants of this workshop are largely members of SG2.3. They exchanged ideas, experience, and software freely. This workshop also serves as a platform for the SG2.3 members to present their contributions to SG2.3 over the past three years. On the last day, a panel discussion was held to summarize the problems and solutions concerning SG 2.3.

3. Major achievements of SG2.3

Over 2003-2007, the members of SG2.3 have been trying to tackle the problems listed in the objectives of SG2.3. Te major achievements are listed below:

- Development of various methods of waveform retracking for range corrections
- Development of various method for modeling shallow-water tides from altimetry
- Application of altimetry to lake level/river changes
- Application of altimetry to polar studies
- Application of altimetry to coastal circulations and western boundary currents
- Application of altimetry to coast/lake gravity field modeling and geophysics

See also the list of papers in the TAO special issue (Section 4).

4. Publications of members of SG2.3

A special issue of the journal Terrestrial Atmospheric and Oceanic Sciences (TAO) will be published to highlight the achievements of the SG2.3 members over 2003-2007. The title is **"Satellite altimetry over land and coastal zones: applications and challenges"**, and the guest editors are:

Cheinway Hwang, National Chiao Tung University, Taiwan
CK Shum, Ohio State University,
Yamin Dang, Chinese Academy of Surveying and Mapping
Jerome Benveniste, European Space Agency

This special issue includes some of the distinguished papers presented in this workshop. It is the first such issue in an earth science journal dealing exclusively with coast and land altimetry. These papers will contribute to the advancement of satellite altimetry. This issue will cover the following subjects: (1) methods for improving quality of coastal altimetry data: (2) waveform retracking for altimetry, (3) shallow-water tides from altimetry, (4) coastal gravity field modeling, (5) land applications of altimetry , (6) altimetry applications and problems in polar seas, (7) lake level and river level changes by altimetry, (8)coastal circulations from altimetry.

The following table shows the accepted papers in this special issue. Most of the papers are contributed by the members of IAG SG 2.3. The publication date is January 2008.

Authors	Title
Ole Andersen, Philippa Berry, Frank G. Lemoine, Flemming Jakobsen and Michael Butts	Satellite Altimetry And GRACE Gravimetry For Studies Of Seasonal Water Storage Variations In Bangladesh
Jérôme Bouffard, Stefano Vignudelli, Marine Herrmann, Florent Lyard, Patrick Marsaleix, Yves Ménard, Paolo Cipollini	Comparison Of Ocean Dynamics With A Regional Circulation Model And Altimetry In The Northwestern Mediterranean
Xiaotao Chang, Chuanyin Zhang, Hanjiang Wen and Jiancheng Li	Gravity Anomaly Recovered From Satellite Altimetry And Its Application To Geodynamics
K. Cheng, C. Kuo, C. Shum, X. Niu, R.	Accurate Linking Of Lake Erie Water

Li, and K. Bedford	Level With Shoreline Datum Using GPS Buoy And Satellite Altimetry
Yonghai Chu*, Jiancheng Li, Weiping Jiang, Xiancai Zou, Chunbo Fan, Xinyu Xu	Monitoring Level Fluctuation Of The Lake In Yangtze River Basin From Altimetry
X. Deng, C. Hwang, R. Coleman and W.E. Featherstone	Seasonal And Interannual Variations Of The Leeuwin Current Off Western Australia From TOPEX/POSEIDON Satellite Altimetry
Cheinway Hwang, Hsuan-Chang Shih, Jinyun Guo, and Yu-Shen Hsiao	Zonal And Meridional Ocean Currents At TOPEX/Poseidon And JASON-1 Crossovers Around Taiwan: Error Analysis And Limitation
Robert Kingdon, Cheinway Hwang , Yu-Shen Hsiao, Marcelo Santos	Gravity Anomalies From Retracked ERS And Geosat Altimetry Over Great Lakes: Accuracy Assessment And Problems
Chung-Yen Kuo, C.K. Shum, A. Braun , and Kai-chien Cheng	Vertical Motions Determined By Combining Satellite Altimetry And Tide Gauges
Sergey A. Lebedev , Andrey G. Kostianoy	Integrated Using Of Satellite Altimetry In Investigation Of Meteorological, Hydrological And Hydrodynamic Regime of the Caspian Sea
Hyongki Lee, C. K. Shum, Chung-Yen Kuo and Yuchan Yi	Application Of Satellite Altimetry For Solid Earth Deformation Studies
Jiancheng Li, Yonghai Chu, Weiping Jiang, Taoyong Jin, Lelin Xing	The Lake Level Variation using Waveform Retracking in Qinghai Lake
Li-Ching Lin and Hsien-Kuo Chang	An adaptive neuro-fuzzy method for tidal prediction considering tide generating forces and sea surface temperature
Timothy J. Urban, Bob E. Schutz and Amy L. Neuenschwander	ICESat Coastal Altimetry
Jicai Zhang, Xianqing Lu	Inversion of the Space Varying Bottom Friction Coefficient in the Bohai, Yellow and East China Seas
Zizhan Zhang, Yang Lu, Houtse Hsu	Spatial and temporal variations of the Kuroshio derived from altimetry and geoid: a case study in the East China Sea
Huang Motao_Zhai Guojun_Ouyang Yongzhong_Lu Xiuping_Liu Chuanyong_Wang Keping	Integrated Data Processing for Multi-satellite Missions and Recovery of Marine Gravity Field
Jeong Woo Kim, Daniel R. Roman and Yeadong Kim	Altimetry Enhanced Free-air Gravity Anomalies

Appendix 7

Report of IAG ICCT Joint Working Group with Commission on Gravity:

JWG 5: Multiscale Modelling of the Gravity Field

Introduction

During the last decades technological progress has changed completely the observational methods in all fields of geosciences with a trend to achieve immediate results, thus reducing time and costs. A reconstruction of the gravity field from data material coming from satellite as well as airborne and terrestrial measurements requires a careful multiscale analysis of the gravity potential, fast solution techniques, and a proper stabilization of the solution by regularization. While global long-wavelength modelling can be adequately done by use of spherical harmonic expansions, harmonic splines and/or wavelets are most likely candidates for medium and short-wavelength approximation. The working group intends to bring together scientists concerned with the diverse areas of geodetically relevant wavelet theory in general and its applications. An essential field of research is the specific character of geodetic multiresolution methods used in addition or in contrary to standard spectral techniques based on spherical harmonic framework.

Objectives

- Theoretical research in the field of spherical and ellipsoidal wavelets as well as wavelet introduction and modelling on geodetically relevant surfaces (like spheroid, geoid, (actual) Earth's surface).
- Studies of harmonic wavelets in geodetic boundary-value problems (e.g., Runge-Walsh wavelets, layer potential wavelets, etc).
- Studies on spline/wavelet kernel modelling, multiscale pyramid algorithms via kernel functions known from (least squares) collocation and spline approaches, noise cancellation, least-squares adjustment and spline smoothing vs. multiscale thresholding, etc.
- Development of specific numerical methods: fast wavelet transform, tree algorithms, data compression, domain decomposition techniques, fast multipole methods, panel clustering, data transmission, etc.
- Comparison of spherical harmonic and/or wavelet modelling: Combined spectral and multiscale expansion of the gravitational potential, degree variances vs. local wavelet variances, spectral and/or multiscale signal to noise thresholding, etc.
- Investigation of different wavelet types in geodetic pseudodifferential equations (using numerical methods such as collocation, Galerkin method, least-squares approximation, etc).
- Regularization of inverse problems by multiresolution, locally reflected multiscale vs. globally reflected spectral regularization, multiscale parameter choice strategies, multiscale modelling in SST, SGG.
- Time dependent multiscale modelling in boundary value and inverse problems, numerical implementation and application to GRACE-, GOCE-data.

Members and Correspondent Members

W. Freeden, Germany (chair)

F. Barthelmes (Germany), T. Gervens (Germany), E. W. Grafarend (Germany), M. Gutting (Germany), K. Hesse (Australia), C. Jekeli (USA), P. Kammann (Germany), W. Keller (Germany),

A. Kohlhaas (Germany), J. Kusche (Netherlands), D. Michel (Germany), V. Michel (Germany), H. Nutz (Germany), J. Otero (Spain), S. Pereverzev (Austria), S. Petrovic (Germany), F. Sacerdote (Italy), F. Sanso (Italy), R. Schmidt (Germany), M. Schreiner (Switzerland), J. Schröter (Germany), W.-D. Schuh (Germany), I. H. Sloan (Australia), N. Sneeuw (Canada), L. Svensson (Sweden), C. C. Tscherning (Denmark), M. Vermeer (Finland), K. Wolf (Germany)

Past Activities

- Presentations at several conferences:
  - Workshop "Inverse Problems", Trippstadt (24.-25.11.2005) (organizers: W. Freeden , V. Michel).
  - Workshop "Multiscale Methods in Geodesy", Helsinki, November/December 2005.
  - Fall Meeting of the American Geophysical Union (AGU) in San Francisco, December 2005.
  - GAMM Annual Conference, Berlin, March 2006.
  - Hotine-Marussi Symposium "Theoretical and Computational Geodesy", Wuhan (China), May/June 2006.
  - 1st Int. Symposium of the International Gravity Field Service (IGFS), Istanbul (Turkey), August/September 2006.
  - Status-Seminar "Observation System Earth from Space", Bonn, September 2006.
  - Approximation Methods for Problems on the Sphere. DMV Annual Conference, University Bonn, September 2006.
  - GeoBerlin, Berlin, October 2006.
- Cooperation between the groups in Kaiserslauten (W. Freeden) and Munich (R. Rummel) about multiscale modelling of temporal changes of the gravitational field measured by GRACE (see: M.J. Fengler, W. Freeden, A. Kohlhaas, V. Michel, T. Peters, "Wavelet Modelling of Regional and Temporal Variations of the Earth's Gravitational Potential Observed by GRACE", Journal of Geodesy, 2007, 81:5-15).
- Cooperation between the groups in Kaiserslautern (W. Freeden) and Stuttgart (E. W. Grafarend) in form of a joint DFG-project: Inverse Multiscale Geoid Computation (IMGC).
- Cooperation between the groups in Delft (J. Kusche) and Kaiserslautern (W. Freeden) about Wavelet Modelling of satellite data and its combination with regional terrestrial data.
  (see: M. J. Fengler, W. Freeden, V. Michel: "The Kaiserslautern Multiscale Geopotential Model SWITCH-03 from Orbit Perturbations of the Satellite CHAMP and Its Comparison to the Models EGM96, UCPH2002_02_0.5, EIGEN-1s, and EIGEN-2." Geophysical Journal International, Vol. 157, pp. 499-514, 2004; and: M. J. Fengler, W. Freeden, J. Kusche: "Multiscale Geopotential Solutions from CHAMP Orbits and Accelerometry." C. Reigber, H. Lühr, P. Schwintzer, J. Wickert (Eds.), Proceedings of the 2nd CHAMP Science Meeting, Springer Berlin, Heidelberg, New York, pp. 139-144, 2004.).
- Cooperation between the groups in Frankfurt (H. Schmeling) and Kaiserslautern (W. Freeden) about plume detection from gravity and topology.
- Cooperation between GeoForschungsZentrum (M. Rothacher) and Kaiserslautern (W. Freeden) about Time Variable Gravity and Surface Mass Processes: Validation, Processing and First Application of New Satellite Gravity Data (TIVAGAM) within the BMBF /DFG Sonderprogramm "Geotechnologien".

- Cooperation with University of Buchs (Switzerland). Papers resulting fromthis cooperation: W. Freeden, S. Gramsch, M. Schreiner, "Local Geoid Modelling From Vertical Deflections", Proceedings of the VI Htine-Marussi Symposium of Theoretical and Computational Geodesy, (accepted, 2007) T. Fehlinger, W. Freeden, S. Gramsch, C. Mayer, D. Michel and M. Schreiner, "Local Modelling of Sea Surface Topography from (Geostrophic) Ocean Flow", ZAMM, (submitted, 2007)
- Contacts to the group of Prof. Dr. M. Vermeer in Helsinki.
- Organization of the international workshop "Inverse Problems" (see below for further details).

International Workshop "Inverse Problems" at the University of Kaiserslautern

From 24th to 25th November 2005 an international workshop on "Inverse Problems" took place at the hotel "Zum Schwan" in Trippstadt (organisers: Prof. Dr. W. Freeden, HDoz. Dr. V. Michel, University of Kaiserslautern, and Dr. J. Flury, GOCE Project Office Germany, Technische Universität München). This workshop was hosted by the Geomathematics Group of the University of Kaiserslautern, by the Johann Radon Institute for Computational and Applied Mathematics in Linz (represented by Prof. Dr. S. V. Pereverzyev) and by the GOCE Project Office Germany (directed by Prof. Dr. mult. R. Rummel, TU München).
The workshop was financially supported by the DFG Graduate Research Training Programme "Mathematics and Practice" and the DFG Priority Programme of the same name at the University of Kaiserslautern. Participants were among others Prof. Dr. mult. E. W. Grafarend (Institute of Geodesy, Universität Stuttgart), Prof. Dr. P. Maaß (Director of the Center of Industrial Mathematics, Bremen University), Prof. Peiliang Xu (Disaster Prevention Research Institute, Kyoto University), Prof. Dr. W. Rundell (Director of the Division of Mathematical Sciences, National Science Foundation, USA) and Prof. Dr. mult. E. Groten (Institute for Physical Geodesy, TU Darmstadt).
Inverse problems play an important role, e.g., in modern medicine, materials science, geophysics or geodesy. An inverse problem is given if we want to determine an inaccessible cause from its observable effect. The challenge for the scientists is that inverse problems are mostly ill-posed and cannot be solved by numerical standard methods. "Ill-posed" means that small errors in the given data cause large errors in the solution. The problem can often be stabilised by a so-called regularisation, i.e., by replacing the problem by a closely related well-posed problem which can be stabilised.
Mathematicians, engineers as well as geoscientists met at the interdisciplinary workshop. 27 speakers, e.g., from the USA, Japan, Austria, Switzerland, Great Britain, the Netherlands and Germany reported on their research and presented the difficulties of inverse problems, especially in geosciences but also in image processing. Prof. Dr. Z. Nashed (University of Central Florida, Orlando), a worldwide respectable scientist, gave the introductory talk. He spoke about the importance of inverse problems and placed emphasis on the reconstruction of signals from disturbed partial information. Prof. Dr. mult. R. Rummel (head of the Institute for Astronomical and Physical Geodesy (IAPG) of the TU München) explained the challenges in modern satellite technology when determining a geopotential or a high-precision geoid. He expected new approaches for research and increased cooperation of geoscientists, geophyisicists and mathematicians from the workshop. For instance, the downward continuation problem arises in satellite geodesy: A geopotential was measured by a satellite and is to be continued to the Earth's surface. The measured data are given in discrete points on the satellite's orbit and are disturbed. In this context, Prof. Dr. S. V. Pereverzyev presented recent regularisation methods for geoscientific applications occuring in the ESA satellite mission GOCE. Prof. Dr. J. Prestin pointed out the importance of radial basis functions. Prof. Dr. P. Maaß talked about an inverse approach to image processing. The Geomathematics Group presented new wavelet (multiresolution) methods to regularise the downward continuation problem for the determination of the gravity or magnetic field of the Earth.
More than 40 scientists attending the workshop were extremely interested in the talks and the

corresponding discussions. Furthermore, recent results of students and doctorands of the Geomathematics Group were presented in a poster session. The positive acknowledgment showed that the workshop achieved its aim, i.e., the connection of mathematical theory and modelling on the one hand and the geotechnical and industrial application on the other hand in the domain of inverse problems.

Planned Activities

- Further Email discussion and electronic exchange.
- Launch of an extended web-page for dissemination of information, expressing aims, objectives, and providing a bibliography.
- Further monitoring and presentation of activities, either of working group members or interested external individuals.
- Organisation of a further workshop about multiscale modelling in geosciences.

Appendix 8

Inter-Commission Study Group 2.7
International Association of Geodesy (IAG)
Commission 2 (Gravity Field)
&
InterCommission Committee on Theory

Towards cm-accurate Geoid - Theories, Computational methods and Validation

Activity Report (2007)

Yan Ming Wang (chair)

Objectives

The geoid study group is mainly focused on the theories and computational methods. During the past few decades, an abundance of gravity and topography data, over both land and ocean, has been collected in various ways. As a consequence, the 1-cm accuracy requirement for the geoid computation is at all time high. This presents a challenge to the geodetic community that demands more sophisticated theories and fast computational means. The major objective of this group is to bring together scientists concerned with the diverse areas of relevant theory in general and its applications. An essential field of research is to provide a frame consisting of theories and numerical computation methods which ensure the 1-cm accuracy can be achieved.

Past activities

Research in geoid studies by members is not restricted to times after the establishment of the group (Jan., 2007). The most recent research topics are the optimal combination the global gravity models with the surface gravity data in regional and local geoid computation and the topographic effect on geoid computations. There is also renewed interest in the fixed boundary value problems for geoid determinations. We list the selected publications by the members in the publication section.

Further activities

A web page for discussion and exchange of information is under construction.
Organizing WG meetings or sessions under appropriate conditions.
Monitoring the research activities of members.

Membership

Y.M. Wang, USA (chair)
M.G. Sideris, Canada
M. Véronneau, Canada
J. Huang, Canada
M. Santos, Canada

D. Roman, USA
J. Saleh, USA
D. Smith USA
B. Heck, Germany
K. Seitz, Germany
H. Denker, Germany
W. Freeden, Germany
L. Sjoberg, Sweden
N. Kuhtreiber, Austria
H. Moritz, Austria
J.C. Li, China
D.B. Cao, China
W.B. Shen, China
F. Mao, China
W. Featherstone, Australia
Z. Martinec, Czech Republic

Selected publications

Goos, J.M., W.E. Featherstone, J.F. Kirby and S.A. Holmes (2003) Experiments with two different approaches to gridding terrestrial gravity anomalies and their effect on regional geoid computation, *Survey Review* 37(288): 92-112.

Vaní_ek, P., J. Janak and W.E. Featherstone (2003) An algorithm for the truncation of spherical convolution integrals with an isotropic kernel, *Studia Geophysica et Geodaetica* 47(3): 455-465, doi: 10.1023/A:1024747114871

Featherstone, W.E. (2003) Improvement to long-wavelength Australian gravity anomalies expected from the GRACE, CHAMP and GOCE dedicated satellite gravimetry missions, *Exploration Geophysics* 34(1-2): 69-76.

Featherstone, W.E., S.A. Holmes, J.F. Kirby and M. Kuhn (2004) Comparison of remove-compute-restore and University of New Brunswick techniques to geoid determination over Australia, and inclusion of Wiener-type filters in reference field contribution, *Journal of Surveying Engineering* 130(1): 40-47, doi: 10.1061/~ASCE!0733-9453~2004!130:1~40!

Sjöberg, L.E. and W.E. Featherstone (2004) Two-step procedures for hybrid geoid modelling, *Journal of Geodesy* 78(1-2): 66-75, doi: 10.1007/s00190-003-0367-9

Zhang, K.F. and W.E. Featherstone (2004) Investigation of the roughness of the Australian gravity field using statistical, graphical, fractal and Fourier power spectrum techniques, *Survey Review* 37(293): 520-530

Tenzer, R., P. Vaní_ek, M. Santos, W.E. Featherstone and M. Kuhn (2005) The rigorous determination of orthometric heights, *Journal of Geodesy*, 79(1-3): 82-92, doi: 10.1007/s00190-005-0445-2

Baran, I., M. Kuhn, S.J. Claessens, W.E. Featherstone, S.A. Holmes and P. Vaní_ek (2006) A synthetic Earth gravity model designed specifically for testing regional gravimetric geoid determination algorithms, *Journal of Geodesy* 80(1):1-16, doi: 10.1007/s00190-005-0002-z

Soltanpour, A., H. Nahavandchi and W.E. Featherstone (2006) The use of second-generation wavelets to combine a gravimetric geoid model with GPS-levelling data, *Journal of Geodesy* 80(2): 82-93, doi: 10.1007/s00190-006-0033-0

Santos, M.C., P. Vaní_ek, W.E. Featherstone, R. Kingdon, A. Ellmann, B.A. Martin, M. Kuhn and R. Tenzer (2006) Relation between the rigorous and Helmert's definitions of orthometric heights, *Journal of Geodesy* 80(12): doi: 10.1007/s00190-006-0086-0

Featherstone, W.E. (2003) An "outsider's" perspectives on Petr Vanicek's approaches to regional geoid modelling, in: Santos, M. (ed) *Honoring the Academic Life of Petr Vanicek*, Technical Report No. 218, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada, 15-32.

Dennis, M.L. and W.E. Featherstone (2003) Evaluation of orthometric and related height systems using a simulated mountain gravity field, in: Tziavos, I.N. (ed) *Gravity and Geoid 2002*, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 389-394. [*peer reviewed*]

Amos, M. and W.E. Featherstone (2003) Development of a gravimetric geoid for New Zealand and a single national vertical datum, in: Tziavos, I.N. (ed) *Gravity and Geoid 2002*, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 395-400. [*peer reviewed*]

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Appendix 9

European Gravity and Geoid Project (EGGP)
IAG Commission 2 Project CP2.1
Status Report, April 2007

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The EGGP started soon after the IUGG General Assembly in Sapporo 2003. First, a steering committee (SC) was set up, consisting of H. Denker (Chair), J.P. Barriot, R. Barzaghi, R. Forsberg, J. Ihde, A. Kenyeres, U. Marti, I.N. Tziavos. A first meeting of the SC was held in Milan, Feb. 3-4, 2004 (kick-off meeting). During the meeting, the status and possible improvements of the European geoid, the project structure, the input data sets, the methodology, and the time schedule were discussed. It was decided to have only one data and computing center at the Institut für Erdmessung (IfE), Leibniz Universität Hannover. The main reason for this was to guarantee the confidentiality of high-resolution gravity and terrain data, which is a prerequisite for most of the responsible national agencies.

After the SC meeting, national correspondents/delegates from all European countries were invited to become project members. About 30 persons, having access to the relevant data sets or being engaged in geoid computations, accepted to join the project. Meetings of the project members and the SC were held at the GGSM2004 symposium in Porto 2004 (28 participants) and at the IGFS symposium in Istanbul 2006 (23 participants). On both meetings, the main discussion concentrated on possible improvements of the relevant data sets. Several problem areas were identified (e.g., the Mediterranean Sea), and the project members helped to remedy the existing deficiencies.

Interim results and project reports were given anually at scientific meetings in Porto 2004 (Denker et al. 2005, Denker 2005a), Austin 2005 (Denker 2005d) and Istanbul 2006 (Denker et al. 2007). Moreover, EGGP results can also be found in Denker et al. (2004) and Denker (2004, 2006a and 2006b).

Since the start of the project, significant improvements of the gravity data base were made, including new data sets for several countries, e.g., Austria, the Baltic and Scandinavian countries, Belgium, Bulgaria, Croatia, France, Germany, Greece, Italy, Luxemburg, Netherlands, Poland, Serbia, Slovenia, and Switzerland. In addition to this, the public domain data sets from the Arctic Gravity Project became available (Forsberg and Kenyon, 2004). Furthermore, all older gravity data sets were revised regarding the underlying reference systems, the target systems being ETRS89 (European Terrestrial Reference System 1989), EVRS (European Vertical Reference System) and absolute gravity. Significant progress was also made in the collection and reprocessing of ship gravity data. New data sets were received for the Baltic Sea, North Atlantic, Mediterranean Sea, and around France. The ship gravity data for the European seas, collected from several institutions, were crossover adjusted using a bias per track error model in order to reduce instrumental and navigational errors, incorrect ties to harbour stations, and other error sources. The editing of some bad observations resulted already in an improvement of the crossover differences by a factor of two, while the crossover adjustment again reduced the crossovers by a factor of two (Denker and Roland, 2005). Furthermore, new global and regional altimetric gravity anomalies (e.g., Marchenko et al., 2005, Marchenko and Yarema, 2006) became available and were utilized. A study on the combination of ship and altimetric gravity data is presented in Roland and Denker (2005c), while the evaluation of the terrestrial and satellite gravity data is discussed in Roland and Denker (2005a).

Improvements were also made regarding the digital elevation models (DEMs). Austria, Germany and Switzerland released new 1" _ 1" DEMs, while the Scandinavian countries provided new 3" _ 3" DEMs. Furthermore, the older existing national DEMs were incorporated in the data base. However, especially in Eastern Europe and some other areas, fill-ins from global public domain data bases had to be used, either because high-resolution DEMs do not exist or were not released for confidentiality reasons. For this purpose, the SRTM3 model with a resolution of 3" _ 3" (JPL, 2007) and the public domain global model GTOPO30 with a resolution of 30" _ 30" (USGS, 2007) were employed (Denker, 2005b). All available DEMs were merged into a new European DEM with a common grid size of 3" _ 3", covering the area 20°N – 85°N and 50°W – 70°E. Furthermore, for the area of Germany, Austria and Switzerland, a corresponding 1" _ 1" DEM was created. The 3" _ 3" and 1" _ 1" DEMs comprise about 6.6 and 1.7 billion elevations, respectively. This is a significant improvement compared to the previous EGG97 computation with DEM resolutions ranging from 7.5" _ 7.5" up to 5' _ 5'.

In addition to the gravity and terrain data, several new GPS/levelling data sets were acquired for Austria, Germany, Russia, etc. Furthermore, the activities within the EUVN-DA project, an initiative to collect a dense network of GPS and levelling control points in Europe (Kenyeres et al., 2006 and 2007), provided valuable new data sets. At the moment, these data sets serve primarily for control purposes, but later on it is planned to compute also combined geoid/quasigeoid solutions including GPS/levelling data.

Regarding the global geopotential models, the CHAMP and GRACE missions have led to significant improvements in the modelling of long wavelength gravity signals (e.g., Denker, 2005a and 2005c). This is documented among others by the accumulated formal geoid error, which does not exceed 0.01 m for spherical harmonic degrees up to about 25 for the CHAMP models (Reigber et al., 2004a) and 75 for the GRACE models (Reigber et al., 2004b). On the other hand, the limit of 0.01 m is already exceeded at degree 8 for the EGM96 model.

All available data sets were utilized for the computation of several updated European geoid/quasigeoid models. The computations started with the old EGG97 terrestrial gravity data set and the new CHAMP and GRACE geopotential models. Then successively the new gravity and terrain data sets were incorporated. All computed quasigeoid models were evaluated by GPS/levelling data from the European EUVN data set (Ihde et al., 2000) and by national campaigns. When using the EGG97 terrestrial data sets together with the new CHAMP and GRACE geopotential models, the RMS differences from the GPS/levelling comparisons reduced up to 60 % for the GRACE based solutions and up to 30 % for the CHAMP based solutions, as compared to the previous EGG97 model relying on EGM96. Furthermore, also the update and re-processing of the gravity and terrain data led to substantial improvements in the GPS and levelling comparisons in all cases, ranging from 2 % up to about 40 %; the improvement was in particular high in those areas where the data base could be significantly extended. In addition, the long wavelength errors existing in EGG97 were substantially reduced to typically below 0.1 ppm. The presently available results indicate an accuracy potential of the gravimetric quasigeoid models in the order of 3 – 5 cm at continental scales and 1 – 2 cm over shorter distances up to a few 100 km, provided that high quality and resolution input data are available. This is a very significant improvement compared to the last published (quasi)geoid model EGG97, the key elements being improved terrestrial and satellite gravity field data (e.g., Denker 2005b and 2005c).

So far all computed quasigeoid models are based on the spectral combination approach. However, test computations with the wavelet approach were done as well (Roland and Denker, 2005b), and the application of the fast collocation technique, developed by the Milan group (e.g., Sansò and Tscherning, 2003), is planned but not realized so far.

After incorporating some additional gravity data sets received lately, a completely updated geoid/quasigeoid model (EGG07) shall be finished soon and presented at the coming IUGG General Assembly 2007 in Perugia. The new geoid/quasigeoid models allow a number of interesting applications, such as the accurate determination of W_0 (reference geopotential of the vertical datum) and vertical datum unifications. Moreover, contributions to the definition of a European Vertical Reference System (EVRS) become possible.

Thanks to the efforts of our French colleague Henri Duquenne, a very valuable test data set was created. The data set consists 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 see Duquenne, 2007). The data set can be used to test different methods, softwares, reduction procedures, etc. However, due to time restrictions, the test data set could not be fully exploited so far.

In summary, significant progress was made within the framework of the European Gravity and Geoid Project (EGGP) regarding the collection and homogenization of high-resolution gravity and terrain data. Many new data sets became available, and especially the new geopotential models from the CHAMP and GRACE missions improved the geoid/quasigeoid modelling very much.

As not all desired updates can be included in the EGG07 model, and because there is still room for improvements, it is proposed to continue the project for another four year term. This is also important in order to keep the access to the proprietary high-resolution gravity and terrain data, which are in many cases provided exclusively for the purpose of the EGGP and must be deleted after the end of the project.

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Appendix 10

Report of CP2.2 (North American Geoid) – not available.

Appendix 11

REPORT OF COMMISSION PROJECT 2.3: AFRICAN GEOID PROJECT

(part of Sub-Commission 2.4: Regional Geoid Determination)

For the period: January 2006 - December 2006

General:

During the year under review members have focussed on refining techniques and on assessing the SRTM and GRACE models in the context of a geoid model for Africa. Members of the group computed national geoid models for Algeria, Egypt and South Africa. Additional GPS/levelling data in Algeria and South Africa allowed further analysis of the accuracy of geoid models in those regions. Different models for corrector surfaces between the gravimetric and GPS/levelling geoids were evaluated for Algeria. Tailored models were investigated for Egypt. A revised geoid model, incorporating the SRTM and GRACE data, for the whole of Africa was also computed.

Members of the group attended the EGU General Assembly in Vienna; the 22nd annual meeting of the Egyptian Geophysical Society, in Cairo (both in April 2006); and the 1st International Symposium of the International Gravity Field Service in Istanbul, in August 2006.

Future Plans:

Members of the group will attend and present papers at the 24th General Assembly of the IUGG in Perugia in July 2007. A member will also attend the meeting of the Egyptian Geophysical Society in March 2007. Two members of the group have also joined the Working Group assessing the quality of the new NGIA EGM2006 geopotential model and will participate in assessing its quality in selected parts of Africa.

One of the major stumbling blocks to an improved geoid model for Africa is the lack of available data in significant parts of Africa. This situation is unlikely to change unless major sponsors are able to support airborne gravity surveys in the worst-affected areas. The alternative is to wait and hope for the results of the GOCE mission.

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Members:

Charles Merry (Chairman)	South Africa
Hussein Abd-Elmotaal	Egypt
Sid Ahmed Benahmed Daho	Algeria
Peter Nsombo	Zambia
John Saburi	Tanzania

Appendix 12

Report of Commission Project 2.4 “Antarctic Geoid” (AntGP)

Mirko Scheinert
TU Dresden, Institut für Planetare Geodäsie, 01062 Dresden, Germany
April 30, 2007

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 densify satellite data. Because of the region and its special conditions collaboration extends beyond the field of geodesy – an interdisciplinary cooperation is anticipated, especially incorporating geophysics and glaciology. This is also reflected in the group membership (cf. below).

During the first four-years 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. It took a lot of efforts to investigate the current situation of gravity data coverage in Antarctica and to get into discussion with the respective institutions where gravity data are held, and to develop a mutual understanding especially when looking at the different goals of geodesy and geophysics dealing with gravity data in Antarctica. A lot of work has still to be done. Concerning new gravity surveys in Antarctica, the International Polar Year 2007/2008 (IPY), which started recently (March 01, 2007), plays an important role to pursue the goals of AntGP. Concerning the compilation of Antarctic gravity data, it is now possible to start with the built-up of a suitable database. *Therefore, we strongly suggest to continue the work of the Commission Project 2.4 “Antarctic Geoid”.*

Concerning the IPY, a lot of work has been focussed on the preparation of scientific IPY projects. In this context, planned aerogeophysical and geodetic surveys will provide new data to fill in data gaps in Antarctic gravity. The following IPY projects should be mentioned: Project 67 “Origin, evolution and setting of the Gamburtsev subglacial highlands (AGAP)”, project 97 “Investigating the Cryospheric Evolution of the Central Antarctic Plate (ICECAP)”, project 42 “Subglacial Antarctic Lake Environments (SALE-UNITED)”, project 152 “Trans-Antarctic Scientific Traverses Expeditions (TASTE-IDEA)”, project 185 “Polar Earth Observing Network (POLENET)”.

In 2006, a milestone was the XXIX SCAR Meeting and Open Science Conference, held in Hobart, July 9-19, 2006. This conference provided an excellent opportunity to present the goals of AntGP and to discuss possibilities of specific work in Antarctica. The linkage to the bodies of SCAR could be deepened, since M. Scheinert was elected chair of Project 3 “Physical Geodesy” within the work plan 2006–2008 of SCAR Standing Scientific Group on Geosciences, Expert Group on Geospatial Information and Geodesy (GIANT – Geodetic Infrastructure in Antarctica).

An updated overview on AntGP could be given at the 1st International Symposium of the International Gravity Field Service “Gravity Field of the Earth”, Istanbul, August 28 – September 01, 2006 (Scheinert et al., 2006b). Even if not directly dedicated to the goals of AntGP, nevertheless a workshop “GPS in the IPY: The POLENET project”, focussed on the geodetic part of the IPY project 185 POLENET, held in Dresden, October 4–6, 2006, provided also a platform to meet members of AntGP and to present and discuss specific points with relevance to AntGP (e.g. relative and tidal gravimetry in Antarctica).

In order to discuss the gravity data situation in Antarctica the chair of AntGP conducted work visits to institutions with involvement in AntGP, namely to Russia (G. Leitchenkov/VNIIOkeangeologia) and to Great Britain (F. Ferraccioli/British Antarctic Survey).

To present AntGP to the community, a website is being maintained under `www.tu-dresden.de/ipg/antgp`

Future plans and activities

Future activities are well defined following the "Terms of Reference". Since any Antarctic activities call for a long-term preparation the main points to be focussed on do not change. Even more, to cope with the activities within the International Polar Year (March 2007 to March 2009) puts a major motivation to continue the work of AntGP for a next four-years period starting at the IUGG 2007.

(a) Promotion and realization of new gravity surveys in Antarctica

As described above, the upcoming IPY plays an important role for the international coordination and preparation of such surveys. Due to the huge logistic efforts of Antarctic survey campaigns, coordination is organized well in advance and on a broad international basis. In 2006, this refers especially to the preparation of IPY activities.

(b) Built-up of databases

Within AntGP, a 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).

Conferences and workshops play an important role to coordinate work between AntGP members and the diverse communities. At the upcoming IUGG General Assembly, Perugia, July 2007, AntGP will be presented and should be continued for a second period. Work activities have to be reviewed and focussed taking the perspectives of the IPY into account.
A second conference of mayor importance is the X International Symposium on Antarctic Earth Sciences, to be held in Santa Barbara, August 26-31, 2007.

Membership (as of February 2007)

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
René Forsberg	Danish National Space Center, Denmark
Larry Hothem	USGS, USA
Wilfried Jokat	AWI Bremerhaven, Germany
Gary Johnston	Geoscience Australia
Fausto Ferracioli	British Antarctic Survey, United Kingdom
A.H. William Kearsley	University of New South Wales, Australia

Steve Kenyon	NIMA, USA
Christopher Kotsakis	University of Calgary, Canada
German L. Leitchenkov	VNIIOkeangeologia, Russia
Jaakko Mäkinen	FGI, 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

Robin Bell	Lamont-Doherty Earth Observatory, USA
Graeme Blick	LINZ, New Zealand
John Brozena	Naval Research Lab, USA
Cheinway Hwang	National Chiao Tung University, Taiwan
John Manning	University of New South Wales, Australia
Dave McAdoo	NOAA, USA

Selected conferences and workshops with participation of AntGP members

3rd EGU General Assembly, Vienna, Austria, April, April 3-7, 2006.

XXIX SCAR Meeting and Open Science Conference, Hobart, Australia, July 8-16, 2006.

1st International Symposium of the International Gravity Field Service, Istanbul, Turkey, August 28 – September 1, 2006.

Workshop "GPS in the IPY: The POLENET Project", Dresden, Germany, October 3-6, 2006.

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Appendix 13

IAG – Gravity and Geoid Projects in South America

SC2.1: Gravimetry and Gravity Networks Project

SC2.4: Regional Geoid Determination Project

Commission Project CP 2.5: South American Geoid

Commission Project CP2.7: Gravity in South America

Prepared by: Denizar Blitzkow and Maria Cristina Pacino

REPORT

July 2007

ACTIVITIES

Fundamental Gravity Network (FGN) in South America: A total of 33 gravity stations have been established in Ecuador in cooperation between EPUSP, IBGE (Brazil), IGM and INOCAR (Ecuador) and with NGA (loan of gravity meters). The network has been adjusted in 2005 by least square method and the results have been presented in the EPUSP master dissertation of Carlos Alberto Correa e Castro Jr. A problem that still exists in Ecuador is the inexistence of absolute gravity stations. Chilean FGN consists of a total of 54 stations, established by EPUSP, IBGE (Brazil) and IGM (Chile). The gravity values are referred to absolute stations in Iquique, Colina, Puerto Montt and Punta Arenas and a least squares adjustment is under preparation. A similar FGN was established in Paraguay with 46 stations. In order to refer the gravity values to some consistent reference, an absolute station in Valinhos (Brazil) was used, with a connection from Valinhos to Foz do Iguaçu, then to Assunción.

PMRG (Project for the Geodetic Reference System Change) in Brazil: SIRGAS2000.4 has been adopted in Brazil since February 2005. A new geoid model for Brazil has been computed and delivered in a grid of 10′ as part of the new reference system. A software named MAPGEO2004 was also provided for interpolation in any point from the geoid grid. The results have been presented in the EPUSP doctor thesis of Maria Cristina B. Lobianco.

Course: STOKES-HELMERT'S SOLUTION TO GEODETIC BOUNDARY VALUE PROBLEM. It was teached by Prof. Dr. Petr Vaní_ek, in Rio de Janeiro, October 2005. It was supported by IBGE, University of New Brunswick and CIDA (Canadian International

Development Agency) and it was coordinated by Maria Cristina B. Lobianco and Denizar Blitzkow.

Geoid in Argentina: A new geoid model for Argentina was computed and the result is part of the doctor thesis of Claudia Tocho, submitted to the National University of La Plata in 2006.

Other efforts: A new set of gravity data is now available for Colombia and Ecuador due to an effort of Laura Sanchez and Alfonso Tierra to validate the data in both countries. The next geoid model version will benefit from this effort.

A gravity survey was carried out in south of Chile, along Carretera Austral, as part of a joint cooperation between EPUSP, IBGE, GETECH and IGM.

Several absolute measurements have been carried out with two absolute gravitymeters purchased in 2006 by National Observatory, Brazil:

- measurements with FG-5 #223 on IfE 142 – Vassouras and in National Observatory Laboratory;
- measurements with A-10 #011 on the Calibration Baseline at Agulhas Negras;
- measurements with A-10 #011 on National Observatory Vertical Calibration Baseline;
- measurements with A-10 #011 on IGSN 71 40123A station on Rio de Janeiro; and
- measurements with A-10 #011 on metrological laboratories from Brazilian Calibration Network.
- measurements with A-10 #011 on two tide gauge stations, University of São Paulo, Oceanographic Institute, in Cananéia and Ubatuba. A third measurement was made at Institute of Astronomy, Geophysics and Atmosferic Science, in a geodynamic laboratory;

National Observatory future plans:

- measurements with FG-5 #223 on the remaining absolute IfE stations.
- establishment of new absolute stations with FG-5 #223 on North-South arch and other Brazilian selected places (for example, Macaé, Mossoró, Aratu, Cuibá, Belém and Manaus);
- cooperation with other South American countries in absolute and relative gravimetry, aiming for applications in Geophysics, Geodesy and Metrology;
- refinement of national patterns on mass, force, pression, viscosity, flow and vibration, through absolute measurements on INMETRO metrological laboratories;
- measurements with A-10 #011 on other metrological laboratories of Brazilian Calibration Network – RBC;
- maintenance and expansion of the Brazilian Gravity Fundamental Network;
- validation of older gravity surveys via absolute gravity and GPS measurements;
- determination of vertical movements on areas under existing induced subsidence.

Symposium: GRAVITY AND GEOID IN SOUTH AMERICA
VENUE: INSTITUTO GEOGRAFICO MILITAR - BUENOS AIRES (ARGENTINA)
DATE: 25 – 29 SEPTEMBER, 2006
SPONSORS:
Instituto Geográfico Militar de Argentina
Facultad de Ciencias Exactas, Ingeniería y Agrimensura (Universidad Nacional de Rosario)

Facultad de Ciencias Astronómicas y Geofísicas (Universidad Nacional de La Plata)
Polytechnic School (University of São Paulo)
Agencia Nacional de Promoción Científica y Tecnológica de Argentina
Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina
International Gravity Field Service (IGFS – IAG)

The symposium was organized in a joint effort of the IAG Projects CP2-7 (Gravity in South America) and CP2-5 (South American Geoid), and sponsored by IGFS, together with several Argentinean and Brazilian organizations. Its main objective was to broaden and to deepen the terrestrial gravity field knowledge of South American professionals, leading to an adequate handling of the vertical reference, and providing a forum of debate on the current theoretical, practical, and common problems.

The activities were arranged as follows:

- Two workshop days for updating on new methodologies and current models, as well as the practical use of these concepts (René Forsberg);
- two days to inform about the activities, achievements and future prospects in several South American countries through oral presentation and posters;
- the last day for discussion and planning of joint activities.

More than fifty participants from Argentina, Brazil, Chile, Ecuador, Uruguay and Venezuela attended thirty presentations and, at the final day, discussed several recommendations and suggestions.

Future plans: Measuring campaigns

A budget for a new absolute gravity measurement campaign has been approved and it will be carried out in two steps:

- 2007: reoccupation and densification of absolute gravity stations in Argentina, Brazil, Uruguay and Ecuador using FG5 – 223 from National Observatory (Rio de Janeiro, Brazil), complemented by a relative gravity campaign to connect the national´s networks; and
- 2008: absolute gravity campaign using A10-011, also from National Observatory, at tide gauges and permanent GPS stations.

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Appendix 14

IAG Commission 2, CP2.6 South East Asian Geoid
A. H. W. (Bill) Kearsley

In the period 2003-2007, it has been difficult, given the geopolitical, financial and other pressures, to arrange specific meetings of the parties interested in this geoid sub-commission.
However there have been two presentations at two related meetings which need reporting.
1. A paper on the aims, objectives and problems of Commission 2, CP2.6 was presented at the meeting of the PCGIAP (United Nations Permanent Committee on Geographic Information Infrastructure for the Asia-Pacific) in Cairns, August 2005 chaired by John Manning. This proved to be of real benefit, as many of their (i.e. PCGIAP's) aims and objectives dovetail with ours, and there is now a definite policy at the level of national governments involved in PCGIAP to recognise the IAG's initiatives in this regard and encourage projects which support geoid studies in the South-East Asian region and beyond.

2. A similar report on Commission 2, CP2.6 was presented at the "Geoid, gravity and height workshop" held in Ulaanbaatar, Mongolia, on June 6-8, 2006, under the Chairmanship of Rene Forsberg. One aim of this workshop was to focus efforts on coordinating activities on height system unification and geoid knowledge in the Asian region, so it was entirely relevant that I should attend to present the viewpoint from South East Asia. A number of important and entirely relevant resolutions came from this meeting, and I will append them to this report, although I suspect that Rene Forsberg will have already presented them in his report to IAG on this meeting.

3. One major issue which did emerge from this meeting was the need to extend the geographical scope of the sub-commission into the whole of Asia, and to perhaps encompass the whole region covered by the PCGIAP (see point 1.) However it should be recognised that some national authorities are extremely cautious over sharing data etc. so this idea may not be practical.

Report from
International Association of Geodesy
Workshop on
Height Systems, Geoid and Gravity of the Asian-Pacific
Ulaanbaatar, Mongolia, 6-8, June, 2006

Resolutions for IAG Commission Project 2.6 "The Geoid for South East Asia".

At the recent IAG meeting on Height Systems, Geoid and Gravity of the Asian-Pacific held in Ulaanbataar in June 2006, the issues relevant to the IAG's GGOS program for the region, and the PCGIAP requirements for height unification in the Asia-Pacific region were discussed, especially as they related to the critical need for a homogeneous and precise geoid in the South East Asian region. The discussions covered many matters, including the optimum fundamental reference surface for heights, the need to relate the leveling networks between countries, and the apparent lack of gravity data. The points raised included

1. Common Vertical Datum

1. There is great value in cooperation between neighboring countries, both in the sharing of resources, and in relating their systems to a global reference frame, in the vertical as well as the horizontal sense.

2. A Study Group of the IAG (ICP2.1) is very close to recommending a value for W_0 for the reference geoid for the earth. It is expected that this will ratified at the next General Meeting at IUGG2007 in Peruggia and adopted in the upcoming earth geopotential model EGM06. It seems timely that the national authorities move to determine the relationship between their national leveling datum and this new global reference for heights, and thus enable the unification of vertical datums across the region.

3. Note that we are not proposing that all heights in the national network are amended to reflect the global reference system; it is aimed at unifying the heights into one system simply for the purpose of regional geoid determinations.

4. It is also important for countries in the region to tie their national vertical leveling networks, in the same way the countries of Europe have done.

2. Common Data

EGM06 will be a significant asset for local precise geoid determinations, but there will still be the need to augment the EGM06 geoid values, especially in those regions whose data were not available for the EGM06 model, if adequate N values can be achieved to transform GPS heights to 3rd order (or better) leveling standards

1) The main obstacle to precise geoid determination, at both the regional and national level, is the lack of (publicly available) gravity data across the region.

2) It is known that there *is* data available in the national archives which are not yet in the public domain.

3) The lack of gravity data, especially in the land border areas, is a significant obstacle to precise geoids in these areas for all countries lying along the borders.

4) There is therefore a real need is for neighbouring countries to share gravity data in the areas of common borders. Only then will the deterioration in precision of the geoid determination at these borders be prevented. In contrast, there will be a seamless transition in the geoid across national borders.

5) For similar reasons, it would be valuable for countries to share those data where GPS has been measured at Benchmarks in the border regions – to provide geometric control over the gravimetric determinations of the geoid.

6) Gravity data would only be needed within a 0.5 degree (50 km) zone of the border, and at a precision equivalent, say, to that achieved by airborne techniques. In other words, data could be degraded to the nearest 1 to 2 mGal, and with an 8 to 10 km resolution

We recognize the sensitivity in matters of sovereignty, national security and intellectual property that exists at policy level on the sharing of data, but emphasise that the sharing of data in the border zones is to the mutual benefit of the countries concerned. We are convinced that there are means (such as those suggested in 2.6 above) by which these difficulties can be resolved, and that the great benefits which accrue from sharing of data can be realized without compromising either the issues of national or security the integrity of the geoid values.

RESOLUTION

Recognising that

there are, in the very near future, major developments in both global geopotential models, and in the definition of the global geoid, and

there are deficiencies in the publicly available gravity data, and that

there are sensitivities on the part of national administrations regarding the sharing of this data,

The participants of the workshop recommend

- that, when the value of W_0 is ratified at IUGG Peruggia, the national geodetic authorities determine the offset of the national leveling datum to this global vertical datum, and
- that, where feasible, the levelling networks at borders regions be connected (as was done for, e.g., European countries), so that the offsets between these networks are established, and they can then be related to each other, and to the global geoid, and.
- that, when EGM06 is published, an IAG computational workshop be held in a central location in SE Asia to establish the regional geoid for all participating countries based upon this model. This workshop should include, where possible, the sharing of gravity and geometric geoid values along common borders. The workshop is to be performed in a most secure environment so as not to compromise the national integrity or the security of these data.

Appendix 15

Progress report for IAG/Commission 2 IC-WG2:
"Evaluation of Global Earth Gravity Models"

J. Huang and C. Kotsakis

25 May 2007

The inter-commission working group (IC-WG2) on the "Evaluation of Global Earth Gravity Models" was established between the International Gravity Field Service (IGFS) and the Commission 2 of IAG in 2005. Its main objective is to develop standard validation and calibration procedures, and to perform the quality assessment of GRACE-, CHAMP- and GOCE-based satellite-only and combined solutions for the static Earth gravity field. The following items highlight the activities of this working group up to May 2007:

1. 27 members were invited to join the group in order to provide a global (to the extent possible) geographical coverage for the regional EGM evaluation tests. There are also 9 additional corresponding members in the group's membership. For the time being, the regions without participation are South Asia and Middle East.
2. The members have conducted extensive evaluation tests with the various EGMs (EIGEN-CHAMP, GGM01, GGM02, EIGEN-GRACE, and EGM06 etc.) obtained from CHAMP's and GRACE's mission results. The EGM evaluation results from different regions are not consistently in agreement, giving rise to alternative and interesting interpretations about the quality of the current global geopotential models. A review paper on these results, along with a general overview of the possibilities and limitations of EGM calibration and validation procedures with the aid of external data, is in preparation and it will be presented at the IUGG07 conference.
3. The group proposed a work plan to evaluate the upcoming EGM07 model in collaboration with the US National Geospatial-Intelligence Agency (NGA). For that purpose, most of the group members have benchmarked the NGA's spherical harmonic synthesis code in their own systems.
4. A group meeting was held on August 31, 2006 in Istanbul, during the first IGFS International Symposium. There were about 26 participants. The minutes from this meeting are available from the group's webpage. The main recommendations include publishing the EGM96 evaluation papers online; creating the group website dedicated to the group activities; and compiling a precise global GPS-leveling dataset. The 1st and 2nd recommendations have been put in place. The third one is being planned.
5. A group website has been developed by C. Kotsakis to provide a forum for the group members to obtain and contribute information related to the

group activities. The website provides a password-protected link that is dedicated to the EGM07 evaluation. The website address is: http://users.auth.gr/~kotsaki/IAG_JWG/IAG_JWG.html

6. Many of the group members have already provided their presentations, reports and papers related to the WG's objectives. This material is publicly available and it can be downloaded from the group's website.

7. A group meeting is planned to take place in Perugia, during the IUGG07 General Assembly. The main issues that will be discussed during this meeting include: reviewing the current status of the group, proposing and planning the group activities for next year, compiling a global GPS/leveling dataset, and establishing collaboration with other groups and centers that are currently working on similar topics.

IAG Inter-Commission Project
ICP1.2 Vertical Reference Frames

Final Report of IAG ICP1.2

(Jointly by Commissions 1 and 2)

For the period 2003 - 2007

Author: Johannes Ihde (Germany), Chair ICP1.2

Reviewers: Bill Kearsley, Matt Amos, Bernhard Heck, Laura Sanchez

Terms of Reference of ICP1.2

The Earth's surface may be described by its geometry and the potential of the Earth's gravity field. The determination of heights includes both of these aspects - the geometric part and the geopotential part. Presently, space geodetic techniques allow an accuracy in geometric positioning of about 10-9 of the Earth´s radius in global and continental scales. Gravity field parameters, including the physical height components, can at present be determined only 2 to 3 orders of magnitude less accurately than the geometric parameters. Moreover, the current height reference frames around the world differ in their vertical datums (e.g., the mean sea-level at the fundamental tide gauges) and in the theoretical foundations of the height systems. There is no global height reference system defined or realized, as with the International Terrestrial Reference System (ITRS). Considerable progress in the definition and realization of an unified, global vertical reference system will be achieved from the data of the new satellite gravity field and altimetry missions.

Based on the classical and modern observations, the ICP1.2 on Vertical Reference Frames shall study the consistent modelling of both, geometric and gravimetric parameters, and provide the fundamentals for the installation of a unified global vertical reference frame.

Objectives

- To elaborate a proposal for the definition and realization of a global vertical reference system (World Height System – WHS);
- To derive transformation parameters between regional vertical reference frames;
- To establish an information system describing the various regional vertical reference frames and their relation to a world height frame (WHF).

Program of Activities

- Harmonization of globally used height data sets;
- Study of combination procedures for height data sets from different techniques;
- Study of information on regional vertical systems and their relations to a global vertical reference system for practical applications;
- Unification of regional (continental) height systems.

Members

Alireza A. Ardalan (Iran), Carine Bruyninx (Belgium), Milan Bursa (Czech Republic), Tonie van Dam (Luxemburg), Gleb Demianov (Russia), Will Featherstone (Australia), Johannes Ihde (Germany), Christopher Jekeli (USA), Adolfientje Kasenda (Australia), Bill Kearsley (Australia), Roland Klees (Netherlands), Gunter

Liebsch (Germany), Markku Poutanen (Finland), Laura Sanchez (Colombia), Tilo Schöne (Germany), Steve Shipman (UK), Jaroslav Simek (Czech Republic)

During the four years the ICP1.2 working group was extended by:

Matt Amos (New Zealand), Wolfgang Bosch (Germany), Alessandro Capra (Italy), Robert Cunderlik (Slovakia), Hermann Drewes (Germany), Bernhard Heck (Germany), Jan Krynski (Poland), Urs Marti (Switzerland), Jaakko Mäkinen (Finland), Marcel Mojzes (Slovakia), Dan Roman (USA), Zdislav _ima (Czech Republic), Viliam Vatrt (Czech Republic), Marc Véronneau (Canada), Marie Vojtiskova (Czech Republic), Herbert Wilmes (Germany).

During the four years the ICP1.2 working group was partly joint by:

Ruth Adams (UK), Jonas Ägren (Sweden), Susana Barbosa (Portugal),Matthias Becker (Germany), Dorota Brzezinska (USA), Francoise Duquenne (France), Henri Duquenne (France), Jan Ferko (Slovakia), Joana Fernandes (Portugal), Georgia Fotopoulos (Canada), Roger Hipkin (UK), Petr Holota (Czech Republic), Jianliang Huang (Canada), Karl Heinz Ilk (Germany), Michael Kuhn (Australia), Jan Kouba (Canada), Roberto Teixeira Luz (Brazil), Jan Marsa (Czech Republic), Jürgen Müller (Germany), Diethard Ruess (Austria), Eimuntas Parseliunas (Lithuania), Martin Vermeer (Finland), Franziska Wild-Pfeiffer (Germany).

Meetings and workshops

- European Vertical Reference System Workshop, 5-6 April 2004 in Frankfurt on Main, Germany (draft minutes)
- Business Meeting of ICP1.2, 31 August 2004, on GGSM2004 in Porto, Portugal (minutes)
- Business Meeting of ICP1.2, 22 August 2005, on the IAG Scientific Symposium in Cairns, Australia (minutes)
- ICP 1.2 Workshop, 11-12 April 2006 in Prague, Czech Republic (minutes)
- ICP1.2 Splinter/Business Meeting, 28 August 2006 at the 1st IGFS Symposium in Istanbul, Turkey

Status and Results

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)** - File VRS_conventions_3.0_2007-05-01. 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.

A global unified vertical reference system for an International Vertical Reference System (IVRS) can be realized by:

- A global network of stations with coordinates in ITRF and geopotential numbers referred to a conventional global reference level. This network should include co-location of permanent GNSS, tide gauges, permanent (SG) and periodical (AG) gravity stations.
- A global reference level derived from a conventional global gravity model (CGGM) from satellite gravity missions only in combination with a global sea level model from satellite altimetry.
- Both based on a set of consistent conventional numerical standards
- In addition local and regional gravity observations around the IVRS stations are required.

Regional and national height reference systems can be integrated into an IVRS by GNSS/levelling aligned to ITRF and using the CGGM and the numerical standards.

Changes of the solid and fluid Earth surface can be observed with respect to the conventional IVRF level by relevant observation techniques. The IVRS level is defined by a conventional W_0. The conventional IVRS level has to be related to the instantaneous mean sea surface level (MSSL).

Deficiencies

In view to a planned ISO registry for geodetic parameters, the establishment of an information system describing the various regional vertical reference frames and their relation to an IVRS was not realized. This includes the determination of transformation parameters between regional vertical reference frames and the unified global height system.

Further open topics are the relationships between an IVRS and the International Terrestrial Reference System (ITRS) (Basic relations between ITRS and IVRS conventions, parameters, realization, models).

Proposed continuation

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 IAG has to clarfy 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 associations.

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), the International Hydrographic Organisation (IHO), the International Federation of Surveyors (FIG), and. the Interservice Geospatial Working Group (IGeoWG) of NATO.

Johannes Ihde, Chair ICP1.2
June 15, 2007

Annex:

Numerical Standards

The Geodetic Reference System 1980 (GRS 80, 1980) defines major parameters for geodetic reference systems related to a level ellipsoid. It is agreed by the International Union of Geodesy and Geophysics (IUGG), International Association of Geodesy (IAG) and International Astronomical Union (IAU). The GRS80 parameters are recommended by IAG for the conversion of ITRF Cartesian coordinates to ellipsoidal coordinates. It is used worldwide for many map projections and million of coordinates are related to it.

At the IUGG General Assembly 1991 in Vienna new values for the geocentric gravitational constant GM and the semi-major axis a of the level ellipsoid were recommended. Since this time these parameters have been used in global gravity models e.g. EGM96. The two other defining parameters were not changed.

In the IERS 2003 conventions (Mc Carthy and Petit, 2004) numerical standards are listed (Table 1.1). These conventions have thew effect of standards and when read with chapters 4.1.4 and 4.2.5 recommended the use of GRS80 for transformations. The value of the geocentric gravitational constant (GM) has not changed since 1991. The parameters in Table 1.1 have the status of standards. In parallel in chapters 4.1.4 and 4.2.5 the GRS80 is recommended for transformations.

Table 1 contains parameters of different level ellipsoids. The gravitational constants GM of GRS80 and IERS 2003 conventions differ in the metric system by about 0.9 m. The semi-major axis of both standards differs by 0.4 m. It has to be stated, that the IERS 2003 conventions recommends different level ellipsoid parameters for different applications.

GRS80 is recommended (and generally used) for geometrical applications. For global gravity models, various inconsistent values are used in practice.

The IAG needs to remove this inconsistency to enable the development of integrated geodetic applications (cf., Hipkin, 2002). The geoid potential parameter W_0 of a Global Vertical Reference System defines the relationship of the physical heights to the Earth body. The parameter W_0 must be consistent between systems to ensure the relations to be reproducible.

Table 1. Level ellipsoid parameters

Ellipsoid	Semi-major axis a in m	Flattening f^{-1}	Geocentric gravitational constant GM in $10^8 m^3 s^{-2}$	U_0/W_0 in $m^2 \cdot s^{-2}$	_e in $m \cdot s^{-2}$
Int. Ell. 1930 (Hayford)	6 378 388	297	3 986 329		
GRS 67	6 378 160	298.247	3 986 030		
GRS 80	6 378 137	298.2572221 ± 01	3 986 005	6 263 6860.850	9.78032677
IUGG 91	6378136.3 ± 0.5		3 986 004.41 ± 0.01		
IERS 2003 Conventions (zero tide)	6378136.6 ± 0.1	298.25642 ± 0.00001	3986004.418 ± 0.008	62636856.0 ± 0.5	(9.78032666)*

Angular velocity of the Earth rotation _ in 10^{-11} rad s^{-1} 7 292 115

In addition to the existing IERS numerical standards other parameters shall be calculated and included in the IERS conventions e.g.

_e normal gravity at equator
_p normal gravity at pole
* not consistent with IERS 2003 Conventions

(Remark: The numerical value of W_0 has to be revised in view of recent work done at the DGFI)

Appendix 17

IAG Commission 3 – Earth Rotation and Geodynamics
Report on GGP Activities 2003-2007
D. Crossley and J. Hinderer, June 22 2007

1. Stations

We show in the Figure 1 the location of most of the stations in the GGP network for the decade 1997-2007. The cluster of stations in Europe and N.E. Asia are shown separately.

Two stations in the network stopped recording during the current reporting period (2003-2007). These were Bandung, Indonesia, and Boulder, Colorado. The situation in Bandung was instrument failure due to a sever storm that flooded the facility and lifted the instrument off its supporting pillar. The internal components in the dewar were OK, but the damage was too severe to be easily or quickly repaired. There has been talk of re-constituting a station in Indonesia, but in another location. The station and instrument are run by Kyoto University, Japan.

The situation is Boulder is different. Due to the retirement of key personnel in Boulder, the maintenance of the data acquisition failed in May 2004 and no further data has been available. NOAA has ownership of the instrument, and it is still functioning according to some reports, but we are unsure of its future, whether in Boulder or elsewhere. Useful suggestions about transferring it to Alaska, or to another site in the US have been discussed within GGP and passed on to NOAA.

Two other stations have had troubles that have resulted in data interruptions. One is the instrument in Kyoto that has had tilt problems for a long time that apparently have not been fixed. Also the instrument in Syowa, Antarctica has had some drift problems and we have not seen data for some time.

Thankfully all other stations in the network are functioning well and sending data to the GGP database at ICET. Most of these stations have now brought themselves up to date at least into early 2007. Walferdange has so far not sent data to GGP.

Two new stations have been recording since 2005: MunGyung in S. Korea, and Kamioka in Japan. The former is run by J.-W. Kim of Sejong University, Korea, also associated with the geodesy group at Ohio State University. Station Kamioka was installed in the high technology physics underground complex for neutrino detection in central Japan. It is run jointly by Kyoto University and NAO Mizusawa. Both of these SGs have data sets not yet transferred to ICET. Two new instruments were installed in Hsinchu, Taiwan, by C. Hwang and colleagues of the National Chiao Tung University. One had to be returned to GWR for repairs but is expected back imminently. The other is recording well in an underground facility in Hsinchu and we have seen preliminary data.

Finally, two very recent installations were completed early this year. The first is at the historic Geodetic Observatory in Pecny, Czech Republic. The second was installed at the Wadia Institute of Himalayan Geology in Dehradun, India to study earthquake precursory signals in conjunction with other geophysical methods. Both installations were successful and we look forward to receiving their data.

As for future stations, we are anticipating the installation of an SG in Manaus, Amazon Basin, as part of the effort of GFZ (Potsdam) to characterize the very large annual hydrology signal over the basin seen by the GRACE satellites. The anticipated date is Fall 2007. We also know of several other planned locations identified on the maps. There will be an SG in Texas to monitory hydrology (C. Wilson, U. Texas, Austin), and a second instrument in Wuhan to be installed by the Chinese Bureau of Seismology. The installation in Tahiti is in the works, with a second instrument in the southern US at Sunspot, the site of the lunar laser ranging facility, also being planned. The German group is planning a station on the Baltic coast, see Figure 1(c).

Overall the list of stations will soon reach 30, of which at least 25 should be functioning within the next year or two.

2. GGOS

Along with many other IAG organizations, GGP will contribute data to GGOS as part of the extensive range of goals identified in the GGOS Reference Document (GGOS-2020). The combined use of SGs and AGs to monitor the long term changes in the surface gravity field has now become commonplace and we look forward to the opportunity to see SGs installed at more of the fiducial (or core) stations of the proposed GGOS ground-based network. One of the important functions of ground-based data will be to constrain the position of the Earth's Center of Mass as a fundamental variable in the determination of the gravity field for space and satellite missions.

Of the current GGP stations, only a few are installed at space-geodetic stations (e.g. Wettzell, Tigo Concepcion, Ny-Alesund, Sutherland). Many of the other installations are doing hydrology-based research, or are functioning for a specific purpose but yet recording useful data that can be widely used (examples given later).

3. ICET

As will be reported elsewhere, the future location and organization of the International Center for Earth Tides is being discussed, and may be decided at meetings at the IUGG. GGP has a a special interest in the outcome, as ICET has played a strong supporting role for the processing of GGP data, as well as other services related to GGP. We have, of course, contributed some ideas to the ETC and others in the IAG.

4. IRIS

We have had a project now for almost 2 years, to get GGP raw data (recorded at 1, 2, or 5 sec sampling) into the global seismic database IRIS (Incorporated Research Institutions for Seismology). There have been some difficulties in specifying the complete SG instrument response in the very precise format required by seismology. To a geodesist, the issue is very simple: what is the calibration (or scale) factor? This means the DC response of the instrument to convert volt to acceleration. This is a topic with a long history, and it is well known that SGs can be calibrated to better than 0.1% in amplitude (approaching 0 .02% in special experiments). But the phase response at high frequencies can only be accurately measured using special equipment not normally available at SG stations. Information on the technique is available at http://www.eas.slu.edu/GGP/phasecal.html. We have struggled somewhat with the issue and this has delayed the project.

Happily we now have the means to finalize this issue with the help of real seismologists. This will enable us to follow the example of station Membach. Through the efforts of M. V. Camp, data from the MB SG (special seismic output) has been sent to IRIS for more than a year. We are aided in this venture by GFZ Potsdam, and we promise some real results from other GGP stations soon.

5. Workshops and Special Publications

GGP normally meets once a year in connection with a major meeting or as a stand-alone workshop. occasions are noted for the record, since Sapporo, 2003. As always, the shorter meetings are for business only, while the specialized workshops (in 2004, 2006) are the major opportunity to exchange scientific information.

All events are reported in GGP Newsletters that are distributed to the GGP mailing list, available at http://www.eas.slu.edu/GGP/ggpnews.html.

2004

(a) **Earth Tides Symposium, Ottawa, Canada**. Because the ETC overlaps almost completely with the GGP community, the ET meetings are equivalent to stand-alone GGP meetings in terms of scientific importance. The papers from this symposium are available as a special publication of the Journal of Geodynamics (Volume 41, 2006) http://www.sciencedirect.com/science/journal/02643707

(b) In October 2004 there was an International Symposium on Remote Sensing, held on Jeju Island, Korea and organized by the Geohazard Information Laboratory of Sejong University. Among the papers presented, several were from GGP and GRACE perspectives and these are available in the Korean Journal of Remote Sensing, Vol. 21 (1), February 2005.

(c) A special issue of Journal of Geodynamics (Volume 38, 2004) was published to summarize the achievements of the first 6-year phase of GGP. It can also be accessed from the Science Direct website above.

2006

(a) **GGP Workshop, Jena**. A workshop on “Analysis of Data from Superconducting Gravimeters and Deformation Observations regarding Geodynamic Signals and Environmental Influences” was held in Jena in March. This brought together GGP members and those working on the environmental influences on gravity. The proceedings and papers from this workshop are available online through ICET (Bulletin d’Informations des Marees Terrestre) at http://www.astro.oma.be/ICET/bim/141.html

2007

- **(a) GGP Workshop, Taiwan.** The Taiwanese hosted the "First Asia workshop on superconducting gravimetry" in Hsinchu, Taiwan, March 12-15. It had the distinction of being the only workshop (so far) to be held within a tunnel complex only a few meters from the SG room itself (the activities of the conference of course were recorded in the data). The purpose of the workshop was to emphasize the increasing number of SGs in Asia, and to focus attention on scientific problems in this part of the world. Of special interest is the very high uplift rate of Taiwan itself, which is currently to be monitored both by AG and SG measurements. Scientific papers from the workshop can be found under the Scientific Program on the website http://space.cv.nctu.edu.tw/SG/Asia_workshop.html.
- **(b)** Just a mention here of the upcoming series of volumes on the Treatise on Geophysics, Geodesy Volume, edited by T. Herring and G. Schubert. It includes an extensive treatment of SG issues, as well as articles on AGs and other topics of interest to GGP. The volumes will be released at the Fall AGU in San Francisco.

6. Acknowledgements

GGP could not function without the cooperation of the many dedicated individuals who maintain their instruments and willingly share their data with the scientific community through the GGP database. We are also indebted to Bernard Ducarme for his unfailing support of GGP at ICET, and his assistants Leslie Vandercoilden and Marc Hendricx. His absence next year will be strongly felt within GGP. Of equal note is the recently announced retirement of Tadahiro Sato who has pioneered many new ideas and projects in gravimetry, particularly with SGs. His place at the head of the Japanese SG database operations is taken by Yoshiaki Tamura. We also thought Jurgen Neumeyer had retired, but apparently not. He has been instrumental (no pun intended) in helping the installation of new SGs.

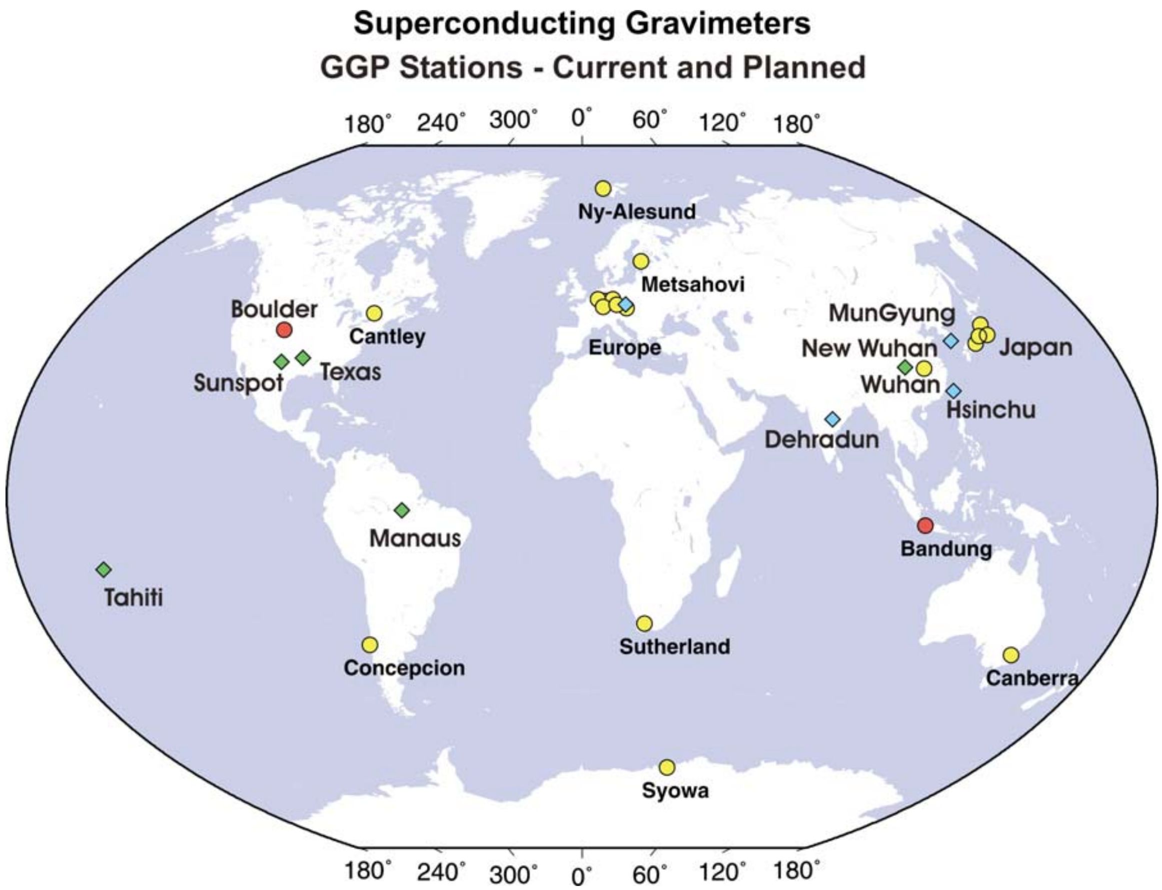


Figure 1 (a). The worldwide distribution of SGs. Stations in yellow are operating and those in red have been retired. Diamonds are in new (lt blue) or planned (green) locations.

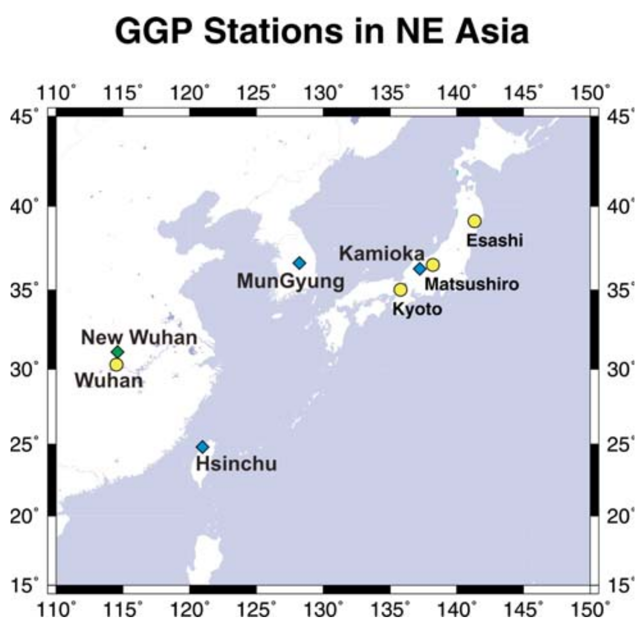


Figure 1 (b). Stations in Asia

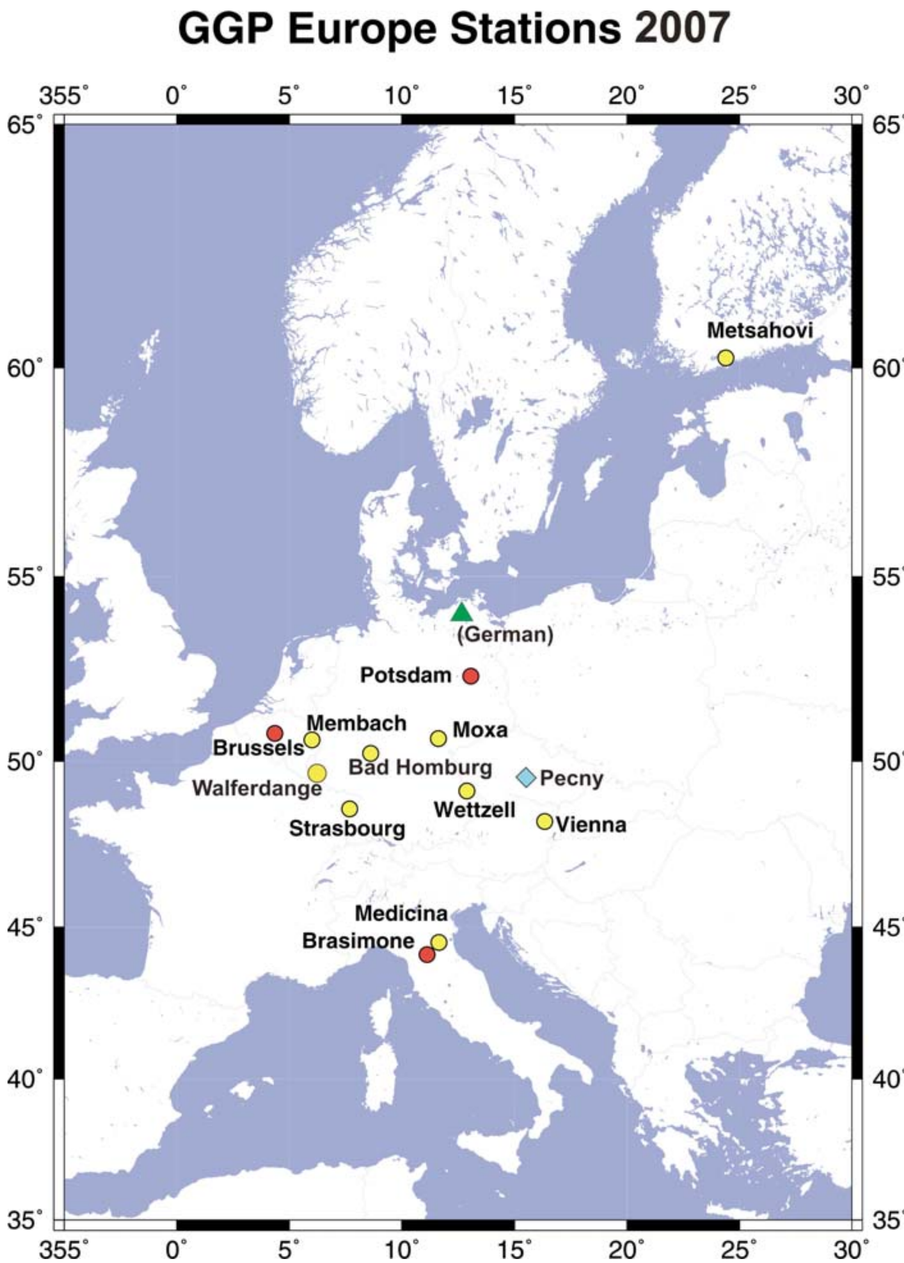


Figure 1 (c). Stations in Europe (excluding Ny-Alesund)

Commission 3: Earth Rotation and Geodynamics

REPORT OF ACTIVITIES
(2003–2007)

President: Véronique Dehant (Belgium)
Vice President: Mike Bevis (USA)

1. Overview

The reorganization of the IAG took effect at the IUGG meeting in Sapporo in 2003. The new Commission 3 is dealing with Earth rotation and geodynamics activities.

The Advisory Board of Commission 3, created in 2003, has been contacted many time in order to provide comments and advices to the President and to represent the interests within the commission. The Advisory Board confers via email, and has had formal meetings each year. The Advisory Board consists of the following members (their responsibilities are also given below):

President:	Véronique Dehant
Vice-President:	Mike Bevis
Past Presidents:	Clark R. Wilson and Martine Feissel-Vernier
Heads of Sub-commissions:	
Sub-commission 3.1 Earth Tides:	G. Jentzsch (Germany)
Sub-commission 3.2 Crustal Deformations:	M. Poutanen (Finland)
Sub-commission 3.3 Geophysical Fluids:	R. Gross (USA)
Head of Inter-commission Project:	
Inter-commision project 3.1 GGP:	D. Crossley (USA)
Inter-commision project 3.2 WEGENER:	S. Zerbini (Italy)
Commission 3 representatives:	
To inter-commision commitee on Theory:	T. Van Hoolst (Belgium)
To inter-commision commitee on Planetary Geodesy:	O. Karatekin (Belgium)
To inter-commision project 3.1 GGP[1]:	D. Crossley (USA)
To inter-commision project 3.2 WEGENER:	T. Van Dam (Luxembourg)
To IERS:	C. Wilson (USA)
To IAU commission 19:	M. Rothacher (Germany)
Member at large:	
Kosuke Heki (Japan)	

[1] GGP = Global Geodynamics Project

The commission is co-sponsoring two WGs

1. on “Theory of crustal deformations” of ICC on Theory (Chair: Heki Sensei),
2. on “Differential INSAR” of Commission 4 (Chair: Xiaoli Ding).

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

The activities in scientific research related to Commission 3 are mostly developed in the sub-commission report, with one important exception, the new research in the frame of precession and nutation. This research has been initiated by the Descartes Prize received by the Nutation Consortium in 2003. The money (300 000 €) has been dedicated to young scientist proposals. A call for proposals has been sent out at the beginning of 2004, and a second call in 2006 and about 20 proposals have been selected for either PhD students or postdocs for periods of work ranging from 3 months to 2 years. Additionally, money has been dedicated to travel support for participation in meetings for disfavored countries.

In addition to this, the activities of these last two years include

1. Participation in special meetings related to geodynamics and Earth rotation, such as Journées Systèmes de Références Spatio-temporels in Paris, ECGS Chandler Wobble Workshop in Luxembourg (on ‘Forcing of polar motion in the Chandler frequency band: a contribution to understanding inter-annual climate variations’**).** One important concern related to our commission is the impact of the 2005 tsunami on geodynamics. Sessions at AGU and EGU meetings have been totally dedicated to that subject. The IAG General Assembly in Cairns contains as well many papers on that subject.
2. Participation in the IAG Project Global Geodetic Observing System (GGOS). Some of the Descartes fellows have a GGOS flag on their project.
3. Linking the Sub-Commission together: we have encouraged joint sub-commission meetings. The three Presidents of the sub-commissions have agreed to have a common Symposium in 2008 in Jena, Germany.
4. Linking Commission 3 with its sister commission of the IAU, Commission 19 on ‘Earth Rotation’. This link has been done using the website of both commissions and through the sharing of information, easy to do for this term as the presidents of both commissions are the same person (V. Dehant).

5. Encouraging and stimulating the services related to Commission 3. This has again been performed by using money of Descartes Prize as several proposals have the objectives to help the IERS Product Center on Global Geophysical Fluids.

In addition to this, following the adoption of new resolutions on the definition of the way to pass from the terrestrial reference frame to the celestial reference frame, using the Non Rotating Origin (NRO), the Royal Observatory of Belgium has decided to dedicate some money to perform 3D representations which explain it. These 3D representations are on the web. Some explanations have been added. The new link between the frames takes full advantage of precision available with modern VLBI and other space techniques. The new precession-nutation models are an important element of high precision geodesy that enables the study of geodynamics.

The web pages of Commission 3 are: http://www.astro.oma.be/IAG/

2. Report of Sub-commission 3.1 on 'Earth Tides'

Author: G. Jentzsch

After taking over the presidency from Shuzo Takemoto in July 2003, Gerhard Jentzsch asked Spiros Patiatakis to become Vice-President of Earth Tides Sub-Commission (ETsC), and Olivier Francis to continue as Secretary. They prepared the 15th International Symposium in Ottawa, August 2004. The symposium was a successful event, although only about 80 participants took part. The proceedings, entitled 'Earth Tides and Geodynamics – Probing the Earth at Subseismic Frequencies' (Jentzsch G., Editor), appeared as a special volume of the Journal of Geodynamics, Vol. 41, Nos. 1-3, January-April 2006, 368 p.

Already in 2004, another special issue, entitled 'Time Varying Gravimetry, GGP, and Vertical Crustal Movements' (Jentzsch G., Crossley D., Hinderer J., and Takemoto S., Eds.), was published in Journal of Geodynamics, Vol. 38, Nos. 3-5, October/December 2004, 501 p. This volume was the outcome of the session G4 during the EGU meeting in 2003, augmented by additional papers.

In April 2004, Gerhard Jentzsch participated in the celebration of the 70th birthday of Houtze Hsu in Wuhan, China. He presented a talk with the title "Earth Tides – a Beautiful, but Remote Subject?" It was printed in a comprehensive volume on 'Progress in Geodesy and Geodynamics' (1100 pages, edited by H.-P. Sun), already completed at the event. H.T. Hsu was a former President of the Earth Tides Commission (previously called-so), and he opened China to Earth tide research. He especially tied strong connections to European scientists and their institutions.

The SC3.1 has three working groups which continued during the period 2003-2007:

- Earth Tides in Geodetic Space Techniques, co-chaired by H. Schuh and Wu Bin,

- Analysis of Environmental Data for the Interpretation of Gravity Measurements, co-chaired by C. Kroner and G. Jentzsch, and

- Gravitational Physics, chaired by L. Mansinha.

A new working group was created:

- Precise Tidal Prediction, chaired by Y. Tamura

During the EGU General Assembly in Vienna in April 2005, the sub-commission had a joint GGP and ETsC meeting. During the week prior to the EGU conference in 2006, between March 27 and 31, a combined meeting of the working groups on ‘Analysis of Environmental Data for the Interpretation of Gravity Measurements’ and the new WG on ‘Precise Tidal Prediction’ together with a GGP workshop was organized in Jena. The sub-commission received funding of this meeting to support some participants. There were nearly 40 participants from all over the world (Canada, USA, Japan, China, South Korea, Egypt, as well as different European countries). All presentations were available on the website of the institute in Jena, and they were published in BIM (Bulletin d’Information des Marées terrestres).

During he last Earth Tide Symposium in Ottawa, 2004, it was decided that the 16th International Symposium on Earth Tides will not only be held in Jena in 2008, but it should be organized as a joint meeting of all sub-Commissions of Commission 3 including inter-commission projects and study groups. Taking into account that more than 50% of all presentations were not specifically on Earth tides, but on geodynamics and environmental effects as well as on instrumental topics, the sub-commission already agreed in Ottawa to extend the scope of the next symposium accordingly. This symposium will take place during the first week in September 2008 (Sept. 5-9). The motto of the symposium will be “New Challenges in Earth Dynamics”. A flyer will be distributed during the IUGG-General Assembly in Perugia, 2007.

Besides the preparations of the next symposium another important task covered some of the sub-Commission activities: There are discussions concerning the move of ICET to another place, because the Royal Observatory of Belgium will not continue to host ICET after Bernard Ducarme’s retirement at the end of this year. Several potentially interested institutions were asked, but the decision will be possible only during the IUGG General Assembly, because the offered conditions of two remaining applicants are not yet clear.

3. Report of Sub-commission 3.2 on ‘Crustal Deformation’

Author: M. Poutanen

Members of the directing board:

Markku Poutanen (Chair), Jim Davis, Kosuke Heki, John Manning, Janusz Sledzinski, Susanna Zerbini

General objectives of the Sub-Commission 3.2

- to study tectonic motions, including plate deformation;
- to study postglacial rebound, but also glacial dynamics and glacial isostatic adjustment in the currently glaciated area of the Earth, as well as the water and ice mass balance;
- to study local crustal movements, some of which could be potentially hazardous
- to study sea-level fluctuations and changes in relation to vertical tectonics along many parts of the coastlines and in relation to environmental fluctuations/changes affecting the geodetic observations;
- to promote, develop and coordinate international programs related to observations, analysis and data interpretation for the three fields of investigation mentioned above;
- to promote the development of appropriate models.

The SC3.2 comprises sub-entities or working groups corresponding either to different geographical regions or different important and actual topics involved in the field of the SC studies. Currently, there exists the Permanent Working Group on 'Geodynamics of the Central Europe'.

The steering committee had a meeting during the IAG Dynamic Planet assembly in Cairns, August 2005. Participants were Markku Poutanen, Susanna Zerbini, Janusz Sledzinski, John Manning and Luisa Bastos (WEGENER). Topics included future plans of the group, and connections to the WEGENER group.

Web pages of the IAG SC3.2 are in http://IAGSC32.fgi.fi.

Permanent working group Geodynamics of the Central Europe

Permanent Working Group on '*Geodynamics of the Central Europe*', (reported by Janusz Sledzinski, Poland) has continued studies on geotectonic regions of Central Europe. The formal membership list of the WG includes 29 scientists from 12 European countries. The programme of the WG (Plan of Action for 2003-2006) includes the following subjects:

- Geodetic and geodynamic programmes: CERGOP = Central Europe Regional Geodynamics Project, CEGRN = Central European GPS Reference Network Consortium, Post-UNIGRACE action = Unification of gravity system in Central and Eastern Europe, and several local geodynamics projects. These include monitoring of recent crustal movements in Eastern Alps and the North and Eastern Adriatic, geodynamics of the Pannonian Basin, Tatra Mountains, Northern Carpathians and the Balkan Peninsula.
- Working Group on University Education Standards;
- Working Group on Satellite Navigation Systems;

- Cooperation CEI Section C "Geodesy"– European Geophysical Society (EGS) / European Geosciences Union (EGU).

The results of the CERGOP and other CEI projects are released for the IAG scientific groups dealing with geodynamic investigations. The reports of the group can be found on SC3.2 web page (http://IAGSC32.fgi.fi).

Connections to other groups, memberships

Contacts between SC3.2 and WEGENER (Working group of European Geoscientists for the Establishment of Networks for Earth science Research, chaired by L. Bastos) continued. Zerbini is a member of the WEGENER governing board. Zerbini and Poutanen participated in the board meeting of WEGENER in Vienna in April 2005 and were members of the Program Committee for the WEGENER Assembly in Morocco 09/2004 and Zerbini for the Assembly in Nice 9/2006.

Markku Poutanen is the representative of the Commission 3 in the GGOS (IAG Project Global Geodetic Observing System) Steering Committee, and Susanna Zerbini is the GEO Committee representative. GGOS will be the most important single effort in geodesy in the coming decades, thus contributing also on the crustal deformation studies.

Presidium of the Nordic Geodetic Commission has established a task force to prepare the plans for the NGOS – Nordic Geodetic Observing System. The plan will follow the guidelines and principles of the GGOS (Global Geodetic Observing System) of IAG. NGOS will be a regional implementation of GGOS. Markku Poutanen is the chairman of the Task Force.

Markku Poutanen participates on the IPY (International Polar Year) geodynamics plan POLENET: Polar Earth Observing Network. It is an international plan, chaired by Terry Wilson of OSU, and accepted as an IPY project. One of the goals is to study present-day motions on Antarctica.

Future plans

A joint symposium of SC3.1, 3.2 and 3.3 is planned to be held in September 2008 in Jena. Chairman of the SC3.1, Gerhard Jentzsch is the chairman of the organizing committee.

A proposal was prepared for the International Lithosphere Program (ILP). The ILP was established in 1980 by the International Council of Scientific Unions (ICSU) at the request of the International Union of Geological Sciences (IUGS) and the International Union of Geodesy and Geophysics (IUGG). The proposal, DynaQlim (*Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas*) was submitted to the ILP in 2007 and will be discussed in the IUGG Perugia. If accepted, it will become a task force of the ILP, and it will be a multi-disciplinary project connecting both IUGS and IUGG. Markku Poutanen is coordinating the proposal, and there are more than 30 scientists from ten countries in the proposal. DynaQlim will be an inter-disciplinary project for studying the relationship between glacial isostatic adjustment (GIA), upper mantle structure, dynamics and Quaternary climate.

4. Report of Sub-commission 3.3 on 'Geophysical Fluids'

Author: R. Gross

Directing Board

President: Richard Gross (USA)
Vice President: Aleksander Brzezinski (Poland)
Member: Ben Chao (Taiwan)

Terms of Reference

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.

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.

Report

Investigating the impact of geophysical fluids on the Earth's gravity, rotation, and shape continues to be a very active area of research as judged by both the number of special sessions devoted to this topic at the major EGS, EGU, AGU, and IAG conferences that were held during 2003 to 2007 and by the successful Chandler wobble workshop that was held during April 21–23, 2004 in Luxembourg at which geophysical fluid excitation of the Chandler wobble was a major topic of discussion. Special sessions on geophysical fluids will continue to be organized at future EGU, AGU and IAG conferences. In addition, at the invitation of Gerhard Jentzsch, President of IAG Sub-Commission 3.1 on Earth Tides, Sub-Commissions 3.2 and 3.3 and the Inter-Commission Project on the Global Geodynamics Project will participate in and co-organize the next Earth Tide Symposium to be held in Jena, Germany in 2008. Holding such a joint symposium will strengthen interactions between these Sub-Commissions and Inter-Commissions of the IAG.

Sub-Commission 3.3 continues to be a very active participant in the Global Geophysical Fluids Center (GGFC) of the IERS. The President of Sub-Commission 3.3 (R. Gross) is the head of the GGFC Special Bureau for the Oceans, and a member of its Directing Board (B. Chao) was the former head of both the GGFC Special Bureau for the Mantle and of the GGFC itself. B. Chao continues to participate in the GGFC as a member of the Special Bureau for the Mantle, of the Special Bureau for Hydrology, and of the Special Bureau for Tides. The data sets archived at the GGFC Special Bureaus continue to expand, providing a continuing source of data for present and future investigations of the impact of geophysical fluids on the Earth's gravity, rotation, and shape.

Sub-Commission 3.3 also actively participates in the IAG's Global Geodetic Observing System (GGOS), with the President of Sub-Commission 3.3 (R. Gross) being the chair of the GGOS Science Panel. Variations in the transport of the global geophysical fluids are major causes of the variations in the geodetic parameters of the Earth that are being measured by GGOS. The GGOS measurements can therefore be used to gain a greater understanding of the transport of the geophysical fluids and of their interaction with and impact on the solid Earth.

5. Report of intercommission project 3.1 on Global Geodynamics Project 'GGP'

Author: D. Crossley and J. Hinderer

Directorate

D. Crossley (Chair), J. Hinderer (Secretary).

Terms of Reference

The GGP project began on 1 July 1997 and Phase 1 ended on 1 July 2003. A continuation of the project, GGP Phase 2, 2003-2007 is being reported here. The general aspects of GGP and its organization were outlined in detail in our previous report (Sapporro, 2003) and need not be included here.

The main purpose of GGP was, and remains, to record the Earth's gravity field with high accuracy at a number of worldwide stations using superconducting gravimeters (SGs). An important requirement is the frequent monitoring of absolute gravity at each site to co-determine secular changes. A list of publications related to GGP and SGs is available at the GGP website, as are a number of newsletters published for the benefit of the community. The main website is http://www.eas.slu.edu/GGP/ggphome.html. The data is being used in an extensive set of studies of the Earth, ranging from global motions of the whole Earth such as the Chandler wobble to surficial gravity effects such as atmospheric pressure and groundwater. The SG stations are run independently by national groups of scientists who send data each month to the GGP database at the International Centre for Earth Tides (ICET) in Brussels.

Report

1. Stations

We show in the Figure 1 the location of most of the stations in the GGP network for the decade 1997-2007. The cluster of stations in Europe and N.E. Asia are shown separately.

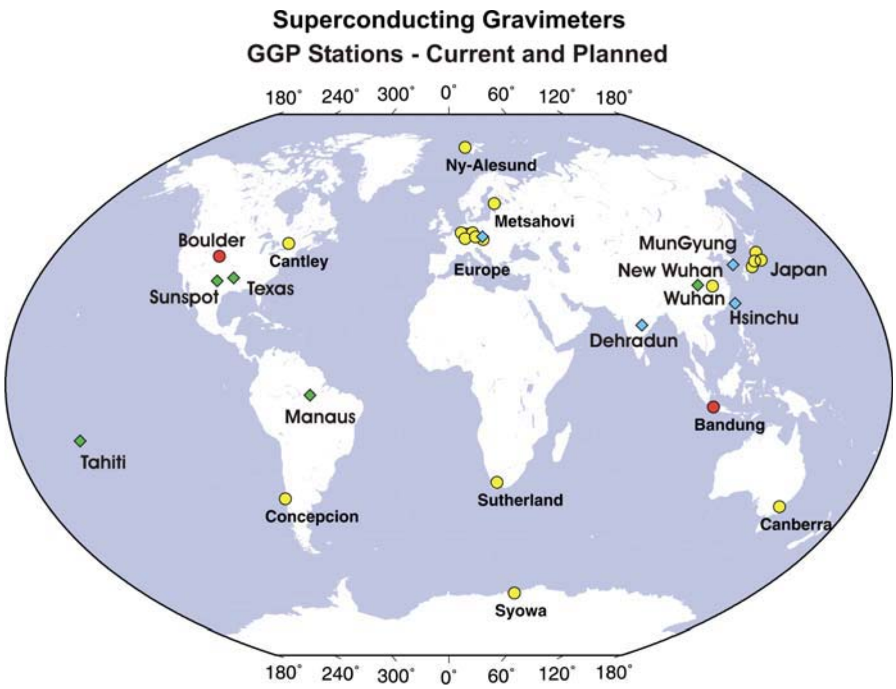
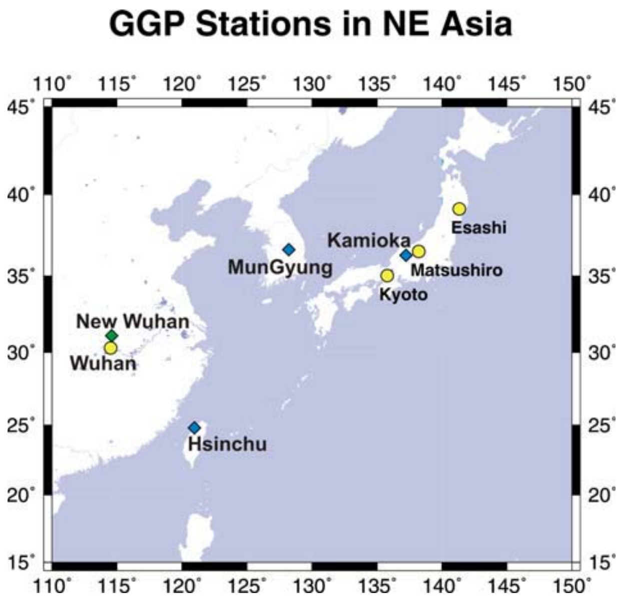


Figure 1 (a). The worldwide distribution of SGs. Stations in yellow are operating and those in red have been retired. Diamonds are in new (lt blue) or planned (green).



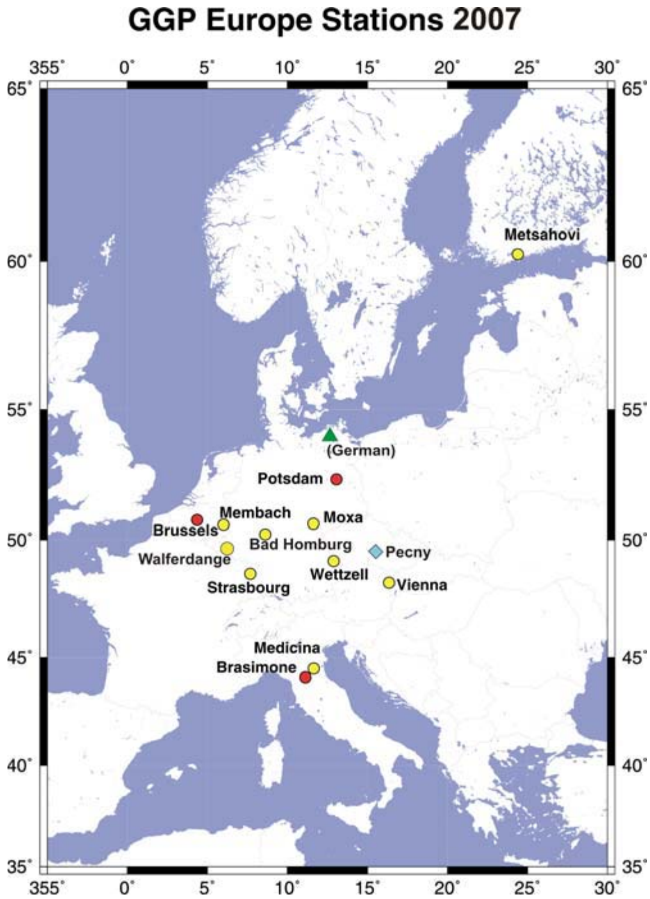


Figure 1 (b). Stations in Asia

Figure 1(c). Stations in Europe (excluding Ny-Alesund)

Two stations in the network stopped recording during the current reporting period (2003-2007). These were Bandung, Indonesia, and Boulder, Colorado. The situation in Bandung was instrument failure due to a sever storm that flooded the facility and lifted the instrument off its supporting pillar. The internal components in the dewar were OK, but the damage was too severe to be easily or quickly repaired. There has been talk of re-constituting a station in Indonesia, but in another location. The station and instrument are run by Kyoto University, Japan.

The situation is Boulder is different. Due to the retirement of key personnel in Boulder, the maintenance of the data acquisition failed in May 2004 and no further data has been available. NOAA has ownership of the instrument, and it is still functioning according to some reports, but we are unsure of its future, whether in Boulder or elsewhere. Useful suggestions about transferring it to Alaska, or to another site in the US have been discussed within GGP and passed on to NOAA.

Two other stations have had troubles that have resulted in data interruptions. One is the instrument in Kyoto that has had tilt problems for a long time that apparently have not been fixed. Also the instrument in Syowa, Antarctica has had some drift problems and we have not seen data for some time.

Thankfully all other stations in the network are functioning well and sending data to the GGP database at ICET. Most of these stations have now brought themselves up to date at least into early 2007. Walferdange has so far not sent data to GGP.

Two new stations have been recording since 2005: MunGyung in S. Korea, and Kamioka in Japan. The former is run by J.-W. Kim of Sejong University, Korea, also associated with the geodesy group at Ohio State University. Station Kamioka was installed in the high technology physics underground complex for neutrino detection in central Japan. It is run jointly by Kyoto University and NAO Mizusawa. Both of these SGs have data sets not yet transferred to ICET. Two new instruments were installed in Hsinchu, Taiwan, by C. Hwang and colleagues of the National Chiao Tung University. One had to be returned to GWR for repairs but is expected back imminently. The other is recording well in an underground facility in Hsinchu and we have seen preliminary data.

Finally, two very recent installations were completed early this year. The first is at the historic Geodetic Observatory in Pecny, Czech Republic. The second was installed at the Wadia Institute of Himalayan Geology in Dehradun, India to study earthquake precursory signals in conjunction with other geophysical methods. Both installations were successful and we look forward to receiving their data.

As for future stations, we are anticipating the installation of an SG in Manaus, Amazon Basin, as part of the effort of GFZ (Potsdam) to characterize the very large annual hydrology signal over the basin seen by the GRACE satellites. The anticipated date is Fall 2007. We also know of several other planned locations identified on the maps. There will be an SG in Texas to monitory hydrology (C. Wilson, U. Texas, Austin), and a second instrument in Wuhan to be installed by the Chinese Bureau of Seismology. The installation in Tahiti is in the works, with a second instrument in the southern US at Sunspot, the site of the lunar laser ranging facility, also being planned. The German group is planning a station on the Baltic coast, see Figure 1(c).

Overall the list of stations will soon reach 30, of which at least 25 should be functioning within the next year or two.

2. GGOS

Along with many other IAG organizations, GGP will contribute data to GGOS as part of the extensive range of goals identified in the GGOS Reference Document (GGOS-2020). The combined use of SGs and AGs to monitor the long term changes in the surface gravity field has now become commonplace and we look forward to the opportunity to see SGs installed at more of the fiducial (or core) stations of the proposed GGOS ground-based network. One of the important functions of ground-based data will be to constrain the position of the Earth’s Center of Mass as a fundamental variable in the determination of the gravity field for space and satellite missions.

Of the current GGP stations, only a few are installed at space-geodetic stations (e.g. Wettzell, Tigo Concepcion, Ny-Alesund, Sutherland). Many of the other installations are doing hydrology-based research, or are functioning for a specific purpose but yet recording useful data that can be widely used (examples given later).

3. ICET

As will be reported elsewhere, the future location and organization of the International Center for Earth Tides is being discussed, and may be decided at meetings at the IUGG. GGP has a a special interest in the outcome, as ICET has played a strong supporting role for the processing of GGP data, as well as other services related to GGP. We have, of course, contributed some ideas to the ETC and others in the IAG.

4. IRIS

We have had a project now for almost 2 years, to get GGP raw data (recorded at 1, 2, or 5 sec sampling) into the global seismic database IRIS (Incorporated Research Institutions for Seismology). There have been some difficulties in specifying the complete SG instrument response in the very precise format required by seismology. To a geodesist, the issue is very simple: what is the calibration (or scale) factor? This means the DC response of the instrument to convert volt to acceleration. This is a topic with a long history, and it is well known that SGs can be calibrated to better than 0.1% in amplitude (approaching 0 .02% in special experiments). But the phase response at high frequencies can only be accurately measured using special equipment not normally available at SG stations. Information on the technique is available at http://www.eas.slu.edu/GGP/phasecal.html. We have struggled somewhat with the issue and this has delayed the project.

Happily we now have the means to finalize this issue with the help of real seismologists. This will enable us to follow the example of station Membach. Through the efforts of M. V. Camp, data from the MB SG (special seismic output) has been sent to IRIS for more than a year. We are aided in this venture by GFZ Potsdam, and we promise some real results from other GGP stations soon.

5. Workshops and Special Publications

GGP normally meets once a year in connection with a major meeting or as a stand-alone workshop. Occasions are noted for the record, since Sapporo, 2003. As always, the shorter meetings are for business only, while the specialized workshops (in 2004, 2006) are the major opportunity to exchange scientific information.

All events are reported in GGP Newsletters that are distributed to the GGP mailing list, available at http://www.eas.slu.edu/GGP/ggpnews.html.

2004

(a) **Earth Tides Symposium, Ottawa, Canada**. Because the ETC overlaps almost completely with the GGP community, the ET meetings are equivalent to stand-alone GGP meetings in terms of scientific importance. The papers from this symposium are available as a special publication of the Journal of Geodynamics (Volume 41, 2006) http://www.sciencedirect.com/science/journal/02643707

(b) In October 2004 there was an International Symposium on Remote Sensing, held on Jeju Island, Korea and organized by the Geohazard Information Laboratory of Sejong University. Among the papers presented, several were from GGP and GRACE perspectives and these are available in the Korean Journal of Remote Sensing, Vol. 21 (1), February 2005.

(c) A special issue of Journal of Geodynamics (Volume 38, 2004) was published to summarize the achievements of the first 6-year phase of GGP. It can also be accessed from the Science Direct website above.

2006

(a) **GGP Workshop, Jena**. A workshop on "Analysis of Data from Superconducting Gravimeters and Deformation Observations regarding Geodynamic Signals and Environmental Influences" was held in Jena in March. This brought together GGP members and those working on the environmental influences on gravity. The proceedings and papers from this workshop are available online through ICET (Bulletin d'Informations des Marees Terrestre) at http://www.astro.oma.be/ICET/bim/141.html

2007

(a) GGP Workshop, Taiwan. The Taiwanese hosted the "First Asia workshop on superconducting gravimetry" in Hsinchu, Taiwan, March 12-15. It had the distinction of being the only workshop (so far) to be held within a tunnel complex only a few meters from the SG room itself (the activities of the conference of course were recorded in the data). The purpose of the workshop was to emphasize the increasing number of SGs in Asia, and to focus attention on scientific problems in this part of the world. Of special interest is the very high uplift rate of Taiwan itself, which is currently to be monitored both by AG and SG measurements. Scientific papers from the workshop can be found under the Scientific Program on the website http://space.cv.nctu.edu.tw/SG/Asia_workshop.html.

(b) Just a mention here of the upcoming series of volumes on the Treatise on Geophysics, Geodesy Volume, edited by T. Herring and G. Schubert. It includes an extensive treatment of SG issues, as well as articles on AGs and other topics of interest to GGP. The volumes will be released at the Fall AGU in San Francisco.

6. Acknowledgements

GGP could not function without the cooperation of the many dedicated individuals who maintain their instruments and willingly share their data with the scientific community through the GGP database. We are also indebted to Bernard Ducarme for his unfailing support of GGP at ICET, and his assistants Leslie Vandercoilden and Marc Hendricx. His absence next year will be strongly felt within GGP. Of equal note is the recently announced retirement of Tadahiro Sato who has pioneered many new ideas and projects

in gravimetry, particularly with SGs. His place at the head of the Japanese SG database operations is taken by Yoshiaki Tamura. We also thought Jurgen Neumeyer had retired, but apparently not. He has been instrumental (no pun intended) in helping the installation of new SGs.

6. Report of intercommission project 3.2 on 'WEGENER'

Author: S. Zerbini

7. Report of intercommission 3.2 on 'WEGENER'

Author: S. Zerbini

Members

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Representative of Commission 1: Alessandro Caporali
Representative of Commission 3: Tonie van Dam

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:

- Continue as 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. GEODAC is promoting the use of state-of-the-art methodologies and latest results/solutions by supporting the scientific community when requested. GEODAC already contains most of the functions that were planned to be implemented. Examples 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. At present, GEODAC is processing data of the GPS stations of the Iberian area. GPS data from episodic campaigns performed in Iberia, Italy and Morocco are already stored and available for access. Log utilities to describe the properties of the GPS stations according to the IGS template were implemented. A forum where the GEODAC users can post questions and suggestions was also created. A link to other geodata sources, namely NEIC (National Earthquake Information Center) was already established. Additionally, GEODAC can support teams that do not have powerful processing capabilities. In spring 2007, 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 aims 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).
- 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;
- 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 conference, hosted by Géosciences Azur, CNRS-University of Nice, took place on September 4-7, 2006, in Nice (France). The next conference will take place in Darmstadt (Germany) at the Conference Center of the Darmstadt University of Technology, on September 15-18, 2008 and it will be hosted by the Institut für Physikalische Geodäsie, of the Technische Universität Darmstadt.

To keep close contacts among the Directing Board members and to coordinate the activities, teleconferences are being held regularly.

IAG Commission 3 “Earth Rotations and Geodynamics”
Subcommission 3.2 “Crustal Deformation”

PROGRESS REPORT

on

ACTIVITIES OF THE IAG PERMANENT STUDY GROUP “GEODYNAMICS OF THE CENTRAL EUROPE”

Janusz Sledzinski
Chairman of the
of the Subcommission 3.2 “Crustal Deformation”
of the Commission 3 “Earth Rotations and Geodynamics”;
International Coordinator of the CEI WGST Section C “Geodesy”.

REPORT COMPILED FROM CONTRIBUTIONS
SUBMITTED BY FOLLOWING WG MEMBERS:
A.Caporali, P.Dumitru, M.Fadur, I.Fejes, J.Hefty, G.Milev, M.Mojzes, T.Rus, G.Schmitt, K.Vassileva, F.Zablotskij

Report presented at the General Assembly
of the International Association of Geodesy
Perugia, Italy
2-13 July 2007

ACTIVITIES OF THE IAG PERMANENT STUDY GROUP "GEODYNAMICS OF THE CENTRAL EUROPE"

IAG Subcommission 3.2 "Crustal Deformation" of the Commission 3 "Earth Rotations and Geodynamics"

PROGRESS REPORT

Janusz Sledzinski
Chairman of the IAG Permanent Working Group "Geodynamics of the Central Europe"
of the Subcommission 3.2 "Crustal Deformation"
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A.Caporali, P.Dumitru, M.Fadur, I.Fejes, J.Hefty, G.Milev, M.Mojzes, T.Rus, G.Schmitt, K.Vassileva, F.Zablotskij

Abstract.

The Report includes concise information on recent geodetic and geodynamic projects that are realised by the members of the IAG WG "Geodynamics of the Central Europe" in the frame of different international projects. Most of the members of the Group cooperate with the CEI (Central European Initiative) WG Science and Technology Section C "Geodesy". This is an organisation of 17 European countries that has a wide geodetic and geodynamic programme coinciding with what is listed in the charter duties of the IAG Permanent Working Group. Several international projects realised within the CEI Section C "Geodesy" were financially supported by the European Commission (CERGOP-1, CERGOP-2, UNIGRACE). In this Report there are outlined the main achievements of the international geodynamic project CERGOP (Central Europe Regional Geodynamics Project) realised within the time 1994 –2006. The establishment and maintenance of the Central European GPS Reference Network (CEGRN) consisting of about 100 sites on the territory of European 14 countries was performed with an accuracy of 2-4 mm in horizontal coordinates and 4-8 mm in vertical coordinates. Since 1994 nine epoch five-day monitoring satellite GPS CEGRN campaigns were carried out in 1994, 1995, 1996, 1997 (CERGOP-1) and 1999, 2001, 2003, 2005 and 2007 (CERGOP-2). Second phase of the project CERGOP was concluded in 2006.

Another CEI project UNIGRACE (Unification of gravity systems in Central and Eastern Europe) consisted in establishing seventeen absolute gravity stations covering the area from the Baltic Sea to Adriatic and the Black Sea forming the excellent frame for connection of all national gravimetric networks and providing the unified precise gravity frame in Central and Eastern Europe. The gravity observations were made by five absolute gravimeters from Austria, Finland, France, Germany and Poland. Two observation campaigns of the Project UNIGRACE have been successfully concluded (1998/1999 and 2000/2001).

The programme of activities of the Section C includes also the activities of the Working Group on Satellite Navigation Systems and actions realised by the Working Group on University Education Standards. The close cooperation links with EGS/EGU (European Geophysical Society/European Geosciences Union) existing since 1997 are outlined.

1. LIST OF THE MEMBERS OF THE IAG PERMANENT WORKING GROUP "GEODYNAMICS OF THE CENTRAL EUROPE"

Each member of the Permanent Working Group is involved in and is responsible for a definite area of the activities.

- Janusz Sledzinski (Poland) - Chairman of the Subcommission;
- Jozsef Adam (Hungary) - links between national geodetic/geodynamic networks and EUREF;
- Asim Bilajbegović (Bosnia and Herzegovina) – geodynamics of Dinarides and Adriatic Sea;
- Stefan Cacoń (Poland) - geodynamic research of the region of Sudetes;
- Alessandro Caporali (Italy) – geodynamics of the area covered by the CERGOP;
- Istvan Fejes (Hungary) - links between CERGOP and other geodynamic IAG projects;
- Dumitru Ghiţău (Romania) - information on kinematics of the Romania regions;
- Jozef Glazek (Poland) – information on new studies on geologic structures in Central Europe;
- Gyula Grenerczy (Hungary) - geodynamic investigations in the Pannonian Basin;
- Jan Hefty (Slovakia) - problems of coordinate systems, EUREF, ITRF and ETRF;
- Dumitru Ioane (Romania) - joint research of geodesists, geologists and geophysicists in Romania;
- Claudio Marchesini (Italy) - information on research of Eastern Alps and the North and Eastern parts of Adriatic Sea;
- Iginio Marson (Italy) - interregional gravimetric connections, gravimetric projects of IAG/CEI;
- Damir Medak (Croatia) - information on the research in the geodynamic test area Plitvice Lakes;
- Georgi Milev (Bulgaria) - information on geodynamic research in Balkan Peninsula;
- Marcel Mojzeš (Slovakia) - geodynamics of the Tatra Mountains;
- Medzida Mulić (Bosnia and Herzegovina) – geodynamics of the region of Bosnia and Herzegovina;
- Vasile Nacu (Romania) – geodynamic research of the Romanian region;
- Peter Pešec (Austria) - geodynamic use of CEI permanent GPS stations within IGS programmes;
- Bosko Pribičević (Croatia) - information on the research in the geodynamic test area Plitvice Lakes;
- Jerzy Rogowski (Poland) - geodynamic use of CEI permanent GPS stations within IGS and other IAG programmes;
- Tiberiu Rus (Romania) – contribution of Romanian GPS permanent stations to the Balkan geodynamic investigations;
- Vladimir Schenk (Czech Republic)- information on geophysical and geological research in the region of Sudetes;
- Guenter Schmitt (Germany) - information on kinematics of the Romania regions;
- Jaroslav Šimek (Czech Republic) - problems of homogeneity and time changes of precise levelling networks and vertical datum in Central Europe.
- Guenter Stangl (Austria) - determination of velocity vectors for the area of Central Europe;
- Korneli Tretyak (Ukraine) – geodynamics of the region of the Pik Pop Ivan in Charnohora;
- Keranka Vassileva (Bulgaia), - information on geodynamic research in Balkan Peninsula;
- Francesco Vespe (Italy) – geodynamic research in Central and Eastern part of Mediterranean area, problems of coordinate and height systems;
- Florjan Vodopivec (Slovenia) – geodynamics of Northern Adriatic Sea and Eastern Alps region;
- Fedor Zablotskij (Ukraine) - geodynamics of the Northern Carpathians.

2. GENERAL CHARTER DUTIES OF THE WORKING GROUP

The general charter duties of the Working Group are the following:

- to integrate the geodynamic research in the region of Central and Southern Europe based on high accuracy space geodetic surveys and to provide a precise geodetic reference frame for studies on geodynamics of Central Europe, in particular on areas Pannonian Basin, Bohemian Massif, Teisseyre-Tornquist Zone, Carpathian Orogenic Belt, Subalpine Region and Balkanides;

- to provide a reliable three-dimensional tectonic velocity field covering the Central Europe region and integrate it into hierarchically higher level (i.e. global) tectonic models as well as to prepare and publish geotectonic monographs highlighting and summarizing the latest research and studies on regions under study;
- to contribute to other geodynamic programmes organised and coordinated by International Association of Geodesy related to the region of Central Europe, such as EUREF, WEGENER.
- to support local area geodynamic research, environmental studies, seismic hazard assessment, meteorology etc. in Central Europe region based upon the high accuracy space geodetic measurements carried out on an integrated geodynamic network of permanent GPS stations in CEI countries;
- to coordinate and to integrate the international geodetic and geodynamic programmes supported by IAG and CEI;
- to create close links between running projects of IAG and those of CEI, e.g. CEI CERGOP - Central Europe Regional Geodynamics Project and IGS (International GPS Service) and EUREF (European Reference Frame), use of CEI permanent GPS stations within IGS and other programmes for maintenance of the ETRF and ITRF, etc.;
- to initiate common geodetic and geodynamic projects for the region of Central and Eastern Europe;
- to foster the cooperation among universities and research centres from Central Europe and Western countries in the field of geodesy and geodynamics, promoting actions contributing to the development of innovative technologies and participation of CEI scientists in international IAG research programmes;
- to organise scientific symposia, working conferences and workshops on geodetic, gravimetric, geodynamic programmes and satellite techniques to discuss results and future planned actions (e.g. Working Conferences of the programmes of CERGOP - Central Europe Regional Geodynamics Project, UNIGRACE - Unification of Gravity Systems in Central and Eastern Europe, Symposia "GPS in Central Europe, etc.).

3. CONCISE INFORMATION ON CENTRAL EUROPEAN INITIATIVE

In November 1989 the Foreign Ministers of Austria, Hungary, Italy and Yugoslavia at the conference in Budapest founded an organisation named QUADRAGONALE. A few months later, in April 1990 (Vienna) former Czechoslovakia joined this organisation forming the PENTAGONALE and in July 1991 at the conference of Prime Ministers in Dubrovnik Poland was admitted creating the HEXAGONALE. In July 1992 the HEXAGONALE was renamed as Central European Initiative. Violent political development in Europe, break-up and civil war in Yugoslavia, disintegration of Czechoslovakia, formation of new countries in the region of Eastern and Southern Europe, all these events caused considerable changes in organisation and international cooperation within the Central European Initiative. The current (as on 1.06.2007) status of the CEI membership is the following: Albania, Austria, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Hungary, Italy, Macedonia, Moldova, Poland, Romania, Serbia and Montenegro, Slovakia, Slovenia and Ukraine.

The main objectives of the CEI cooperation are to encourage dialogue and cooperation in the region, to strengthen the stabilisation within the region of Central Europe, to promote all-European integration processes, to bring its non-EU members closer to the European Union and to avoid the creation of new divisions among advanced and less advanced countries as well as to help the Central and Eastern European countries in entering the integrated world by adjusting their multi-lateral relations to Western European standards.

The CEI is an intergovernmental organisation of 17 European member countries operating through the annual meetings (usually in November every year) of the Heads of Government and the Ministers of Foreign Affairs. The annually rotating CEI presidency is assisted by the CEI Executive Secretariat in

Trieste, Italy. It has the legal status of an international organisation and is responsible for the administrative and conceptual support in the preparation and follow-up activities. The CEI Secretariat for CEI Projects is located in the CEI-ES Headquarters in Trieste and maintains a permanent office at the EBRD, London, with the task of assisting the CEI with economic, strategies, investment projects, international events and programmes, including the organisation of the CEI Summit Economic Forum.

Working Groups constitute the basic structural component of the CEI. They plan and approve initiatives, agreements and projects which they promote and complete in cases requiring financing, or which they pass to the National Coordinators or Foreign Ministries for approval and financing. At the moment there are 17 CEI Working Groups organising the international cooperation of all 17 CEI member countries in different fields: Geodesy and other geosciences are represented in the Working Group "Science and Technology". There are three sections: Section A – Geology, Section B – Geophysics and Section C – Geodesy". In this paper we report programmes and achievements just this Section C.

In the international cooperation in geodesy and geodynamics take part almost all CEI member countries. At the moment (as on 1 August 2005) the scientists from thirteen CEI countries are very active and participate for years in many actions initiated and organised by the Section. Up to now four CEI member counties do not participate in realisation of Section C programmes. They are Albania, Belarus, Macedonia and Moldova. We do hope that also these countries would be able to undertake the cooperation in the near future. On the other hand two other non-CEI countries, Germany and Finland, closely cooperate in realisation of CEI geodetic and geodynamic programmes.

4. PROGRAMME OF ACTIVITIES OF THE WORKING GROUP

Very active international cooperation of the WG teams is noted in the following areas:

- **Geodetic and geodynamic programmes**
- **Regional European programmes**:
    - CERGOP = Central Europe Regional Geodynamics Project;
    - CEGRN = (Central European GPS Reference Network) Consortium,
    - Post-UNIGRACE action (Unification of gravity system in Central and Eastern Europe).
- **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;
    - projects realised in bilateral/multilateral agreements of CEI countries, e.g. Czech-Polish-Slovak Cross-Border Studies of Regional Geodynamics (Sudetes, Beskydy, Tatra, Pieniny Mts);
- **Activities of the Working Groups on University Education Standards and on Satellite Navigation Systems**
- **Cooperation with other scientific organisations - European Geophysical Society (EGS)/European Geosciences Union (EGU).**

Below there is given a concise information on the status of realisation of some selected projects and some gained achievements.

5, PROJECT CERGOP (Central Europe Regional Geodynamics Project)

Project CERGOP (Central Europe Regional Geodynamics Project) was initiated in 1993 by the scientists from FÖMI Satellite Geodetic Observatory Penc (Hungary), the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology and the Space Research Centre of the Polish Academy of Sciences. It was approved for realisation by the CEI member countries in May 1993 in Książ Castle, Poland. Eleven countries participated in the first phase of the Project: Austria, Croatia, the Czech Republic, Germany, Hungary, Italy, Poland, Romania, Slovakia, Slovenia, Ukraine. In the years 1995-98 the European Commission supported CERGOP in the frame of the COPERNICUS programme.
The first phase of the Project was concluded in 1998 and the second phase of the Project CERGOP-2 "A Multipurpose and Interdisciplinary Sensor Array for Environmental Research in Central Europe (CERGOP-2/Environment)" was concluded in 2006. The Project was financially supported by the European Commission.

The general objectives of the Project were the following:

- to integrate the geodynamic research in the region of Central Europe based on high accuracy space geodetic surveys and an integrated geodynamic network;
- to provide a precise geodetic frame - so called Central European GPS Reference Network (CEGRN) – for geodynamic research in the region of Central, Eastern and Southern Europe;
- to provide the velocity (displacement) vectors of the area under study;
- to initiate studies on local geodynamics of some areas of Central Europe,
- to collect satellite observations for studies and interpretation of geodynamic interactions in Central Europe;
- to foster the international cooperation among research groups of participating countries;

The programme and scope of work of the second phase of the Project has been considerably enlarged.
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As main achievements of the CERGOP we can mention:

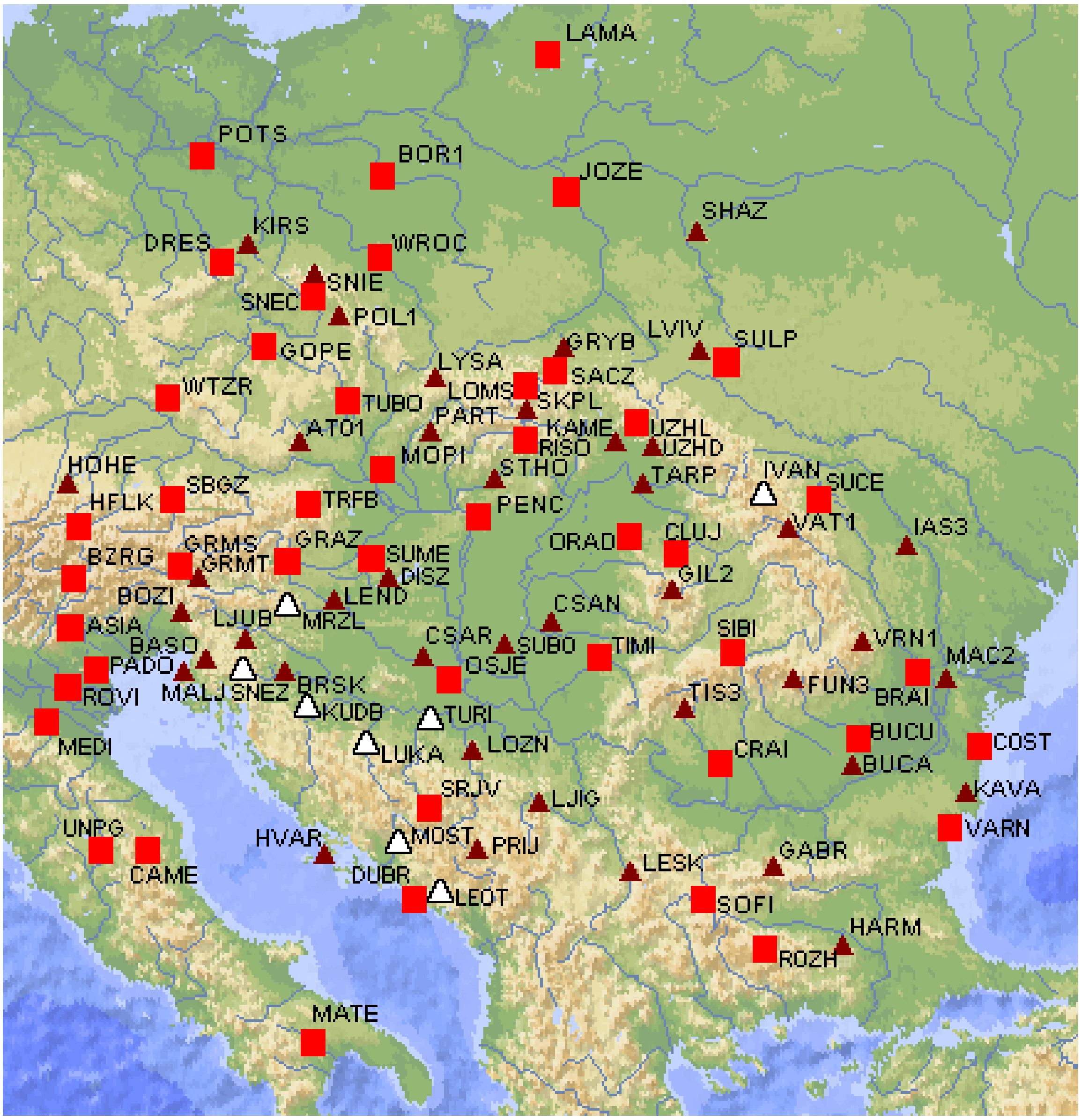
- Establishment of the Central European GPS Reference Network (CEGRN) of the highest accuracy standard - 2-4 mm in horizontal coordinates and 4-8 mm in vertical coordinates; it consisted of 35 European stations in the first phase of the Project and about 100 stations in the second phase. The CEGRN covers the area of the following countries: Austria, Bosnia&Herzegovina, Bulgaria, Croatia, the Czech Republic, Germany, Hungary, Italy, Romania, Poland, Slovakia, Slovenia and Ukraine (about 15% of the territory of Europe). About 50 % of the CEGRN stations will receive permanent status.
- Calculation of velocity vectors for Central European stations; the monitoring campaigns of CEGRN provided already significant kinematic results about intraplate tectonic motions in Central Europe,
- At the end of the first phase of the project there ware published eight geotectonic monographs of the European regions:
  - -Bohemian Massif (editor P.Vyskočil),
  - -The Teisseyre-Tornquist Zone (J. Liszkowski),
  - -Pannonian Basin (G. Grenerczy),
  - -Northern Carpathians (F. Zablotskij),
  - -Southern Carpathians (D. Ioane),
  - -Central Europe - summary and proposals for future investigations (P. Vyskočil, J. Sledzinski),
  - -Bulgarian Krupnik-Kresna region (G. Milev),
  - -Bulgarian Chirplan-Plovdiv region (G. Milev).

At the end of the second phase of the Projects there were published the following geotectonic monographs:

"Geodynamic studies in Romania-Vrancea Zone" (editor: T. Rus). REPORTS ON GEODESY, IGGA WUT, Warsaw, No.6 (81),2006.

"Report on Geodynamics of Central Europe". Work package WP.10. "(editor: J. Sledzinski), REPORTS ON GEODESY, IGGA WUT, Warsaw, No.4 (79). 2006.

"Geodynamics of the Balkan Peninsula" (editor G. Milev). REPORTS ON GEODESY, IGGA WUT, Warsaw, No.5 (80). 2006.



Stations of the Project CERGOP (Network CEGRN)

Nine monitoring GPS CEGRN campaigns were performed up to now. Four campaigns were organised in the frame of the first phase and five campaigns during the second phase of the Project. They are listed below.

CEGRN Monitoring GPS Campaigns

Campaign		Date	
CERGOP-1:			
	CEGRN'94	2 May – 6 May	1994
	CEGRN'95	29 May – 3 June	1995
	CEGRN'96	10 June – 15 J une	1996
	CEGRN'97	4 June – 10 June	1997
CERGOP-2:			
	CEGRN'99	14 June – 19 June	1999
	CEGRN'01	18 June – 23 June	2001
	CEGRN'03	16 June – 21 June	2003
	CEGRN'05	20 June – 25 June	2005
	CEGRN'07	17 June – 22 June	2007

CERGOP Data Centre is hosted by Graz Lustbühel Observatory. At the moment five institutes have declared to maintain and operate CEGRN Processing Centres in the second phase of the Project:

- FÖMI, Satellite Geodetic Observatory, Penc, Hungary;
- Institute of Geodesy and Geodetic Astronomy of the Warsaw Universityof Technology, Warsaw, Poland;
- Agenzia Spaziale Italiana Centro di Geodesia Spaziale, Matera, Italy;
- Space Research Institute of the Austrian Academy of Sciences, Austria
- Department of Theoretical Geodesy of the Faculty of Civil Engineering of the Slovak University of Technology, Bratislava, Slovakia.

One of the main important parts of the international activities within the EU Project CERGOP is the work of CERGOP Study Groups. They cover particular fields of activities supporting realisation of the Project and form the respective "work packages" (somehow sub-projects) of the EU Project CERGOP-2/Environment (CSG). At present – in the programme of CERGOP-2 there are seventeen work packages listed below.

WP.1. Internet based seamless database for environmental studies (chaired by Austria),
WP.2. Station quality assessment and upgrade (Hungary),
WP.3. Periodic determination of the reference frame CEGRN (Hungary),
WP.4. Creation of new permanent observation facilities in CEI countries (Germany),
WP.5. GPS data analysis and the definition of reference frames (Slovakia),
WP.6. Analysis of the long-term coordinate time series (Italy, Padova),
WP.7. Geokinematical modelling and strain analysis (Slovakia),
WP.8. Impact of atmospheric effects on GPS height determination (Czech Republic),
WP.9. GPS based rapid service for meteorology and hazard assessment (Italy ASI),

WP.10. Geodynamics of Central Europe (Poland),

WP.10.1. Crustal movements in the Eastern Alps and Northern Mediterranean (Slovenia),
WP.10.2. Three dimensional plate kinematics in Romania (Romania),
WP.10.3. Integration of present geodynamic investigations in the Pannonian Basin (Hungary),
WP.10.4. International geodynamic test area Plitvice Lakes (Croatia),
WP.10.5. Geodynamics of the Tatra Mts. (Poland, Slovakia),
WP.10.6. Geodynamics of the Northern Carpathians (Ukraine),
WP.10.7. Geodynamics of the Balkan Peninsula (Bulgaria).

6. CONSORTIUM FOR CENTRAL EUROPEAN GPS GEODYNAMIC REFERENCE NETWORK (CEGRN)

Long-term experience gained from the realisation of the Project CERGOP has proved the importance of international collaboration in the field of space geodesy, geodynamics and Earth sciences and the need for a coherent, high accuracy and high quality reference network in Central Europe for geodynamic investigations. It became evident that only a coordinated programme of measurements, scientific and technical development of methods and international access to wide amount of monitoring results gathered in a long period of time can give the proper background for any further geodynamic interpretations.

The CEGRN Consortium is a non-profit organisation of institutes that supports and promotes, coordinated establishment, maintenance and upgrade of CEGRN sites, monitoring the CEGRN by permanent and epoch type measurements and the establishment, maintenance and development of CEGRN Data Centre and Processing Centres.

The member institutes contribute to the CEGRN with their own established and accepted sites, with site maintenance and with coordinated observations on these sites. They are committed for the highest quality standards and a minimum of 5*24 hours observations every second year. They supply observational data to the common Data Centre. Additional contribution of designated institutes consists of operation the Data Centre and/or Processing Centres. The Consortium shall agree on a programme for the development of scientific potential of the CEGRN and shall formulate and submit proposals for new scientific and technological developments. These proposals may specify the member institutes in which such developments should be carried out. The Consortium may submit proposals either to national or international entities.

The "Memorandum of Agreement" of the Consortium was signed on 5 September 2001 in Budapest, Hungary. The representatives of the following institutions are now member of the Consortium (see:www.fomi.hu/cegrn).

- Space Research Institute, Austrian Academy of Sciences, Graz, Austria
- Geodesy Department of the Faculty of Engineering, Sarajevo, Bosnia and Hercegovina
- Institute for Water Problems, Bulgarian Academy of Sciences, Sofia, BulgariaUniversity of Zagreb, Faculty of Geodesy, Zagreb, Croatia
- Research Institute of Geodesy, Topography and Cartography, Zdiby, Czech Republic
- Institute fűr Physikalische Geodäsie, Technische Universität Darmstadt, Germany
- FÖMI Satellite Geodetic Observatory, Budapest, Hungary
- Centro di Geodesia, Agencia Spaziale Italiana, Matera, Italy
- Department of Geology, Paleontology and Geophysics, University of Padova, Italy
- Institute of Geodesy and Geodetic Astronomy, Warsaw Univ. of Technology, Warsaw, Poland
- The Institute of Cadastre, Geodesy, Photogrammetry and Cartography, Bucharest, Romania
- The Geodetic Authority, Republic of Serbia
- Dept. of Theoretical Geodesy, Slovak University of Technology, Bratislava, Slovakia
- Faculty of Civil and Geodetic Engineering, University of Ljubjana, Slovenia
- Chair of Geodesy and Astronomy, Lviv Polytechnic National University, Lviv, Ukraine

The CEGRN can be considered as a well-established research infrastructure in Central Europe for Earth sciences. Therefore this infrastructure can be used as a prominent research and educational tool in the region. Most of participating institutions are university institutes with educational experience in Earth science disciplines. Therefore the Consortium can also be a forum for a wide educational activities. Some training programmes initiated and organising by the Section C Working Group on University Education Standards can be realised in cooperation with the Consortium. The Consortium provides an open discussion forum also for other institutes from all European countries, it forms a broad platform for European international cooperation in the field of Earth sciences, in particular in space geodesy and geodynamics. We expect that the number of member-institutes will increase in the near future.

7. EUPOS (European Position Determination System)

This is a new European initiative of establishment of the multifunctional reference station system in Central and Eastern countries. Formally it is not a CEI Section C Project but nine CEI countries are engaged in the Project.. The Project EUPOS was initiated by the Berlin Senate Department for Urban Development and European Academy of the Urban Development Berlin. The project consists in establishment of about 900 multifunctional satellite reference stations in Central and Eastern Europe. Fourteen countries: Bosnia&Herzegovina, Bulgaria, the Czech Republic, Estonia, Germany, Hungary, Latvia, Lithuania, Macedonia, Poland, Romania, Russian Federation, Serbia & Montenegro, Slovakia and Slovenia) intend to participate in the project. One common project standard set will be observed by all countries, however the project will include the existing or developed infrastructure in participating countries. The system will use as standard the future European system Galileo as soon as this signal is available. Experiences of establishing and operating satellite systems gained by other countries will also be used. The network of reference stations will provide signal for both positioning of the geodetic control points and for land, air and marine navigation. Several levels of positioning accuracy will be offered. The project was consulted with the representatives of European Commission in Brussel and is financially supported by European Union. The participating countries decided to form a Founding – Steering Committee. The conferences of this Committee were devoted to discussions on practical aspects of realisation of establishment of a multi-functional network of GNSS reference stations in Central and Eastern European countries.

8. COOPERATION WITH INTERNATIONAL SCIENTIFIC ORGANISATION

COOPERATION WITH THE EUROPEAN GEOPHYSICAL SOCIETY (EGS) / EUROPEAN GEOSCIENCES UNION (EGS).

Since 1997 there have been organised every year by the CEI Section C "Geodesy" special symposia on geodetic and geodynamic programmes realised in the frame of the international cooperation of CEI countries. They are included to the programme of annual General Assemblies of the European Geophysical Society. The Convener of these symposia is Prof. Dr. Janusz Sledzinski (Warsaw, Poland) and the Co-Convener Prof. Dr. Jan Kostelecký (Prague, the Czech Republic). About 45 papers on GPS campaigns in CEI countries, on CERGOP and UNIGRACE, on activities of the CSGs and contribution of permanent GPS stations in CEI countries to international programmes, etc. are usually presented at the oral and poster sessions of the EGS-CEI symposia. Within 1997-2005 there were presented 450 papers highlighting activities of the Section C's study and working groups.

EGS-CEI Symposia

"Geodetic and Geodynamic Programmes of the CEI (Central European Initiative)"

1997:	G14 Vienna (A),	21-25.04.1997;	66 pres.
1998:	G16 Nice (F),	20-24.04.1998;	36
1999:	G4 Haag (NL),	19-23.04.1999;	45
2000:	G12 Nice (F),	24-29.04.2000;	49
2001:	G9 Nice (F),	26-30.03.2001;	46
2002:	G10 Nice (F),	21-26.04.2002;	51
2003:	G18 Nice (F),	7-12.04.2003;	46
2004:	G11 Nice (F),	25-30.04.2004;	55
2005:	G9 Vienna (A),	25-29.04.2005;	56
2006:	G6 Vienna (A),	2 - 7.04.2006;	44
2007:	G11 Vienna (A),	15–20.04.2007;	30
	T o t a l	1997 - 2007	524 presentations

9. OTHER WORKS PERFORMED BY THE WG MEMBERS IN DIFFERENT COUNTRIES.

9.1. STUDIES RELATED TO GEODYNAMICS IN CENTRAL EUROPE PERFORMED BY THE SLOVAK UNIVERSITY OF TECHNOLOGY, BRATISLAVA, SLOVAKIA

REFERENCE FRAMES (J. Hefty)

The reference frames issues are studied in Slovak Republic at various levels – continental, regional and national. Slovak University of Technology act as the EUREF Local Analysis Center (LAC SUT). The sub-network analysed consists of 40 stations distributed mainly in Central Europe and partially in other regions of Europe (West Europe, North-East Europe and Mediterranean). The standard products of LAC SUT as well as some other specific products like coordinate series with subdaily resolution are summarized in (Hefty & Igondová, 2004, Hefty, 2002 and Hrčka & Hefty, 2006). The denser network of about 40 permanent GPS stations concentrated in Central Europe is analysed at SUT in framework of the CERGOP-2/Environment EU project. Analysis method, coordinate time series and evaluation of stability of network stations is described in (Hefty, Kartikova & Kováč, 2003, Hefty, Gerhátová, Igondová & Kováč, 2004, Hefty, 2005a). The history of GPS epoch observations in Central Europe starts from 1994 when first campaign of Central Europe Geodynamic Reference Network (CEGRN) was performed. The analysis of all CEGRN campaigns until 2006 resulting to coordinates and velocities for more than 50 stations is in (Hefty & Gerhátová, 2006, Hefty et al., 2005, Hefty, 2005b, Hefty, 2005c). Problems of effective combination of permanent and epoch-wise GPS observations are investigated in (Hefty, 2004, Hefty, Kováč & Igondová, 2004). The Slovak national GPS networks and levelling networks of 1st order are analysed in (Hefty & Vanko, 2005).

EARTH ROTATION & GEODYNAMICS (J. Hefty)

Geokinematics of Central European region was investigated on the basis of long-term GPS observations in several projects. The site velocities from permanent stations are evaluated and analysed in (Hefty, Gerhátová, Igondová & Kováč, 2004, Hefty, Igondová & Hrčka, 2005), kinematics from epoch stations is subject of papers (Hefty et al., 2005, Hefty & Gerhátová, 2006). The relatively stable Central Carpathians, northward oriented drifts of Adriatic part and Dinarides and southward oriented motion of East Balkan are outputs of CEGRN monitoring (Hefty, 2005b, Hefty et al., 2005). The homogenized velocity field and subsequent deformation analyses based on horizontal velocities in Central Europe are subject of papers (Hefty& Duraciova, 2003, Hefty, 2005b, Hefty, 2005c).

Periodic site coordinate variations in diurnal and sub-diurnal bands are evaluated and analysed on the basis of permanent GPS networks. The results summarized in (Hefty, 2002, Hefty et al., 2004, Hrčka & Hefty, 2006) proves the existence of slight high-frequency variations in majority of GPS stations and points on some deficiencies in modelling of reference frames, ocean loading and locally induced site variations.

POSITIONING & APPLICATIONS (J. Hefty)

The astronomical positioning at more than 30 points using the portable Circumzenithal 50/500 instrument was applied for geoid determination in Poland. Observations and their analysis were performed within the Polish – Slovak cooperation (Bogusz et al., 2005).

Methods of integration of terrestrial and satellite geodetic observations are analyzed in (Gerhátová & Hefty, 2003) yielding the complex 3D network with gravity field parameters determined. The

integration of heterogeneous GPS networks in unique model is studied in (Hefty, 2004, Hefty, Kováč & Igondová, 2004).
Determination of relative GPS antenna phase centres and the resulting coordinate drifts and variations are investigated in (Hefty & Plánovský, 2002, Hefty, 2004). The influence of extreme catastrophic environmental phenomena on permanent GPS observations is investigated in (Igondová & Hefty, 2005).

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AREA OF ACTIVITIES:
GEODYNAMICS OF THE TATRA MOUNTAINS (M. Mojzes)

Tatra Mnt. are part of the West Carpathian arc and part of the border between Carpathian system and Polish platform. The geodynamic investigation of Tatra Mnt. started from 1998. The crust movement investigation in Tatra Mnt. region was a local sub project of the CERGOP-2/Environment supported by the European Union. In order to study this important area and especially its dynamical properties, the special test network of GPS points has been established by Polish and Slovak cooperation (Warsaw University of Technology and Slovak University of Technology in Bratislava). The GPS network consists of 11 sites, 7 in Slovak Republic and 4 in Poland. The size of the investigated area is approximately 40 km by 60 km. The GPS epoch measurements lasted from 3 to 5 days every year from 1998 to 2006. The data was processed by Bernese software with standard procedures. After analysis of GPS data, the mean horizontal relative velocity to Eurasian platform was 1.1 mm/year in azimuth 318 degrees and the mean vertical relative velocity was -1.2 mm/year determined from the period 1998 to 2006. Information about the movements of Tatra Mnt. has been presented in EGU General Assembly in 2006. For testing of relative vertical movements the repeated absolute gravity measurements at the chosen points have been used. The absolute gravity test has a good agree with GPS measurements. The results of the test have been presented at the EGU General Assembly in Vienna in 2007.

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9.2 UNIVERSITY OF KARLSRUHE, GERMANY (G. Schmitt, Nuckelt) Collaborative Research Center 461 „Strong Earthquakes – A Challenge for Geosciences and Civil Engineering" - Subproject B1 "Three-dimensional Plate Kinematics in Romania"

Activities in the last two-three years:

- 2006: GPS-campaign in Romania, cooperation of CRC 461 (Germany), ISES (The Netherland), University of Bucharest and University of Civil Engineering Bucharest (Romania)
- Reprocessing of all GPS observation using Bernese GPS Software 5.0, the available data were collected in GPS campaigns between 1995 and 2006
- Detailed analyses on GPS data concerning multipath effects and influences of antenna phase centre variations
- Time series analyses of GPS permanent station Bucharest (Romania)
- Development of a new approach for velocity field interpolation using multilevel B-spline techniques, including error propagation
- Strain analyses based on B-spline approximation surfaces

Recent results:

- Time series analyses of GPS permanent station Bucharest:
  - Seasonal effects were detected for the height coordinate of station BUCU
  - Possible correlation with changes of ground water level
- Three dimensional velocity field for Romania:
  - Based on reprocessed GPS data,
  - Velocities of GPS stations are estimated using the kinematic model of deformation analyses
  - Velocity field interpolation using multilevel B-splines
  - Areas of significant movement can be distinguished
  - Principal strains and shear strains were derived from the velocity field
  - Quality information for velocity field and strains

The Romanian scientists will organise in Bucharest an international symposium "On Strong Vrancea Earthquakes and Risk Mitigation" 4-6 October 2007.

9.3 STATE UNIVERSITY "Lviv, Polytechnic" UKRAINE (F. Zablotskij).

The scientists from the Lviv University were carrying out investigations of the vertical and horizontal movements of the Earth surface in the Carpathians region. The repeated levelling data were also used. There were obtained the new results of the horizontal displacements of the points of the Carpathian geodynamic test field. They are represented in the form of the deformation velocity vectors. Further works at the Pip Ivan test field were performed. The precise coordinates of the station Pip-Ivan Mountain (the second highest top of the Ukrainian Carpathians) were determined basing on the data obtained from the campaigns of 2002, 2003 and CEGRN'2005. A new permanent satellite station SHAC was established. Ukrainian stations took part in all last CEGRN campaigns. The Ukrainian scientists prepared a monograph "Investigations of recent geodynamics of the Ukrainian Carpathians". The manuscript of this monograph was submitted to the European Commission at the end of the CERGOP Project.

9.4 STATUS OF GEODETIC ACTIVITIES IN ROMANIA (T. Rus, P. Dumitru, M. Fadur)

The Romanian colleagues submitted an exhaustive report on activities in different kinds of geodetic works. In the report there are outlined the most important aspects concerning the new GPS permanent network (evolution, extension, services). New levelling data were used jointly with GPS for determination of the new model of the Romanian quasi-geoid.

9.5 GEODYNAMIC RESEARCH IN BALKAN PENINSULA (G. Milev, K. Vassileva)

The territory of the Balkan Peninsula is the most active region in Central and Eastern Europe in geodynamical respect. A number of hazardous geodynamic processes of endogenic (earthquakes, contemporary movements of the Earth's crust, mud volcanoes) and exogenic origin (natural and technogenic), including landslides, abrasion, erosion, subsidence, collapse, rockfalls, mud-stone flows, deformations caused by mine workings, karsts, etc., are observed in the area.

The single processes and cases are superposed or interact with each other in many respects. Their combined display, range of manifestation and multilateral, in many cases destructive effect is especially typical for the Balkan Peninsula territory.

At present the space of the Balkan Peninsula falls within the zone of collision between three large plates - Euroasian, African and Arabian, which are themselves divided in smaller ones.

Related geodynamic investigations accomplished concern:

- Systematisation and analysis of the existing investigations for the region.
- Accomplishment of complex measurements, investigations and generalizations with respect to:
  - seismological conditions and processes,
  - geophysical fields interpretations related to the geodynamical processes,
  - see bottom geology and processes,
  - seismotectonics,
  - geology and geomorphology,
  - geodesy,
  - complex analysis and interpretation.

The investigations are mainly based on the results of the Central European Regional Geodynamics Project (CERGOP) of the 5-th Framework Programme of EC.

Existing permanent stations and some new established ones (permanent and epoch) on the territory of the Balkan Peninsula are involved in the study. Two new CERGOP permanent stations (VARN, ROZH) were established in Bulgaria early in 2005. VARN and ROZH stations are collocated with absolute gravity stations and connected to the National Levelling Network and they are included as an element of the EUREF project – ECGN (European Combined Geodetic Network).

Several GPS CEGRN campaigns have been carried out and data from stations covered the territory of the Balkan Peninsula have been collected, processed and analyzed.

In the CEGRN'03 all 15 BULREF points on the territory of Bulgaria were involved.

The velocity vectors estimated from combine campaign solution show undisturbed behaviour for all BULREF stations for the period of 10 years, period between two campaigns. The values of station velocities are very similar and differences vary with an amount of maximum up to 2 mm in north component and in east component. Also the deviations to the NUVEL model velocities are in a reasonable size. This indicates that no unexpected jumps or outliers occurred in the behaviour of stations during that time.

Respective station velocity vectors estimated for the territory of the Balkans are compatible with the NNR-NUVEL1A velocity model and results from other studies.

The generalized results from the investigations of the Balkan Peninsula and Bulgaria show that:

- Orientation of the global velocity vectors is generally north-east and south-east direction,
- Horizontal movements are of amount of 2 mm/yr,
- Results achieved are reliable as they have been obtained by different approaches and by independent researchers,
- Comparison of the particular solutions within the CERGOP-2 project shows an agreement.
- Without doubt the Balkan Peninsula exhibits a pronounced and active geodynamics with respect to other regions in Central and Eastern Europe.

As a generalized result of the efforts of the Bulgarian and Balkan countries partners is the Monograph "Geodynamics of the Balkan Peninsula", published in Reports on Geodesy, Poland, end of 2006, 648 pp. Many scientists (about 100 authors) from different Earth sciences - geodesy, geophysics, geology and other branches from all Balkan countries and some other European countries contributed to it. The Monograph presents general data and prerequisites for the part of global geodynamics comprising BP. Different aspects of studies are accomplished by the particular countries. Assessments and relevant generalized conclusions, analysis and generalization of the results obtained from the GNSS - geodetic investigations, complex interpretation of the velocity and deformation vector field, generalized geodynamics of BP have been done. The investigation results outline possibly most representative picture of the geodynamic phenomena occurred in the Balkan Peninsula and their interpretation on the background of the Mediterranean geodynamics. It is oriented to a large range of specialists from the Earth sciences, disaster protection – more particularly earthquakes, monitoring and prevention of environment, planning and urbanization, and many others.

10. CONCLUSION

CEI WGST Section C "Geodesy" declares further close cooperation with the International Association of Geodesy in any form that would be considered as the most effective. The research and interpretation of recent crustal movements detected by satellite techniques are recognised as most important and urgent action within the mentioned workpackages of the CERGOP-2. The Section C "Geodesy" will provide the velocity vectors (displacement vectors) from the regions of Central Europe covering the area of CEI countries. The results of the CERGOP and other CEI projects will be release for the IAG scientific groups dealing with geodynamic investigations.

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IAG Commission 4 – Positioning & Applications

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 Organizations. Recognizing the central role that GNSS plays in many of these applications, the Commission's work will focus on several GPS-based techniques. These 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 GPS positioning technology itself (alone or in combination with other positioning sensors) as well as its applications in surveying and engineering. Recognizing 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.

Steering Committee
Chris Rizos – President
Pascal Willis – Vice President
Dorota Grejner-Brzezinska – Chair SC4.1
Heribert Kahmen – Chair SC4.2
Susan Skone, Hans van der Marel – Chairs SC4.3
Xiaoli Ding – Chair SC4.4
Yang Gao – Chair SC4.5
Marcelo Santos – Member at Large
Ruth Neilan – IAG representative

1) Structure of the IAG Commission 4

Sub-Commissions & associated Working Groups:

SC4.1: Multi-sensor Systems
- WG4.1.1 Advances in Inertial Navigation and Error Modelling Algorithms
- WG4.1.2 Indoor and Pedestrian Navigation
- WG4.1.3 Advances in MEMS Technology and Applications

SC4.2: Applications of Geodesy in Engineering
- WG4.2.1 Measurement Systems for the Navigation of Construction Processes
- WG4.2.2 Dynamic Monitoring of Buildings
- WG4.2.3 Application of Knowledge-based Systems in Engineering Geodesy
- WG4.2.4 Monitoring of Landslides & System Analysis

SC4.3: GNSS Measurements of the Atmosphere
- WG4.3.1 Ionospheric Scintillation
- WG4.3.2 Performance Evaluation of Ionosphere Tomography Model
- WG4.3.3 Numerical Weather Predictions for Positioning

SC4.4: Applications of Satellite & Airborne Imaging Systems

WG4.4.1 Permanent Scatterer / Corner Reflector / Transponder InSAR
WG4.4.2 Atmospheric Effects in InSAR / InSAR Meteorology
WG4.4.3 InSAR for Polar Regions
WG4.4.4 Imaging Systems for Ground Subsidence Monitoring

SC4.5: Next Generation RTK

WG4.5.1 Network RTK
WG4.5.2 Carrier Phase based Precise Point Positioning
WG4.5.3 High Precision Positioning on Buoys and Moving Platforms
WG4.5.4 Multiple Carrier Phase Ambiguity Methods & Applications

Study Groups:
SG4.1: Pseudolite Applications in Positioning & Navigation

Inter-Commission Study Groups:
IC-SG4.2: Statistics & Geometry in Mixed Integer Linear Models, with Applications to GPS & InSAR (joint with ICCT)
IC-SG1.1: Ionospheric Modeling and Analysis (joint with Commission 1) **NO LONGER ACTIVE**
IC-SG1.2: Use of GNSS for Reference Frames (joint with Commission 1)

There are currently no Commission Projects defined.

The commission web site URL is: http://www.gmat.unsw.edu.au/iag/iag_comm4.htm

2) Linkages with other IAG commissions and external organisations

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. Two examples where these strong links have fostered a symposium series jointly sponsored and organised by the IAG Commission 4 and other organisations are:

(1) The joint IAG-FIG symposium series now known (rather clumsily) as the "xxth Symposium on Geodesy for Geotechnical and Structural Engineering and yyth International FIG Symposium on Deformation Measurements", which brought together previously separately organised symposia that were in competition with each other. An agreement has been reached that these symposia in future will run in the "even years", with the next one being the "4th Symposium on Geodesy for Geotechnical and Structural Engineering and 13th International FIG Symposium on Deformation Measurements" which will be held in Lisbon, Portugal, 12-15 May 2008. The entities responsible are IAG SC4.2 and FIG WG6.1.

(2) The joint IAG-FIG-ISPRS "Mobile Mapping Technology" series of symposia is an excellent example of symposia that recognise the multi-disciplinar nature of positioning, imaging and mapping technologies. The "5th International Symposium on Mobile Mapping Technology " was held in Padua, Italy, 28-31 May 2007. Every effort will be made to run these symposia in the "odd ears", with the next one being the "6th International Symposium on Mobile Mapping Technology" which will be held at the

São Paulo State University, Brazil, in July 2009. The entities responsible are IAG SC4.1, FIG WG5.3, and ISPRS WGs I/2, I/3, I/V, II/6 and V/1.

(3) The joint IAG-FIG-ISPRS "Optical 3-D Measurement Techniques" series of conferences, with the latest being the "8th Conference on Optical 3-D Measurement Techniques" to be held in Zurich, Switzerland, 9-12 July 2007. The entities responsible are IAG SC4.2, FIG commissions 5 and 6, and ISPRS Commission V.

These 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 – Anaylsis and Applications") are now particularly strong, as evidenced by a permanent series of joint symposia.

Linkages have also been established with other IAG entities, some formal, others quite adhoc and informal. A sample of such linkages include:

- Joint symposium of SC4.1, SC4.2 and SC4.4 (Baden, Austria, 22-24 May 2006), in cooperation with the FIG WG6.1, "3rd Symposium on Geodesy for Geotechnical and Structural Engineering and 12th International FIG Symposium on Deformation Measurements". This follows the IAG-only "2nd Symposium on Geodesy for Geotechnical & Structural Applications" (Berlin, Germany, 21-24 May 2002).
- SC4.5 has an informal collaboration with the IGS RT Products Working Group.
- There is an Inter-Commission SG1.1 "Ionospheric Modelling & Analysis" (with Commission 1 & COSPAR), *although this has been non-active for several years*.
- There is an Inter-Commission SG1.2 "Use of GNSS for Reference Frames" (with Commission 1), and also the IGS GNSS Working Group, which has resulted in the formation of an "umbrella" IAG-IGS Joint WG on GNSS.

A primary objective of Commission 4 is to establish linkages with sister organisations such as FIG, ISPRS, ION, and others. The following summarises these linkages, and outcomes arising from them:

- The former Chair of FIG Commission 5 "Positioning & Measurements" (Matt Higgins) has developed a document indicating the potential linkages between IAG and FIG entities (and not just between the IAG Commission 4 and the FIG Commission 5). Matt Higgins is now one of the Vice Presidents of the FIG, and has received endorsement from the President of FIG to continue to work closely with the IAG.
- The President of IAG Commission 4 (Chris Rizos) and the Chair of FIG Commission 5 (Matt Higgins) were both members of the Organising Committee of the 3rd FIG Regional Conference (Jakarta, Indonesia, 3-7 October 2004), and worked together to ensure a strong IAG "presence" at this conference as well as the 2004 FIG Working Week (Cairo, Egpt, 7-12 May), including the attendance of the IAG President Gerhard Beutler.
- The FIG Commission 5 assisted in organising sessions of relevance to its commission at the Joint Assembly of IAG/IAPSO/IABO (Cairns, Australia, 22-26 August 2005).
- The Chair of SC4.1 (Dorota Brzezinska) was instrumental in working with the U.S. Institute of Navigation (ION) to negotiate an MOU with the IAG, similar to one between the ION and the FIG (again facilitated b Dorota Brzezinska and Matt Higgins).
- "Cross-chairing" arrangements between IAG SC4.1 "Multi-sensor Systems" and the FIG WG5.3 "Integrated Positioning, Navigation and Mapping Systems" (i.e. Chair/Vice-Chair

of these two entities are reversed). One outcome of which was the co-sponsoring of a session at the ISPRS Congress (Istanbul, Turkey, 12-22 July 2004), as well as the biannual "Mobile Mapping Technolog" series of symposia referred to earlier.

- There is a long tradition of IAG, FIG & ISPRS joint sponsorship of conferences going back to the predecessor of SC4.2, the "IAG Special Commission 4" (1995-2003), and this continues with the "6th Conference on Optical 3-D Measurement Techniques" (Zurich, Switzerland, 22-25 September 2003), and "7th Conference on Optical 3-D Measurement Techniques" (Vienna, Austria, 3-5 October 2005), and the "8th Conference on Optical 3-D Measurement Techniques" (Zurich, Switzerland, 9-12 July 2007).
- "Cross-chairing" arrangements between IAG SC4.2 "Applications of Geodesy in Engineering" and the FIG WG6.4 "Engineering Surveys for Construction Works & Structural Engineering" (i.e. Chair/Vice-Chair of these two entities are reversed). One outcome of which was the co-sponsoring of the "1st FIG Int. Symp. on Engineering Surveys for Construction Works & Structural Eng." (Nottingham, U.K., 28 June – 1 July 2004).
- One of the Chairs of SC4.3 (Susan Skone) is Vice-Chair of SG1.1.
- The Chair of SG1.2 (Robert Weber) is also Chair of the IGS GNSS WG.
- Over the last four years there have been several jointly organised or cross-sponsored conferences/symposia, in addition to the organisation of individual sessions (see below).

<u>3) Conferences/symposia with which IAG Commission 4 has been associated with *(planned)*</u>

Conferences or symposia in which Commission 4 entities and members were actively involved in their organisation and promotion in the period 2003-2007 include (this is not an exhaustive list):
- "16th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation", Portland, Oregan, 9-12 September 2003.
- "6th Conference on Optical 3-D Measurement Techniques", Zurich, Switzerland, 22-25 September 2003.
- "10 Years IGS: Workshop & Conference", Bern, Switzerland, 1-5 March 2004.
- "4th Int. Conference on Mobile Mapping Technology", Kunming, China, 29-31 March 2004.
- "European Navigation Conference GNSS 2004", Rotterdam, The Netherlands,16-19 May 2004.
- "1st FIG Int. Symp. on Engineering Surveys for Construction Works & Structural Eng.", Nottingham, U.K., 28 June – 1 July 2004.
- "Western Pacific Geophysics Meeting", Hawaii, USA, 16-20 August 2004.
- "17th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation", Long Beach, California, USA, 21-24 September 2004.
- "3rd FIG Regional Conference – Spatial Information for Economic & Environmental Development", Jakarta, Indonesia, 3-7 October 2004.
- "Int. Symp. on GNSS", Sydney, Australia, 6-8 December 2004.
- "Hydro Society Conference", Ireland, November 2004.
- ION NTM, San Diego, California, USA, 24-26 January 2005.
- "Geoinformatics-05 Conference", Toronto, Canada, June 2005.

- Asia Pacific Space Geodynamics (APSG) Workshop, Geodynamics and Natural Hazards, Hong Kong, 15-17 June 2005.
- "Int. Geoscience & Remote Sensing Symposium (IGARSS)", Seoul, Korea, 25-29 July 2005
- "Dynamic Planet 2005" IAG/IAPSO Scientific Assembly, Cairns, Australia, 26-28 August 2005.
- "18th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation", Long Beach, California, USA, 13-16 September 2005.
- "7th Conference on Optical 3-D Measurement Techniques", Vienna, Austria, 3-5 October 2005.
- "Int. Symp. on GNSS", Hong Kong, December 2005.
- "3rd Symp. on Location Based Services and Telecartography", Vienna, Austria, November 2005.
- "Symp. on GPS/GNSS", Surfers Paradise, Australia, 17-21 July 2006.
- "Western Pacific Geophysics Meeting", Beijing, China, 24-27 July 2006.
- "Int. Geoscience & Remote Sensing Symposium & 27th Canadian Symp. on Remote Sensing", Denver, Colorado, USA, 31 July – 04 August 2006.
- "European Geosciences Union General Assembly", Vienna, Austria, 15 – 20 April 2007.
- "5th Int. Symposium on Mobile Mapping Technology", Padau, Italy, 28-31 May 2007.
- "3rd Symposium on Geodesy for Geotechnical and Structural Engineering and 12th International FIG Symposium on Deformation Measurements", Baden, Austria, 22-24 May 2006.
- "VI Hotine-Marussi Symp. on Theoretical & Computational Geodesy", Wuhan, China, 29 May - 2 June 2006.
- "12th IAIN Congress & 2006 Int. Symp. on GPS/GNSS", Jeju, Korea, 18-20 October 2006.
- "8th Conference on Optical 3-D Measurement Techniques", Zurich, Switzerland, 9-12 July 2007.
- GS004 symposium at the XXIVth General Assembly of the IUGG "Earth: Our Changing Planet", Perugia, Italy, 2-13 July 2007.
- "8th conference on Optical 3-D Measurement Techniques", Zurich, Switzerland, 9-12 July 2007.
- *"Int. Geoscience & Remote Sensing Symp. (IGARSS)", Barcelona, Spain, 23-28 July 2007.*
- *"20th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation", Fort Worth, Texas, USA, 25-28 September 2007.*
- *"4th Int. Symp. on Location Based Services and Telecartography", Hong Kong, 8-10 November 2007.*
- *"IEEE/ION PLANS" meeting to be held in Monterey, California, USA, 5-8 May 2008.*
- *"4th IAG Symp. on Geodesy for Geotechnical & Structural Engineering, and 13th FIG Symp. on Deformation Measurements", Lisbon, Portugal, 15-18 May 2008.*
- *"6th Int. Symp. on Mobile Mapping Technology" to be held in Brazil in July 2009.*

4) Reports from the Sub-Commissions

SC4.1: Multi-sensor Systems

Chair:	Dorota Grejner-Brzezinska (OSU, USA)
Vice-Chair:	Naser El-Sheimy (Univ. of Calgary, Canada)
Secretary:	Jinling Wang (UNSW, Australia)
Member-at-Large:	Guenther Retscher (Vienna Univ. of Technology, Austria)
	Joao Fernando Silva (UNESP, Brazil)

Terms of Reference
To coordinate research and other activities that address the 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 platform. The primary sensors of interest will be Global Navigation Satellite Systems (GNSS) and inertial navigation systems; however the important role of other techniques used for indoor and pedestrian navigation is also recognised. The SC will carry out its work in close cooperation with other IAG entities, as well as via linkages with relevant scientific and professional organisations such as ISPRS, FIG, IEEE, ION.

Activities 2005-2007

- Dorota Grejner-Brzezinska was appointed track chair for the IEEE/ION PLANS meeting to be held in Monterey, California, 5-8 May 2008. Naser El-Sheim is a session chair.
- Dorota Grejner-Brzezinska was an invited speaker at the 32nd International Symposium on Remote Sensing of Environment, Sustainable Development Through Global Earth Observations, 25-29 June 2007, San Jose, Costa Rica.
- 5th International Symposium on Mobile Mapping Technology (MMT'07) was co-sponsored by the IAG Commission 4, ISPRS and FIG, and took place in Padua, Italy, 29-31 May 2007 with about 200 participants and 125 technical papers (http://www.cirgeo.unipd.it/cirgeo/convegni/mmt2007/index.html). Naser El-Sheimy was the chair of the Symposium Scientific Committee; Dorota Grejner-Brzezinska was co-chair of this Committee; Heribert Kahmen, Yang Gao and Jinling Wang, all representing Commission 4, were the Committee members. Naser El-Sheimy. Mohamed Moustafa, Dorota Grejner-Brzezinska and Charles Tooth offered a one day tutorial on Mobile Mapping Systems.
- Naser El-Sheimy was a keynote speaker at the 2007 Middle East conference on Geospatial Information, Technology and Applications 'Map Middle East 2007', Dubai, UAE.
- Dorota Grejner-Brzezinska represented the IAG Commission 4 at the GGOS "Retreat", Oxnard, California, 19-21 February 2007, to comment on how Comm4 could contribute to the future work of the IAG's Global Geodetic Observing System (GGOS).
- Dorota Grejner-Brzezinska was the General Chair for the U.S. Institute of Navigation (ION) National Technical Meeting (NTM), San Diego, California, 22-24 January 2007.
- Naser El-Sheimy served as a member of the program committee for the ISPRS COM I meeting in Paris, 3-6 July 2006, where he and Joe Hutton co-chaired a chaired a session on "Advancement in Navigation and Mobile Mapping". Dr. Dorota Grejner-Brzezinska was a keynote speaker.
- Naser El-Sheimy served as a member of the program committee for the ISPRS COM V meeting in Dresden, September 2006, where he and Prof. Antonio Vettore co-chaired a session on "Vehicle-borne systems".
- Several members of SC 4.1 (and IAG in general) attended the 3rd IAG Symp. on Geodesy for Geotechnical & Structural Engineering, and 12th FIG Symp. on Deformation Measurements, Baden, Austria, 22-24 May 2006, and the FIG Congress, Munich, Germany, 8-13 October 2006, and made presentations.
- Dorota Grejner-Brzezinska (Chair of SC4.1) negotiated an MOU between the FIG and ION in late 2006, to follow the MOU between the IAG and ION in 2005.

- Dorota Grejner-Brzezinska was awarded the U.S. ION's "Thurlow Award" in April 2006.
- The MOU between the Institute of Navigation (ION) and IAG was finalized in early 2005 (Commission 4 was the driving force behind it; Dorota represented both IAG and ION in the process). As a result of this MOU, a joint session, Scientific, timing and space applications, co-sponsored by the IAG Commission 4 was organized at the ION National Technical Meeting (NTM) 2006. Dorota Grejner-Brzezinska (Chair of SC4.1) was the Program Chair for the ION NTM, 18-20 January 2006, Monterey, California. Naser El-Sheimy was the General Chair.
- Dorota Grejner-Brzezinska was the co-organizer of the US Department of Transportation Workshop on Space Based Technology for Transportation, held at The Ohio State University, 30 November – 1 Dec. 2005. The primary focus of this workshop was the 2025 vision on navigation and multi-sensor technology supporting transportation applications.
- Dorota Grejner-Brzezinska presented an invited talk, From Mobile Mapping to Telegeoinformatics: Paradigm Shift in Geospatial Data Acquisition, Processing and Management, at Surveying Week, Korean Society of Surveying, Geodesy, Photogrammetry and Cartography, Seoul, Korea, 3 November 2005.
- Dorota Grejner-Brzezinska, presented an invited seminar, Multisensor System for Automatic Monitoring of Highway Linear Features: Design, Calibration and Performance Evaluation, at Electronics and Telecommunications Research Institute, Telematics/USN Research Division, Daejeon, Korea, 4 November 2005.
- Dorota Grejner-Brzezinska presented an invited seminar, The role of the Center for Mapping at The Ohio State University as a national incubator for commercialization of research in mobile mapping technology, at Cooperative Research Centre for Spatial Information Commercialisation Workshop, University of Melbourne, Melbourne, Australia, 12-13 September 2005.
- Naser El-Sheimy organized a special workshop on "Mobile Mapping Technologies" at the FIG Working Week 2005 and GSDI-8 meeting in Cairo, Egypt, 16-21 April 2005.
- Naser El-Sheimy gave an invited workshop on Mobile Mapping Systems at the first annual Middle East conference on Geospatial Information, Technology and Applications 'Map Middle East 2005', Dubai, UAE.
- Dorota Grejner-Brzezinska was a Technical Chair at the ION GNSS Meeting in Long Beach, California, 13-16 September 2005.

<u>WG4.1.1 Advances in Inertial Navigation and Error Modelling Algorithms</u>
Chair: Sameh Nassar (Univ. of Calgary, Canada)
Co-Chair: Jay Kwon (Sejgon Univ., Korea)

No updates of 2005-7 activities were obtained. The WG was very active in the first 2 years.

<u>WG4.1.2 Indoor and Pedestrian Navigation</u>
Chair: Guenther Retscher (Vienna Univ. of Technology, Austria)
Co-Chair: Bertrand Merminod (Swiss Federal Institute of Technology, Switzerland)

In 2005 the WG jointly organized with the ICA Comission on Ubiquitous Cartography and ISPRS WG V TC2 the 3rd symposium on Location Based Services and Telecartograpy which was held in Vienna, Austria at the end of November. In three sessions on Positioning and

Wayfinding 10 papers were presented also from some of the members of WG4.1.2. The conference proceedings have been published.

Several WG members have met again and presented their research work at the PLANS GNSS conference, which was held in San Diego, California, USA, in April 2006. In the same year the working group was also active in participating at the 12th IAIN Congress and 2006 International Symposium on GPS/GNSS in Jeju, Korea, from 18-20 October.

In 2007 WG 4.1.2 was involved in the 5th International Symposium on Mobile Mapping Technology (MMT'07), Padua, Italy, 28-31 May. The WG 4.1.2 is also one of the organizers of the 4th International Symposium on Location Based Services and TeleCartography to be held at the Hong Kong Polytechnic University to celebrate its 70th anniversary from 8-10 November 2007. The co-organizers of the conference are the ICA Commission on Maps and Internet and Ubiquitous Cartography. Prof. Chris Rizos will give one of the keynote speeches at the opening ceremony.

Note: this WG should continue either in its current ofrm or modified, if needed. Dr. Retscher is a good candidate for continuing chair.

<u>WG4.1.3 Advances in MEMS Technology and Applications</u>

Chair:	Mikel Miller (Sensors Directorate, Wright Patterson Air Force Base, USA)
Co-Chair:	Jan Skaloud (Swiss Federal Institute of Technology EPFL, Switzerland)

Laboratory of Geodetic Engineering (TOPO) at EPFL and Leica-Vectronix initiated collaboration on exploring the new techniques for precise azimuth determination. TOPO/EPFL setup a project with a private industry (TracEdge) to develop GPS/MEMS-integration for precise analysis of sport performance.

TOPO lab is heavily involved in the LIAISON project that unites expertise and activities from major European actors committed to provide end-to-end Location Based Services, applications and solutions. The research activities carried out by EPFL/TOPO in the framework of LIAISON focuses on the use of inertial sensors based on Micro-Electro-Mechanical Systems (MEMS) technology for pedestrian localisation and body posture determination and their coupling with other location techniques, such as Assisted GPS (A-GPS) and WiFi.

EPFL/TOPO participates at the Speed Skiing World-Cup circuit to optimize the placement of photoelectrical timing cells. This optimization leads to breaking the 200 km/h speed barrier for the first time on homeland territory. The research behind this success involves precise trajectory determination by RTK-GPS methods, trajectory filtering and smoothing and GSM/GPRS communication.

TOPO/EPFL and The Swiss Institute of Navigation Organized “Research Day Nav” – 1 day long event focused on Location Based Services in Lausanne on 27 April 2006. The advancement and use of MEMS technology is presented by several participants. A workshop on Pedestrian Navigation using GPS/MEMS technology was given on 28 April.

TOPO/EPFL and The Swiss Institute of Navigation and Swiss Association of Sensors Technology jointly organized the "Navigation Research Day" held in Lausanne on 23 March 2004.

Note: this working group had a late start, but all in all, some good level of research activities has been accomplished. This WG is relevant and should continue in this or modified form.

SC4.2: Applications of Geodesy in Engineering

Chair:	Heribert Kahmen (Vienna Univ. of Technology, Austria)
Vice-Chair:	Gethin Roberts (IESSG, Nottingham University, UK)
Secretary:	Guenther Retscher (Vienna Univ. of Technology, Austria)
Member-at-Large:	Wolfgang Niemeier (Tech. Univer. Braunschweig, Germany)

Terms of Reference

Rapid developments in engineering, microelectronics and the computer sciences have greatly changed both instrumentation and methodology in *engineering geodesy*. To build higher and longer, on the other hand, have been key challenges for engineers and scientists since ancient times. Now, and for the foreseeable future, engineers confront the limits of size, not merely to set records, but to meet the real needs of society minimising negative environmental impact. Highly developed engineering geodesy techniques are needed to meet these challenges. The SC will therefore endevour to coordinate research and other activities that address the broad areas of the theory and applications of engineering geodesy tools. The tools range from convenional terrestrial measurement and alignment technology (optical, RF, etc.), Global Navigation Satellite Systems (GNSS), geotechnical instrumentation, and software systems such as GIS, decision support systems, etc. The applications range from construction engineering and structural monitoring, to natural phenomona such as landslides and ground subsidence that have a local effect on structures and community infrastructure. The SC will carry out its work in close cooperation with other IAG Entities, as well as via linkages with relevant scientific and professional organisations such as ISPRS, FIG, IEEE, ION.

Activities 2005-2007

- "8th conference on Optical 3-D Measurement Techniques", Zurich, Switzerland, 9-12 July 2007.
- SC 4.2 organised together with the FIG the "3rd IAG Symposium on Geodesy for Geotechnical and Structural Engineering" held together with the "12th FIG Deformation Measurement Symp.", Baden, Austria, 22-24 May 2006. The main topics were geodesy on large construction sites, geodesy and mining, monitoring of landslides, dams, tunnels, bridges, laser scanning, GPS/pseudolites, InSar and navigation of construction processes. All WGs had their annual meeting there.
- SC 4.2. organised together with ISPRS and FIG the "7th conference on Optical 3-D Measurement Techniques", Vienna, Austria, 3-5 October 2005. The conference was attended by about 150 participants from 25 countries. Main topics were applications in GIS, mapping, manufacturing, quality control, robotics, navigation, mobile mapping, medical imaging, virtual reality generation and animation. It was an interdisciplinary conference with engineers and scientists from geodesy, photogrammetry, computer science, mathematics, physics and medicine. The working groups WG 4.2.1 and WG 4.2.4 organized an annual meeting during the conference.

- "1st FIG Int. Symp. on Engineering Surveys for Construction Works & Structural Eng.", Nottingham, U.K., 28 June – 1 July 2004.
- "6th Conference on Optical 3-D Measurement Techniques", Zurich, Switzerland, 22-25 September 2003.

WG4.2.1 Measurement Systems for the Navigation of Construction Processes
Chair: Wolfgang Niemeier (Technical Univ. Braunschweig, Germany)
Co-Chair: Guenther Retscher (Vienna Univ. of Technology, Austria)
An important item during the period 2003-2007 was to clarify terminology, which is partly overlapping: *Navigation* can be considered as a real-time, but purely geometrical information (position and orientation) how to come from a starting point A to B. *Steering* can be restricted to the technical process to keep or correct the path of the machine. More general seems to be the term *guidance*, where external geometrical information on the route is included, which can be provided by geodesy. Most complex seems to be the concept of *control*, which includes all aspects for processing a machine from A to B, i.e. the geometrical aspects, the machine actions and the efforts in time and costs.

The following requirements from the construction site are derived, which have to be fulfilled by the geodetic partner, before he will be a partner in the team:

i. *Development of measuring techniques to determine geometry of arbitrary forms and structures with sufficient precision and reliability in almost real-time and – in an ideal concept - without targets.*
ii. *Real-time processing techniques to compute each geometric form and its derivation from a design model.*
iii. *Set-up of communication links and data structures for perfect interaction with information systems used in construction.*

In principle, it should be even possible that the geodetic engineer becomes responsible for all geometric aspects during the planning and realisation phase. With the advent of new sensors, modern geodetic technique, sophisticated communication and efficient processing systems nowadays the geodesist can play this role in the construction process.

Adequate sensor systems are real-time satellite positioning systems of all different GNSS, including pseudolite-augmentations. Besides the automated Total Stations with real-time data transfer and - at least partly - Laserscanners and Lasertrackers are applicable for this task. The main advances are multi-sensor systems. Due to the individuality of construction sites a toolbox has been developed with individual modules that enables to dispose specific automation systems in a simple way by using its "contained expert knowledge". On this basis simulations regarding control and filter algorithms were carried out. Methods to automatically integrate measurement systems into construction processes in automatic or semi-automatic way were investigated. A special focus is directed on the quality assurance and quality safeguarding by optimal use of measurement procedures and surveying instruments to fulfil quality requirements respectively assembly demands.

WG4.2.2 Dynamic Monitoring of Buildings
Chair: Matthew Tait (Univ. of Calgary, Canada)
Co-Chair: Gethin Roberts (IESSG, Nottingham University, UK)
No report has been tended.

WG4.2.3 Application of Knowledge-based Systems in Engineering Geodesy

Chair: Klaus Chmelina (GeoData, Austria)
Co-chair: John Bosco Miima (Technical Univ. Braunschweig, Germany)
The main goal of the WG 4.2.3 is to study and report on topics such as control of measurement- and guidance-systems, deformation analysis, control of alert systems, and the evaluation of their complex data stream through the use of knowledge-based systems. To implement new research outcomes in Artificial Intelligence for deformation analysis and measurement system control.

Members of the WG 4.2.3 have been compiled and collaborated in several research projects. Worth mentioned projects for the analysis of 3D displacements in tunnelling, the automated controlling of multi-sensor systems (e.g. image-based measurement systems) or the prediction of deformations by artificial neural networks or fuzzy systems.

- The continuous monitoring of 3-d displacements during tunnel excavation has become standard in NATM-projects (**N**ew **A**ustrian **T**unnelling **M**ethod). The daily geotechnical interpretation of the observed displacements, carried out by geotechnical experts, plays an important role to ensure a safe and economical ongoing of the project. Up to now this interpretation is mainly based on the manually done inspection of numerous and different types of displacement diagrams. These many graphics have to be interpreted in combination with other separately produced lists and/or graphics showing project-relevant data such as driving data, geological data, etc. With the excavation progress the amount of data to be analysed grows continuously. As a consequence interpretation work becomes more and more time consuming and complex. *Chmelina* has presented the concept of a knowledge based software currently under development which is supposed to support this work by an automatic detection of significant displacement behaviour. There is demonstrated that an appropriate data model for the different types of data and the application of knowledge based concepts such as empirical rules and fuzziness can lead to a practical solution for the automation of the detection process.
- Deformation measurement enables the early detection of damage, failure or an injury to the safe operation of an object in order to be able to react appropriately and in time. Examples for such objects involved in deformation processes are high rise buildings, dams, bridges or unstable rock surfaces. Several factors, like changes of ground water level, tidal phenomena or tectonic phenomena, can be the reason for deformations. *Reiterer et al.* describe a new kind of measurement system which is based on image-based measurement systems, and on knowledge-based and cognitive vision techniques. The system is able to detect not signalised object points by means of appropriate algorithms – the procedure is divided into several steps: image preprocessing, automated point detection and deformation classification. The system is based on new techniques (originally developed in the area of Artificial Intelligence) which shall be used for the task of deformation measurement, analysis and interpretation. The system is currently under development and is the subject for a interdisciplinary research project at the Vienna University of Technology.
- Artificial neural networks are adapted for the use of modelling of geodetic deformations. *Miima* has used temperature, pressure, humidity, water-level variations, and traffic volume as input signals (forces) and respective point component displacements (deformations) as output signal, the "input-output" behaviour of points on the deforming bridge have been modelled. The results indicate an acceptable relational representation of the deformation process of the points.

WG4.2.4 Monitoring of Landslides and System Analysis

Chair: Gyula Mentes (Geodetic & Geophysical Research Institute of HAS, Hungary)

Co-chair: Zhenglu Zhang (Wuhan University, China)

Different measuring techniques were developed for observations and investigation of landslide prone areas:

- Remote sensing or satellite techniques with space-derived information have significant potential for landslide hazard assessment and for improved understanding of landslide processes.
- Photogrammetric techniques are an effective tool for monitoring actively moving landslides and for analyzing the velocity or strain-rate fields. These techniques allow the determination of ground displacements over long periods of time, by comparing the corresponding sets of aerial photographs.
- Ground-based geodetic techniques make use of many instruments and methods of measurement for *absolute* displacement computations.
- Geotechnical techniques make use of sensors permanently working *on* or *in* the structure or region under consideration.
- For accurate landslide inventory mapping and analysis of landslide properties the space-derived data can be integrated with all other available information on landslide occurrence and characteristics, including aerial photos, geotechnical data and geodetic monitoring results as well.

The obtained data were used for the development of an early alert system to forecast a possible landslide. This means that not only the actual movements and deformations of the surface have to be measured but also processes that may precede or cause landslides (e.g. temperature changes, heavy rains, ground water table variation, etc.). These new measuring systems are used on different test sites in China, Geece, Hungary, Italy. Besides the measurement of the slope movements and deformations the connection between movements and geological, geomorphological, hydrological, geomechanical, meteorological parameters were investigated. Since it is not possible to relate these processes by deterministic models new analysis tools based on neural networks and Fuzzy logic were also developed.

SC4.3: GNSS Measurements of the Atmosphere

Chair: Susan Skone (Univ. of Calgary, Canada)

Co-Chair: Hans van der Marel (TU Delft, The Netherlands)

Vice-Chair: Jens Wickert (GFZ, Germany)

Members-at-Large: Anthea Coster (MIT Haystack Observatory, USA)

Terms of Reference

Over the past decade, significant advances in GPS technology have enabled the use of GPS as an atmospheric remote sensing tool. With the growing global infrastructure of GPS reference stations, the capability exists to derive high-resolution estimates of total electron content and precipitable water vapour in near real-time. Recent advances in tomographic modelling and the availability of spaceborne Global Positioning System (GPS) observations has also allowed 3-D profiling of electron density and atmospheric refractivity. Future plans for the GALILEO system will allow further opportunities for exploiting Global Navigation Satelliote Systems (GNSS) as an atmospheric remote sensing tool. Many countries have initiated efforts in this area of research and application. The focus of this Sub-Commission is to facilitate collaboration and communication, and support joint research efforts, for GNSS measurement of the atmosphere. Collaboration with the International GPS Service (IGS), the SG1.1, and other IAG entities and agencies will be promoted through, for example, joint sponsorship of workshops and conference sessions.

Activities 2005-2007

- WG 4.3.3 chair M. Santos convened “Synergy of Geodesy and Meteorology” session at CMOS/CGU/AMS Congress 2007, 28 May – 1 June, St. John’s, Newfoundland, Canada.
- Three members of WG 4.3.1 attended workshop for the IPY project “Upper Atmosphere Monitoring for Polar Year” in Rome, Italy, 21-23 May 2007.
- Members of SC4.3 participated in press release and press conference about solar burst impact on GNSS (at the Space Weather Enterprise Forum 4-5 April 2007, Washington, D.C.).
- Four SC4.3 members participated in the Ionospheric Effects Symposium 3-5 May 2005, in Alexandria, Virginia.
- SC4.3 members from Canada, the United States and Italy presented a joint paper on scintillation effects associated with storm-enhanced densities at northern high latitudes at the ION NTM 2005, 24-26 January 2005, in San Diego, California.
- Four members of SC4.3 attended the “Dynamic Planet 2005” meeting in Cairns, Australia (26-28 August 2005). Members co-convened and co-chaired sessions on “Atmospheric studies using space geodetic techniques” and meetings were held to define terms of reference for the new WG4.3.3.
- Members participated in a national press conference on storm-enhanced density effects observed using GPS-based models of the ionosphere, at the 2005 AGU Fall Meeting, 5–9 December 2005, in San Francisco, California.
- Members have conducted joint fieldwork for scintillation studies in Antarctica during November 2005. A Canadian scintillation receiver was deployed by the USGS in Antarctica to explore the feasibility of establishing a long-term site in the region. Observations were collected near the pole for one month, and this data has been made available to WG4.3.1 for validation of scintillation index derivations.

Plans include support of a number of projects for International Polar Year 2007-2008. SC4.3 members will participate in fieldwork and data analysis of GNSS observations in high-latitude and polar regions - to derive information about ionospheric scintillation, ionospheric phenomena, and polar moisture budgets. Fieldwork includes deployment of GNSS receivers in northern Canada and Antarctica.

Most SC4.3 members are already involved in similar working groups and initiatives elsewhere. This SC must offer something unique through participation in its working groups. WG4.3.3 has been successful in offering a unique forum for meteorologists and geodesists to specifically explore requirements for weather model corrections. The other WGs have been less focused and, as a result, less active. The overall subject matter of SC4.3 is appropriate for future studies but WGs must be well-defined, with realistic goals, to be productive.

WG4.3.1 Ionspheric Scintillation

Chair: B. Fortes (Abdus Salam International Centre for Theoretical Physics)
Co-Chair: TBA

In accordance with outcomes of a WG meeting held at the Beacon Satellite Symposium 2004, members have established standards and validated methods for deriving reliable phase scintillation indices. Inconsistencies between methods implemented by various groups in the past have limited the effectiveness of data sharing to conduct global studies. Standard methods have now been established and implemented in post-processing techniques, and have been compared with internal receiver firmware models. Several members of this WG are involved in the ICESTAR IPY proposal. Members of WG4.3.1 have created an ftp-access database of high latitude GPS ionospheric scintillation data, hosted by National Institute of Geophysics and Volcanology, Rome, Italy.

Several members of WG4.3.1 conducted fieldwork in Svalbard, Norway, summer 2006 – to deploy ionospheric scintillation monitors for GPS scintillation studies.

WG4.3.2: Performance Evaluation of Ionosphere Tomographic Model

Chair: Z. Liu (Univ. of Calgary, Canada)
Co-Chair: A. Komjathy (JPL, USA)

Performance evaluations of various 3-D modeling techniques have been conducted for case study events. Members of the WG presented relevant papers and met at IES 2005 to discuss further joint collaboration. A current focus is the global assimilative ionosphere model (GAIM) approach, in which GPS ground and spaceborne observations, ionosonde measurements, and others are assimilated in a 4DVAR method. Requirements for reliable performance and applications in positioning have been published and presented at ION NTM 2005, ION AM 2005, IES 2005, and AGU 2005.

WG4.3.3: Numerical Weather Predictions for Positioning

Chair: M. Santos (Univ. of New Brunswick, Canada)
Co-Chair: A. Jensen (Denmark)

This WG was approved jointly with SC4.5 in September 2005, with a focus to study various technical aspects of using Numerical Weather Prediction (NWP) model data to map the effect of troposphere on space geodetic signals. Major objectives include standardizing the terminology used by both meteorological and geodetic communities, testing and validating procedures related to ray-tracing through NWP layers, and suggesting quality control criteria to be used for assessing the quality of tropospheric data and results obtained from them. Initial actions have included 1) compiling a list of 13 members (from both geodetic and meteorology communities), 2) building a detailed working plan, 3) compiling a list of relevant references, and 4) establishing a web site and building a discussion list. In 2006-2007, members investigates technical issues in support of the major objectives.

SC4.4: Applications of Satellite & Airborne Imaging Systems

Chair: Xiaoli Ding (The Hong Kong Polytechnic Univ., Hong Kong)
Vice-Chair: Linlin Ge (UNSW, Australia)
Secretary: Makoto Omura (Kochi Womens University, Japan)
Member-at-Large: Ramon F. Hanssen (TU Delft, The Netherlands)

Terms of Reference

Satellite and airborne imaging systems, primarily Synthetic Aperture Radar (SAR) and Light Detection And Ranging (LiDAR) systems, are increasingly being used for geodetic applications such as ground deformation monitoring due to seismic and volcanic activity and man-induced subsidence due to fluid extraction, underground mining, etc. This SC will endevour to promote and report on hardware/software research into these imaging systems that is relevant to geodetic applications. The SC will also facilitate communications and exchange of data, information and research results, in order to encourage wider application of these technologies, particularly in less developed countries. The SC will carry out its work in close cooperation with other IAG entities, as well as via linkages with relevant scientific and professional organisations such as ISPRS, FIG, IEEE.

Activities 2005-2007

- Members of SC4.4 contributed to the International Polar Year 2007-2008 and other Antarctic SAR (mainly ALOS/PALSAR) observation projects in close corporation with the National Institute of Polar Research (Tokyo, Japan) and other international organisations.
- SC4.4 will convene an InSAR session at the GS004 “Positioning & Applications”, XXIVth IUGG General Assembly “Earth: Our Changing Planet”, Perugia, Italy, 2-13 July 2007.
- Members of SC4.4 will participate in the International Geoscience and Remote Sensing Symposium, Barcelona, Spain, 23 - 28 July 2007.
- SC4.4 contributed to the organization of a special InSAR session at the Japan Geoscience Union Meeting 2007 (JGUM2007), Chiba, Japan, 19-24 May 2007.
- Members of SC4.4 participated in and presented their research results at the FIG Working Week “Strategic Integration of Surveying Services”, Hong Kong, 13-17 May 2007.
- Members of SC4.4 participated in and presented their research results 2007 ESA ENVISAT Symposium, Montreux, Switzerland, 23 - 27 April 2007.
- Members of SC4.4 participated in and presented their research results at the European Geosciences Union General Assembly, Vienna, Austria, 15 – 20 April 2007.
- Members of SC4.4 participated in and presented their research results at the FIG Congress, Munich, Germany, 8-13 October 2006.
- SC4.4 contributed to the organisation of the 2006 ERI (Earthquake Research Institute, The University of Tokyo) Workshop “New Generation InSAR”, Tokyo, Japan, 5 - 6 October 2006.
- Members of SC4.4 participated in and presented their research results at the International Geoscience & Remote Sensing Symposium & 27th Canadian Symposium on Remote Sensing, Denver, Colorado, 31 July – 04 August 2006.
- SC4.4 contributed to Geodesy and Geodynamics Summer School, Shanghai, China, 31 July – 10 August 2006.
- SC4.4 organised a Special Session, InSAR Geodesy and Geodynamics, at the Western Pacific Geophysics Meeting (WPGM), organised by the American Geophysical Union (AGU) in Beijing, China, 24-27 July 2006.
- Members of SC4.4 participated in and presented their research results the 3rd Int. Symp. on Future Intelligent Earth Observing Satellites, Beijing, China, 24-26 May 2006.

- SC4.4 organised a InSAR session at the 3rd IAG Symp. on Geodesy for Geotechnical & Structural Engineering, and 12th FIG Symp. on Deformation Measurements, Baden, Austria, 22-24 May 2006.
- Members of SC4.4 participated in and presented their research results at the ESA Fringe 2005 Workshop: Advances in SAR Interferometry from ENVISAT and ERS missions, 28 Nov – 2 Dec. 2005, Frascati, Italy.
- SC4.4 co-organised the 2005 InSAR Technology Workshop, Foresight of InSAR towards the ALOS/PALSAR at EORC/JAXA, Tokyo, Japan, 18 November 2005.
- Several members of SC4.4 participated in the International Geoscience and Remote Sensing Symposium (IGARSS) in Seoul, Korea, 25-29 July 2005 and presented research results on InSAR. A working meeting was held during the Symposium to discuss and plan the activities of SC4.4.
- SC4.4 contributed to the organization of the "Dynamic Planet 2005" symposium in Cairns, Australia, 26-28 August 2005. Several members participated in the symposium and the members held a working meeting with Prof. Chris Rizos, President of Commission 4, in Sydney after the symposium discussing the activities of SC4.4.
- SC4.4 co-sponsored the Asia Pacific Space Geodynamics (APSG) Workshop, Geodynamics and Natural Hazards, held in Hong Kong, 15-17 June 2005.

Plans for next 12 months

- Edit a special issue in Journal of Geodesy with a theme InSAR and Geodesy to be published in March 2008.
- Continue international collaboration on work for the International Polar Year 2007-2008 and other Antarctic SAR (mainly ALOS/PALSAR) observation projects.
- Members of SC4.4 will contribute to the organization of an InSAR special session at the Japan Geoscience Union Meeting 2008 (JGUM2008), Chiba, Japan, 25-30 May 2008.
- SC4.4 will organize an InSAR session at the 4th IAG Symp. on Geodesy for Geotechnical & Structural Engineering, and 13th FIG Symp. on Deformation Measurements, Lisbon, Portugal, 15-18 May.
- SC4.4 will propose to sponsor an InSAR session at the AOGS Assembly to be held in Bushan, South Korea, 2008.
- The work of all the four WGs can be continued. It can be considered to set up a new WG on geodetic applications of LiDAR.

<u>WG4.4.1 Permanent Scatterer / Corner Reflector / Transponder InSAR</u>

Chair: Fabio Rocca (Politecnico di Milano, Italy)
Co-Chair: Chao Wang (Institute of Remote Sensing Applications, Chinese Academy of Sciences)
No report submitted.

<u>WG4.4.2 Atmospheric Effects in InSAR / InSAR Meteorology</u>

Chair: Linlin Ge (UNSW, Australia)
No report submitted.

WG4.4.3 InSAR for Polar Regions
Chair: Makoto Omura (Kochi Womens Univ., Japan)
No report submitted.

WG4.4.4 Imaging Systems for Ground Subsidence Monitoring
Chair: Andrew Manu (Iowa State Univ., USA)
No report submitted.

SC4.5: Next Generation RTK

Chair:	Yang Gao (Univ. of Calgary, Canada)
Vice-Chair:	Lambert Wanninger (Ingenieurbüro Wanninger, Germany)
Secretary:	Wu Chen (The Hong Kong Polytechnic Univ., Hong Kong)
Member-at-Large:	Mark Caissy (Natural Resources Canada, Canada)
Member-at-Large:	John Raquet (Air Force Institute of Technology, USA)
Member-ar-Large:	Sunil Bisnath (York Univ., Canada)

Terms of Reference

Current carrier phase-based Real-Time Kinematic (RTK) positioning at the centimetre accuracy level requires the combination of observations from two GPS receivers, with one serving as the base station with known coordinates and another as the mobile/user station. One significant drawback for this approach, however, is the practical constraints imposed by the requirement that simultaneous observations be made at the user and reference stations, and that the user station be within the vicinity of the reference station typically up to 20 kilometres. Development of methods and algorithms to eliminate such constraints for increased flexibility and accessibility using RTK therefore presents a current trend. This SC will identify, encourage investigation into the important research issues and problems for the development of next generation RTK technologies, report on such developments, and will promote international collaborations among researchers and organisations from academia, government and private sectors. The latter will be done through linkages with sister scientific and professional organisations, and especially with the IGS.

Activities 2005-2007

- SC4.5.1 has produced a web site (http://network-rtk.info), collecting WG member contributions and providing a focus for research on network RTK.
- SC4.5 has made a significant contribution to the promotion of the precise point positioning technology in the past 4 years. To date, the technology has been widely recognised within the positioning community as well as in mapping and remote sensing fields. We have seen increased number of publications on the topic and increased research activities in this emerging field.
- SC4.5.3 published a special issue on precise positioning on moving platform in the "Journal of Geospatial Engineering", Vol 8, No1-2, 2006. Seven papers related to the topics of the WG are included.
- Yang Gao and Sandra Verhagen will each convene sessions at the GS004 symposium "Positioning & Applications", XXIVth IUGG General Assembly "Earth: Our Changing Planet", Perugia, Italy, 2-13 July 2007.
- Mark Caissy, member-at-large of SC4.5 and chair of IGS WG "Real Time Aspects", gave an update and status report on RTWG for the 29th IGS Governing Board Meeting held in

San Francisco, California, 10 December 2006. Chris Rizos is a member of the IGS Governing Board. Yang Gao became a member in the IGS “Real-Time Pilot Project” committee, 2007

- SC4.5.2 organised a Technical Session on “Precise Point Positioning” at the ION-GNSS, Fort Worth, Texas, 26-29 September 2006. Several members of other sub-commissions and working groups also made presentations at this conference.
- Yang Gao organised a Technical Session at Geoinformatics’2006 Toronto, Canada, 13-15 August 2006.
- Yanming Feng was a Session Chair at the International Symposium GPS/GNSS, Gold Coast, Australia, July 2006.
- Mark Caissy, member-at-large of SC4.5 and chair of IGS WG “Real Time Aspects”, co-chaired the Technical Session on “Real-time Network and Products” at the IGS Workshop in Darmstadt, Germany, 8-11 May 2006. Chris Rizos also attended.
- Members of WG4.5.1 co-organized and participated at NTRIP Symposium Technical Session on "Networked DGPS/RTK", Frankfurt (Germany), 6-7 February 2006.
- • Wu Chen, chair of WG4.5.3, was the chair of the local organising committee for International Symposium on GPS/GNSS, Hong Kong, December 8-10, 2005 and organized a Technical Session on “Positioning on Moving Platform”.
- A new Working Group 4.5.4 "Multiple Carrier Ambiguity Resolution (MCAR) Methods & Applications" was formed within SC4.5. The WG was formed to address an emerging research subject concerning about carrier phase ambiguity resolution with multiple frequency observations. The WG is chaired by Dr. Yanming Feng from the Queensland University of Technology, Australia.
- Members of WG4.5.1 co-organized and participated at ION GNSS 2005 Technical Session on "Networked-Based RTK", Long Beach, California, 13-16 September 2005.
- Sunil Bisnath, the chair of WG4.5.2, co-chaired ION GNSS 2005 Technical Session on "Precise Point Positioning”, Long Beach, California, 13-16 September 2005. The session, first started at GNSS04, has been the third year and will again have a session at ION GNSS06.

Plans for next 12 months

- SC4.5.1 will continue to include more contributions in addition to the current 5 areas on its web site (http://network-rtk.info). Several more contributions had been planned but they have been not been completed. One more contribution may be published in the coming weeks.
- SC4.5.2 will complete a white paper on Precise Point Positioning summarising PPP state-of-the-art and potential. Part of the paper will be presented at the XXIVth General Assembly of the IUGG “Earth: Our Changing Planet”, Perugia, Italy, 2-13 July 2007.
- SC4.5.4 plans to edit a research monograph to report the recent advances on MCAR methods and applications in 2007/2008.
- SC4.5.4 plans to organise a Technical Session on multiple frequency methodology and applications at IGNSS2007 to be held in Sydney, Australia, in 4-6 December 2007.
- SC4.5 will organise an international symposium on Precise Positioning and Orbit Determination in April/May 2008.

- Most current WGs will continue such as WG4.5.1, 4.5.2 and WG4.5.4 since the research subjects in those WGs are still the focal points towards the development of next generation RTK systems, demanding innovative solutions. But restructures are necessary to streamline overall research areas and directions for next generation RTK technology development including creating new WGs such as low earth orbit satellite sensor positioning.

WG4.5.1 Network RTK
Chair: Lambert Wanninger (Ingenieurbüro Wanninger, Germany)
Co-Chair: Ola Ovstedal (Agricultural Univ. of Norway, Norway)
No report submitted.

WG4.5.2 Carrier Phase based Precise Point Positioning
Chair: Sunil Bisnath (York Univ., Canada)
Co-Chair: Maxim Kechine (Delft Univ. of Technology, The Netherlands)
No report submitted.

WG4.5.3 High Precision Positioning on Buoys and Moving Platforms
Chair: Wu Chen (The Hong Kong Polytechnic Univ., Hong Kong)
Co-Chair: Mark Dumville (IESSG, Nottingham Univ., UK)
Oscar Colombo (NASA, USA)
No report submitted.

WG4.5.4 Multiple Carrier Ambiguity Resolution Methods & Applications
Chair: Yanming Feng (QUT, Australia)
Co-Chair: Hiroshi Isshiki (Japan)
No report submitted.

5) Reports from the Study Groups

SG4.1 Pseudolite Applications in Positioning & Navigation

Chair: Jinling Wang (UNSW, Australia)
Vice-Chair: Gethin Roberts (Univ. of Nottingham, UK)
Vice-Chair: Dorota Grejner-Brzezinska (OSU, USA)

Activities 2005-2007

- Study Group Discussion on the paper "Pseudolite and the Augmentation of GPS" (authored by Chris Rizos).
- Development of the study group website: http://www.gmat.unsw.edu.au/pseudolite/
- Jinling Wang chaired a Session Chair at the US ION's National Technical Meeting, Monterey, California, 18-20 January 2006. The session was on high precision positioning techniques including the integration of pseudolites with other sensors.
- Contributed to the Commission 4 report to VI Hotine-Marussi Symp. on Theoretical & Computational Geodesy, Wuhan, China, 29 May - 2 June 2006.
- Jinling Wang was a Session Chair at the Int. Symp. on GPS/GNSS, Hong Kong, 8-10 December 2005. The session included one paper on Pseudolite/GPS/INS integration.

- The study group plans to edit a special publication on pseudolite applications in positioning and navigation.
- The term of this SG ends mid-2007.

IC-SG4.2 Statistics & Geometry in Mixed Integer Linear Models, with Applications to GPS & INSAR

Athanasios Dermanis (Aristotle Univ. of Thessaloniki, Greece)

Terms of Reference

The presence of an unknown number of cycles in GPS observations of phase differences has generated a new challenging theoretical problem, which in its utmost generality may be described as the solution of over-determined equations with both real-valued and integer unknowns. Within this problem these particular issues emerge: (a) the selection and design of an optimality criterion that leads to a unique solution, (b) the development of computationally efficient algorithms for obtaining the optimal solution, especially with respect to the integer unknowns which require search within a discrete set, (c) the new types of distributions of the estimated real-valued and integer parameters, (d) particular geometry in connection with the estimated integer parameters, (e) the assessment of the accuracy of the solution in the presence of both random and systematic errors affecting the observations, and (f) new statistical hypothesis testing techniques.

Activities 2005-2007

For the future we plan no specific meeting since we co-organised the "VI Hotine-Marussi Symposium of Theoretical and Computational Geodesy", Wuhan, China, 29 May - 2 June 2006.

IC-SG1.1 Ionospheric Modelling and Analysis

Chair:	Claudio Brunini (Argentina)
Vice-Chair:	Susan Skone (Univ. of Calgary, Canada)

Terms of Reference

As a result of many years of research the climatology of the ionosphere is today quite well known. However, variations of the solar activity and emissions of plasma from the solar corona change the conditions of the Sun-Earth environment and can dramatically disturb the ionospheric mean conditions. The development of sophisticated high technological systems for navigation, telecommunication, space missions, etc., created the need of predicting the meteorological conditions of the space around the Earth, giving rise to a branch of knowledge that today is called space weather. Disruptions of the ionosphere caused by massive solar flares can interfere with or even destroy communication systems, Earth satellites and power grids on Earth. A stringent application of ionospheric models would be to provide real-time corrections and integrity information for aircraft navigation and precision approach.

Using large data bases of classical observations covering different geographical regions and different solar and geomagnetic conditions, several empirical ionospheric models were established. Among them, the International Reference Ionosphere (IRI) is probably the most widely used. IRI is continuously revised and updated through international cooperative effort of different type sponsored by the Working Group created by the Committee on Space Research (COSPAR) and the Union of Radio Sciences (URSI). Today ground-based and space-based GPS observations, and in a less extent observations of other space geodetic dual-frequency observing techniques, e.g., satellite altimetry, bring an unprecedented opportunity for ionospheric studies and may well revolutionize science and technology of the ionospheric meteorology. They provide high quality ionospheric information, with global coverage, simultaneity and time continuity and are easy and free available for ionospheric scientists.

Activities 2005-2007

No report submitted, SG has been inactive for a ver long time.

<u>IC-SG1.2: Use of GNSS for Reference Frames</u>

Chair: Robert Weber (Tech. Univ. of Vienna, Austria)
Co-Chair: C. Bruyninx (Belgium)

Terms of Reference

Up to now the operating satellite navigation systems GPS and GLONASS allow a huge user community easy access to reference frames very close to the most recent realization of the ITRS. The IAG Services IERS (International Earth Rotation and Reference Systems Service) and IGS (International GPS Service) provide the necessary products to tie these frames to the ITRF, which is based upon a set of estimated coordinates and velocities of stable stations observed by all space techniques. The design of the upcoming GALILEO system - its envisaged accuracy and the long-term stability implies - that also GALILEO will become a highly valuable technique for the definition and maintenance of the ITRF. The modernization of GPS and the completion of the GLONASS system will further improve the situation. The goal of Study Group 1.2 is to evaluate and support the use of GNSS for the definition and densification of the International Terrestrial Reference Frame (ITRF).

Activities 2005-2007

- Based on a preliminary reference network design the quality of the tie and anticipated time evolution of the GALILEO Reference Frame with the ITRF has been investigated.
- Members of the Working Group are part of the consortium that was chosen by the European Commission to carry out the project "Galileo Geodesy Service Provider (GGSP)". The GGSP will be responsible for providing the Galileo terrestrial reference frame and also for the links between the Galileo ground segment and the IAG services (IGS, ILRS, IERS). Since the Galileo project does not want to deal with the individual services, the GGSP will be the intermediary.
- The WG supported attempts to equip future GPSIII satellites with retroreflectors by providing technical background information. In this context the interaction with entities involved in the technical set up of modernized GPS (GPS III) and modernized GLONASS has been intensified, unfortunately not to a level similar to the current interaction with the Galileo project team.
- The major activity of the WG in 2006/2007 was the preparation of a 'White Paper on IGS requirements for new GNSS signals'. This paper takes into account expected upgrades of the GNSS space and ground segments and explores potentially optimal sets of GNSS-signals to be tracked by future geodetic GNSS receivers. In this context the paper deals with future TCAR and MCAR techniques, with error mitigation and with inter- and intrasystem biases.

- The revised Terms of Reference, meeting reports as well as technical papers are made available to the public via the Study Groups web-links:

http://mars.hg.tuwien.ac.at/Research/SatelliteTechniques/GNSS_WG_IGS/gnss_wg_igs.html
and
http://www.gps.oma.be/IAG-study-group/workprogram.php

- Second Meeting of WG/SG members with Galileo Project Team at ESOC, Darmstadt, Germany, March 2005.
- Meeting , IKK GALILEO, Vienna, Austria, June 2005.

  Topics: Galileo Concession, Supervisory Authority, GalileoSat Programme.
- Open WG-Meeting during AGU Fall meeting, San Francisco, California, December 2005.

  Topics: Status GNSS / IGLOS-PP / Satellite Antenna Phase-Pattern / DCBs
- Meeting of WG during IGS-AC meeting, ESOC, Darmstadt, Germany, May 2006
- EGU, Vienna, Austria, 2-7 April 2006, session on 'GPS, Galileo and GLONASS: Future Geoscience Challenges'.
- IGS Workshop, Darmstadt, Germany, 8-11 May 2006, session on 'GNSS Modernization and GNSS/LEO Synergies'.
- ION-GNSS, Fort Worth, Texas, 26-29 September 2006, session on 'Timing and Scientific Applications'.

6) GS004 Symposium at IUGG2007

IAG Commission 4 is responsible for organising the symposium GS004 "Positioning & Applications", at the XXIVth General Assembly of the IUGG "Earth: Our Changing Planet", Perugia, Italy, 2-13 July 2006. GS004 will take place over 1.5 days starting the afternoon of Thursday 5th July, and will be organised according to three primary themes:
a) The Challenges of Commission 4: How many of them Theoretical?
Convenor: Sandra Verhagen; co-convenor: Hansjorg Kutterer. This includes papers from those outlining the challenges, as well as those who can contribute to the solutions.
b) PPP v DGNSS: Competition or Complementary?
Convenor: Yang Gao; co-convenor: Bar-Sever Yoaz. We hear a lot about PPP, implying that somehow it will "take over" from current DGNSS techniques in the near future. A theme comparing/contrasting high-accuracy GNSS techniques, and include some IGS contributions (e.g. the implications for going real-time IGS).
c) InSAR/DInSAR: Geodetic Remote sensing?
Convenor: Xiaoli Ding; co-convenor: Linlin Ge. The IAG does not pay enough attention to SAR technology as does ISPRS and IEEE (IGARSS). So a combination of practical (results) and theoretical papers would be appropriate, as DInSAR has been recognised within the GGOS project as an important geodetic technology.

Over 150 abstracts were submitted. After culling and transferring several papers to other symposia, there were still about 120 abstracts. Only 25 were selected for oral presentation. The remainder will be presented as posters.

Aliasing in Gravity Field Modelling

Chair: Christian C, Tscherning

Terms of Reference

A gravity field observable contain information about all coefficients of its associated spherical harmonic series and of other signals of time-varying character. This makes numerical gravity field procedures prone to aliasing. The effect is most clearly seen when estimating spherical harmonic coefficients, but should also be present when regional models are constructed using Fourier series.

In a first phase, only the effects related to the static gravity field will be investigated. If possible, dealiasing and time-varying effects will be studied in a second phase.

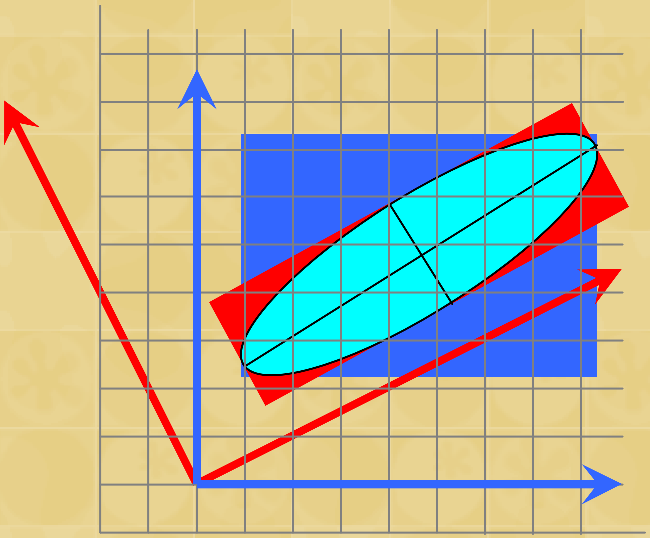
The joint working group will initially through a series of controlled numerical experiments study the effect of aliasing. Simplified as well as realistic global or regional datasets will be generated using coefficients from a spherical harmonic expansion from degree N, 2*N, 3*N etc. to a maximal degree, e.g. 1800.

Final Report

Joint Working Group of the ICCT and Commission 4:

Statistics and Geometry in Mixed Integer Linear Models, with Applications to GPS and InSAR

June 2007



Statistics and Geometry in Mixed Integer Linear Problems with Applications to GPS and InSAR

Chair: Athanasios Dermanis

Joint with Commission 4

Terms of Reference

The presence of an unknown number of cycles in GPS observations of phase differences has generated a new challenging theoretical problem, which in its outmost generality may be described as the solution of over-determined equations with both real-valued and integer unknowns. Within this problem these particular issues emerge:

(a) the selection and design of an optimality criterion that leads to a unique solution;

(b) the development of computationally efficient algorithms for obtaining the optimal solution, especially with respect to the integer unknowns which require search within a discrete set;

(c) the new types of distributions of the estimated real-valued and integer parameters;

(d) particular geometry in connection with the estimated integer parameters;

(e) the assessment of the accuracy of the solution in the presence of both random and systematic errors affecting the observations;

(f) new statistical hypothesis testing techniques.

Objectives

- Attract the attention of researchers outside geodesy (statisticians, mathematicians) to this fascinating topic, with a view towards other possible applications beyond those encountered in geodesy.
- Establish a channel of cooperation on the ground of methodology and support a closer collaboration between “theoreticians“ and “practitioners”.
- Encourage frontier research in the subject concerning e.g. the evaluation–comparison of various different solution principles (e.g. least squares, Bayesian statistics, best linear estimation) as well as of the different algorithms for the realization of the solutions.

Statistics and Geometry in Mixed Integer Linear Problems with Applications to GPS and InSAR

Chair: Athanasios Dermanis

Joint with Commission 4

Membership

Athanasioss Dermanis	Greece
Mohamed Abdel-salam	Canada
Clara de Lacy	Spain
Donghyun (Don) Kim	Canada
Georgia Fotopoulos	Canada
Brigitte Gundlich	Netherlands
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Kentaro Kondo	Japan
Christopher Kotsakis	Greece
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Linyuan Xia	China
Marcelo Santos	Canada
Burkhardt Schaffrin	USA
Sandra Verhagen	Netherlands

Statistics and Geometry in Mixed Integer Linear Problems with Applications to GPS and InSAR

Chair: Athanasios Dermanis

Joint with Commission 4

Research Highlights

Specific integer ambiguity resolution issues related to GNS/GPS technology

Specific integer ambiguity resolution issues related to synthetic aperture radar interferometry

Galileo – Modernized GPS (Three Carrier Frequencies)

Statistical Testing – Validation – Reliability - Success Rates

New Methods or Improvements and Modifications - New Solution Strategies

Theoretical Advances and Elaborations

Penalized ambiguity resolution .

Evaluation and good approximations of joint probability density function (PDFs) for ambiguity residuals

Integer aperture (IA) ambiguity estimatior (largest possible success rate given a user-defined fail rate)

Best integer equivariant (BIE) estimator (superior to the best linear unbiased estimator). Approximation and fast computation of BIE retaining the property of integer equivariance.

Integer aperture bootstrapping estimator (fail-rate controlled by the user)

Integer aperture least-squares (IALS) estimator (performance measured by its fail-rate and success-rate .

Construction of Voronoi cells (pull-in regions), fitting figures of simple shape from inside and outside. New lower and upper bounds on the probability of correct integer estimation.

Extention of least-squares collocation (trend-signal-noise type model) to integer trend parameters.

Minimum mean squared error prediction (best prediction) for models with real and/or integer parameters.

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Dynamic Theories of Deformation and Gravity Fields

Chair: Deter Wolf

Terms of Reference

Recent advances in ground-, satellite and space-geodetic techniques have detected temporal changes of deformation and gravity covering a wide period range. These changes are related to different types of processes acting near the earth's surface or in its interior.
Forward and inverse modelling of the deformation and gravity changes require the development of dynamic theories for 1-D, 2-D and 3-D earth models.

Program of activities

- Development of generalized Love-number formalisms for static forcing functions (normal and tangential surface forces, volume forces, dislocations)
- Development of generalized Love-number formalism for periodic forcing functions Fourier-transformed Love numbers) and a periodic frocing functions (Laplace-transformed Love numbers)
- Development of 3-D viscoelastic earth models for modelling processes responsible for deformation and gravity changes
- Investigation of effects due to density stratification, compressibility, rheology and lateral heterogeneity
- Forward modelling of deformation and gravity changes caused by atmospheric, cryospheric, hydrospheric and internal forcing functions
- Inverse modelling of measured deformation and gravity changes in terms of mantle viscosity and forcing functions

2 Workshops on

Deformation and Gravity Change:
Indicators of Isostasy, Tectonics, Volcanism and Climate Change

1st Workshop
Casa de los Volcanes, Lanzarote,
Canary Islands, Spain
1–4 March 2005

Special Issue of
PAGEOPH 164, 633-878 (2007)

2nd Workshop
Casa de los Volcanes, Lanzarote,
Canary Islands, Spain
27–30 March 2007

Special Issue of
PAGEOPH (in preparation)

Quslity Measures, Quality Control and Quality Improvement

Chair: Hansjörg Kutterer

Joint with Commission 1 and Commission 2

General Information

- Various notions of quality in Geodesy and related fields
  - Definition for results or products
  - Relevance of underlying processes
- Industrial standards such as ISO 9000 family
  - Guide to the Expression of Uncertainty in Measurements
  - Complete evaluation and modelling of observation processes
- Situation
  - No final recommendation or convention on quality measures in Geodesy
  - Open problems in modelling such as for intra-technique combination of space-geodetic techniques
  - No process-related modelling of quality in Geodesy

Quslity Measures, Quality Control and Quality Improvement

Chair: Hansjörg Kutterer

Joint with Commission 1 and Commission 2

Advances in Modelling

- **Extensions of the stochastic model of space-geodetic techniques**
  - VLBI with estimation of variance and covariance components (MINQUE): Tesmer and Kutterer (2004)
  - GPS based on turbulence theory: Schön and Brunner (2007)
  - GPS with measured carrier-to noise density ratio: Wieser (2007a, b)
  - Statistical analysis of GPS time series: Bischoff et al. (2005, 2006): outside WG
- **Quality assessment in reference frame determination**
  - Combination procedures: Krügel and Angermann (2007)
  - Intra-technique combination including the assessment of the Operator-Software impact: Kutterer et al. (2007)
- **Neuro-Fuzzy modelling**
  - Prediction of Earth orientation parameters: Akyilmaz and Kutterer (2005)
  - TEC prediction: Akyilmaz and Arslan (2007)
  - Structural monitoring: Boehm and Kutterer (2007)

Quslity Measures, Quality Control and Quality Improvement

Chair: Hansjörg Kutterer

Joint with Commission 1 and Commission 2

Advances in Estimation and Filtering

- **Outlier identification**
  - Maximum correlation adjustment: Neitzel (2003, 2004)
  - Robust estimation: Yang (2005a, b)
  - BLIMPBE for bias control: Snow and Schaffrin (2004, 2007)
- **Total Least Squares Estimation**
  - Coordinate transformations: Schaffrin and Felus (2005, 2007), Akyilmaz (2007)

Quslity Measures, Quality Control and Quality Improvement

Chair: Hansjörg Kutterer

Joint with Commission 1 and Commission 2

Extended Uncertainty Budget

- **Fuzzy extension of parameter estimation and filtering**
  - Extended error models and extended estimators: Schön (2003), div. Schön and Kutterer
  - Kalman filtering: Neumann and Kutterer (2007)
  - GPS uncertainty budget: Schön and Kutterer (2006)
- **Fuzzy-extended hypothesis tests**
  - Extended test strategy: Kutterer and Neumann (2007)
  - Outlier detection: Neumann et al. (2006)
- **Extended GPS uncertainty budget**
  - Impact of errors in tidal loading models on GPS coordinate time series: Penna and Stewart (2003), Stewart et al. (2005), Penna et al. (2007), Stewart and Penna (2007)

Quslity Measures, Quality Control and Quality Improvement

Chair: Hansjörg Kutterer

Joint with Commission 1 and Commission 2

Conclusions and Outlook

Model refinement still a challenging task in the quality context

- Example: GPS quality
  - Refined stochastic model
  - Multipath
  - Other station effects
- Extended sensor and error models, quality of physical object models
- Rigorous distinction of different types of uncertainty needed
  - Broad selection of mathematical theories
  - Relevance for metrological issues

Extended process-related quality models are still missing

- Extended set of quality parameters: Wiltschko (2004) → outside WG
- Quality-based process optimization in Geodesy

Integrated Theory for Crustal Deformation

Chair: Kosuke Heki

Joint with Commission 1 and Commission 3

Terms of Reference

Owing to recent densification of Global Positioning System arrays in boundary zones of tectonic plates, e.g. in Japan and western North America, there are increasing demands for realistic theoretical models and computational programs incorporating recent theoretical progresses. The joint WG, with expertise in various fields of crustal deformation studies, is expected to strengthen ties between modellers and those working on various observational data of crustal deformation.

Objectives

The WG is supposed to bridge the three commissions by identifying important theoretical problems in crustal deformation studies, looking for solutions, feeding back solutions to research communities. These problems will include, surface deformation of the realistic Earth due to dislocation at depth, crustal movement due to various loads, analysis of time series including jumps and periodic components, combination of data from different techniques, finite element methods to simulate crustal activities in subduction zones, incorporation of viscoelasticity, etc.. The goal is for worldwide researchers to share the most advanced information on models and software packages for particular issues in crustal deformation studies.

Integrated Theory for Crustal Deformation

Chair: Kosuke Heki

Joint with Commission 1 and Commission 3

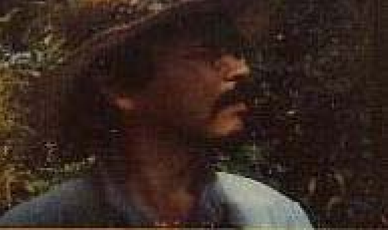
Activities 2003-2007

Establish standard procedures for crustal deformation studies in convergent plate boundaries

1. Models to relate fault dislocation to surface deformation
   (from simple elastic half space to the realistic earth)

2. Sophisticated technique to estimate fault slip distribution from surface deformation data
   (efficient inversion technique)

3. Sophisticated technique to separate secular, transient and periodic time variations
   (time series analysis for data with composite components)

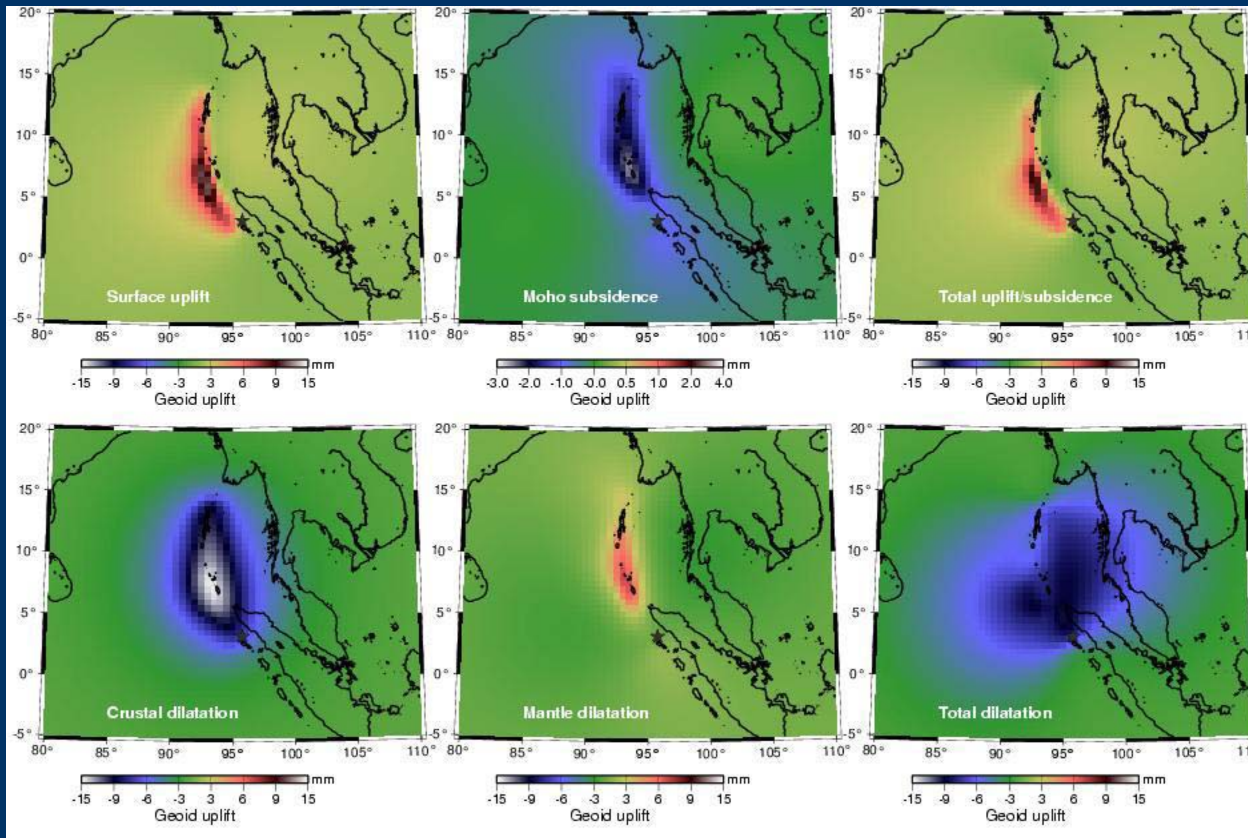


Integrated Theory for Crustal Deformation

Chair: Kosuke Heki

Future themes of scientific interest

1. Unified model for positioning and gravimetry



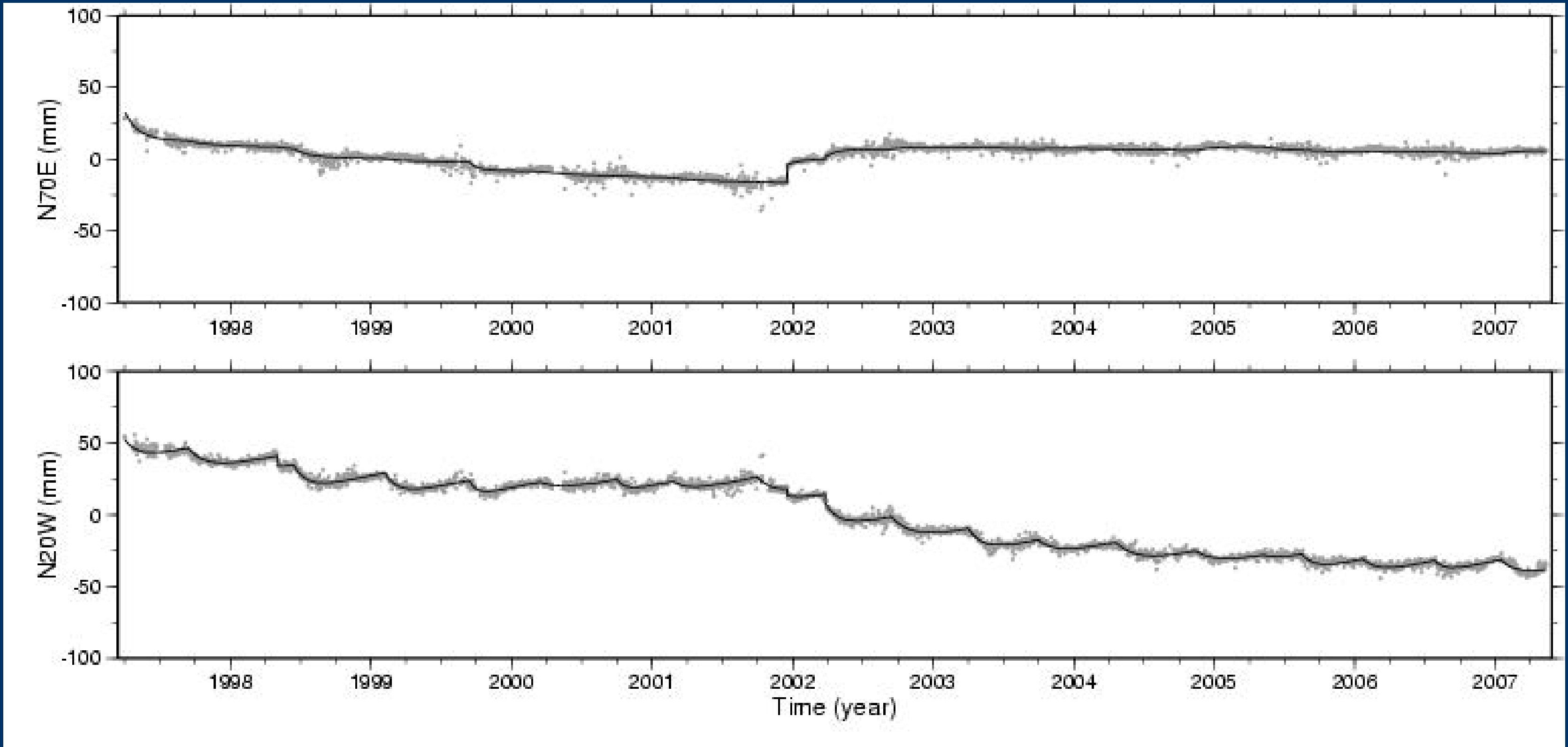
Geoid signatures by 2004 Sumatra Eq. calculated from the same subroutine (DC3D) as we use to calculate crustal deformation in GPS studies (Ogawa & Heki, GRL, 2007)

Integrated Theory for Crustal Deformation

Chair: Kosuke Heki

Future themes of scientific interest

2. Efficient way of analyzing complicated time series



Time series of horizontal position of Hateruma (Okinawa, Japan), composed of secular plate movement, coseismic jumps, and repeating slow slip events (Kataoka & Heki, in preparation).

Multiscale Modelling of the Gravity Field

Chair: Willi Freeden

Joint woith Commission 2

Introduction

During the last decades technological progress has changed completely the observational methods in all fields of geosciences with a trend to achieve immediate results, thus reducing time and costs.

A reconstruction of the gravity field from data material coming from satellite as well as airborne and terrestrial measurements requires a careful multiscale analysis of the gravity potential, fast solution techniques, and a proper stabilization of the solution by regularization. While global long wavelength modelling can be adequately done by use of spherical harmonic expansions, harmonic splines and/or wavelets are most likely candidates for medium and short-wavelength approximation.

The working group intends to bring together scientists concerned with the diverse areas of geodetically relevant wavelet theory in general and its applications. An essential field of research is the specific character of geodetic multiresolution methods used in addition or in contrary to standard spectral techniques based on spherical harmonic framework.

Objectives

- Theoretical research in the field of spherical and ellipsoidal wavelets as well as wavelet introduction and modelling on geodetically relevant surfaces (like spheroid, geoid, (actual) Earth's surface).
- Studies of harmonic wavelets in geodetic boundary-value problems (e.g., Runge-Walsh wavelets, layer potential wavelets, etc).
- Studies on spline/wavelet kernel modelling, multiscale pyramid algorithms via kernel functions known from (least squares) collocation and spline approaches, noise cancellation, least squares adjustment and spline smoothing vs. multiscale thresholding, etc,
- Development of specific numerical methods: fast wavelet transform, tree algorithms, data compression, domain decomposition techniques, fast multipole methods, panel clustering, data transmission, etc.
- Comparison of spherical harmonic and/or wavelet modelling: Combined spectral and multiscale expansion of the gravitational potential, degree variances vs. local wavelet variances, spectral and/or multiscale signal to noise thresholding, etc.
- Investigation of different wavelet types in geodetic pseudodifferential equations (using numerical methods such as collocation, Galerkin method, least-squares approximation, etc).
- Regularization of inverse problems by multiresolution, locally reflected multiscale vs. globally reflected spectral regularization, multiscale parameter choice strategies, multiscale modelling in SST, SGG.

Multiscale Modelling of the Gravity Field

Chair: Willi Freeden

Activities

Presentations at several conferences:

– Workshop ”Inverse Problems”, Trippstadt (24.-25.11.2005) (organizers: W. Freeden ,V. Michel).
– Workshop ”Multiscale Methods in Geodesy”, Helsinki, November/December 2005.
– Fall Meeting of the American Geophysical Union (AGU) in San Francisco, December 2005.
– GAMM Annual Conference, Berlin, March 2006.
– Hotine-Marussi Symposium ”Theoretical and Computational Geodesy”,Wuhan (China), May/June 2006.
– 1st Int. Symposium of the International Gravity Field Service (IGFS), Istanbul (Turkey), Aug/Sept 2006.
– Status-Seminar ”Observation System Earth from Space”, Bonn, September 2006.
– Approximation Methods for Problems on the Sphere. DMV Annual Conference, Univ. Bonn, Sept 2006.
– GeoBerlin, Berlin, October 2006.

Multiscale Modelling of the Gravity Field

Chair: Willi Freeden

Activities

Cooperations

• Cooperation between the groups in Kaiserslauten and Munich (R. Rummel) about multiscale modelling of temporal changes of the gravitational field measured by GRACE
(M.J. Fengler, W. Freeden, A. Kohlhaas, V. Michel, T. Peters: Journal of Geodesy, 2007, 81:5-15).

• Cooperation between the groups in Kaiserslautern) and Stuttgart (E. W. Grafarend)in form of a joint DFG-project: Inverse Multiscale Geoid Computation (IMGC).

• Cooperation between the groups in Delft (J. Kusche) and Kaiserslautern about Wavelet Modelling of satellite data and its combination with regional terrestrial data.
(M. J. Fengler, W. Freeden, V. Michel: Geophysical Journal International, 157, 499-514, 2004;
M. J. Fengler, W. Freeden, J. Kusche: Proceedings of the 2nd CHAMP Science Meeting,Springer, 2004, 139-144).

• Cooperation between the groups in Frankfurt (H. Schmeling) and Kaiserslautern about plume detection from gravity and topology.

• Cooperation between GeoForschungsZentrum (M. Rothacher) and Kaiserslautern about Time Variable Gravity and Surface Mass Processes: Validation, Processing andFirst Application of New Satellite Gravity Data (TIVAGAM) within the BMBF /DFG Sonderprogramm ”Geotechnologien”.

• Cooperation with University of Buchs (Switzerland).
(W. Freeden, S. Gramsch, M. Schreiner: Preceedings VI Htine-Marussi Symposium, 2007,
T. Fehlinger, W. Freeden, S. Gramsch, C. Mayer, D. Michel M. Schreiner: ZAMM, submitted, 2007)

• Contacts to the group of Prof. Dr. M. Vermeer in Helsinki.

Multiscale Modelling of the Gravity Field

Chair: Willi Freeden

Workshop "Inverse Problems"
24-25 November 2005,
Trippstadt / Kaiserslautern

Organized by: W. Freeden, V. Michel, J. Flury

Participants:

F. Bauer,
M. Becker
B. Büchler
M. Burger
J. Cai
D. Constantinescu
I. Einarsson
M. Fengler
J. Flury
W. Freeden
E.W. Grafarend
E. Groten
M. Grothaus
B. Heck
B. Hofmann
T. Hohage
W. Jacoby
B. Kaltenbacher
J. Keiner
A. Kohlhaas
P. Kügler
J. Kusche
P. Maaß
T. Maier
P. Mathe
C. Mayer
V. Michel
Z. Nashed
J. Prestin
S. Pereverzev
T. Peters
A. Rieder
R. Rummel
W. Rundell
U. Schäfer
E. Schock
M. Schreiner
F.J. Simons
N. Sneeuw
U. Tautenhahn
P. Xu

Bureau Gravimétrique International

Project 2007-2011

Presented by

BRGM	Bureau de Recherches Géologiques et Minières
CNES	Centre National d'Etudes Spatiales
CNRS/INSU	Centre National de Recherche Scientifique Institut National des Sciences de l'Univers
EOST	Ecole et Observatoire des Sciences de la Terre
ESGT	Ecole Supérieure des Géomètres et Topographes
UM2/GM	Université Montpellier 2 / Geosciences Montpellier
IGN	Institut Géographique National
IPGP	Institut de Physique du Globe de Paris
IRD	Institut de Recherche pour le Développement
SHOM	Service Hydrographique et Océanographique de la Marine

Foreword

This proposal is submitted to the International Gravity Commission (IGC) of the International Association of Geodesy (IAG) at the 24th IUGG (International Union of Geodesy and Geophysics) General Assembly (July 2-13, 2007), Perugia, Italy. It is aimed at presenting the new project of BGI activities in France for the next four years.

The proposal is structured in three sections presenting (Section 1) the BGI in the international and national contexts (history, status, objectives and tasks, main achievements), (Section 2) the new challenges and the proposed actions (including a brief description of the recent activities at BGI in order to shed light on how the continuity of the present BGI services will be ensured) and (Section 3) the proposed operational plans to continue BGI activities, hopefully with some improvement and also enhancement with respect to gravity interests and recent advances in the area of gravimetry.

The ten supporting French organizations which planned contributions are presented in section 3. They have agreed that if and when the present proposal is accepted, a covenant between them will be established and will describe in detail and guarantee their respective inputs to the hosting and running of BGI over four year renewable periods.

A synthetic report (Annex A) summarizes the main activities and major achievements of BGI for period 2003-2007. The C.V. of the proposed new Director is given in Annex B.

Introduction

Over the last 50 years, BGI has 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 such as validation and valorization of gravity or geoid data, bibliography database, online access to reference gravity stations, provision of tutorials and educational materials, expertise, etc.

Within the last decade, the measuring techniques in gravimetry have been significantly improved, providing new advances in the determination of the earth gravity field and its variations at any temporal and spatial scale. These improvements concern not only ground measurements but also airborne, seaborne and sea bottom measurements which are now complemented by a new type of satellite gravity data. New geodetic and gravity standards and reference systems are defined by geodesists and geophysicists. These evolutions lead to an increasing interest of the Earth sciences community in gravity data for a wide variety of applications (geodesy, physics of the earth, hydrology, oceanography, glaciology, geodynamics, tectonics, seismology, volcanology, earth tide studies, etc.). Consequences of these evolutions on BGI database and activities are expected.

In terrestrial gravimetry, three main inputs can explain the higher quality of the newly acquired gravity observations. (i) The development of new generations of gravity sensors (absolute and relative gravity meters, gradiometers...) and their consequences on accurate determinations of the earth gravity field in most environmental conditions (on shore, off shore and airborne surveys), on the definition of repeated or permanent monitoring networks, etc. (ii) The use of the satellite positioning techniques (GNSS) in land and marine gravity surveys providing more reliable gravity data at a worldwide scale and enhancing co-location of gravity and geodetic observables. (iii) The availability of precise global topography (SRTM for instance) and bathymetry models that contributes to map precisely the variations and anomalies of the earth gravity field.

In the same time, the first gravity-dedicated satellite missions CHAMP[1] and GRACE[2] launched in 2000 and 2002 respectively, provided a new class of information on the static gravity field and on its temporal variations. The imaging of mass transfer at global and regional scales within the superficial layers of the earth can be now retrieved from space. The future GOCE[3] mission (to be launched in early 2008) will also provide the first mapping of the earth gravity field from global to local scales with unprecedented accuracy. These satellite data are defining new standards in gravity field modeling in global and regional scales. Nevertheless, instead of replacing the ground based gravity measurements, these new satellite measurements enhanced their complementarities with terrestrial data. The combination of these techniques thus provides to the Earth science community a continuum of gravity information over the whole spectrum of frequency with strong overlaps between space, ground, sea and airborne observations that need to be calibrated and combined with each others. This enhances the role of global database centers, such as BGI, in archiving the newly available terrestrial or satellite observations and providing updated and validated information to the Earth science community.

In this context we propose to maintain and to improve the BGI services aimed to compile, validate and redistribute gravity data and related information (reference base stations, bibliography database, etc.). Tasks which were not well accomplished, such as the systematic collection and archiving of absolute measurements will be realized. New orientations taking into account the recent developments in database management will be proposed to ease the data accessibility from the BGI database (open access and direct download of public data) and to support its interaction with other existing gravity related databases. As successfully demonstrated in the past, we also think that a contribution of BGI to educational and research activities, valorizing its activities and its global data base, contributes to improve the efficiency and the quality of the services.

To achieve these objectives an updated organization of BGI strengthened by its supporting national and international organizations is proposed.

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[1] CHAMP: high-low satellite-to-satellite tracking system using GPS; accelerometer for measuring non-gravitational forces; launch 07-2000; mission duration 5 years.

[2] GRACE: low-low satellite-to-satellite tracking system using microwaves; GPS on-board receiver; Accelerometers for measuring non-gravitational forces on both satellites; launch 03-2002; mission duration 5 years.

[3] GOCE: satellite gradiometry mission; GPS/GLONASS receiver on-board; drag forces control by common mode accelerometer measurements; launch late 2007; mission duration 20 months.

1. CONTEXT

The present proposal is very dependent on the history of BGI and on its present functioning. It is based on the experience gained at BGI over the last decades and on the long term partnership between BGI and its supporting international and national organizations. Detailed reports from Balmino (1998) and Barriot (2004), the previous Directors of BGI, present the terms and references, the activities and evolution of BGI between 1979 and 2004. A brief presentation from these reports is given hereafter to enhance the present-day role of BGI in the international and national contexts.

1.1. BGI history: a short summary

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 and superconducting gravity meters, birth of spatial geodesy, etc.) provided significant increases of the number, diversity and accuracy of the gravity field observables. Following these evolutions, BGI contributed to provide original database and services for a wide international community concerned by the studies of the earth gravity field.

BGI, an international service

BGI is one of the offices of the Federation of Astronomical and Geophysical 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 Organisation (UNESCO). It belongs to the International Association of Geodesy (IAG) of the International Union of Geodesy and Geophysics (IUGG). 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) and ICET (International Center for Earth Tides). The overall goal of IGFS is to coordinate the servicing of the geodetic and geophysical community with gravity field-related data, software and information.

International Union of Geodesy and Geophysics
Union Géodésique et Géophysique Internationale

IAG	IAGA	IAHS	IAMAS	IAPSO	IASPEI	IAVCEI

International Association of Geodesy (IAG)
International Association of Geomagnetism and Aeronomy (IAGA)
International Association of Hydrological Sciences (IAHS)
International Association of Meteorology and Atmospheric Sciences (IAMAS)
International Association for the Physical Sciences of the Oceans (IAPSO)
International Association of Seismology and Physics of the Earth's Interior (IASPEI)
International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)

Associations of the IUGG (International Union of Geodesy and Geophysics)

IGFS (International Gravity Field Service)
Director Rene Forsberg (Danish National Space Center)

International Gravimetric Bureau (**BGI**) - *Director R. Biancale (CNES/GRGS Toulouse, France)*
Collection, archiving and distribution of gravity data

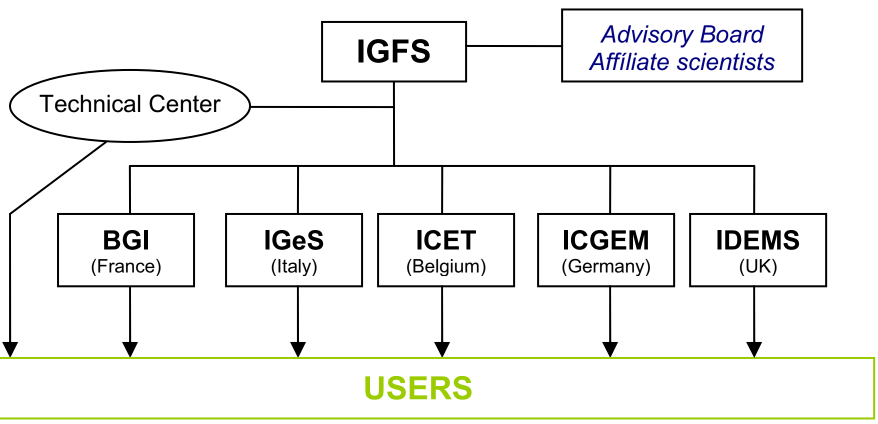
International Geoid Service (**IGeS**) – *Director R. Barzaghi (POLIMI Milani, Italy)*
Collection and distribution of geoid model, geoid schools

International Center for Earth Tides (**ICET**) – *Director B. Ducarme (ORB Brussels, Belgium)*
Collection and archiving of global earth tide data

International Center for Global Earth Models (**ICGEM**) – *Director J. Kusche (GFZ Potsdam, Germany)*
Distribution of satellite and surface spherical harmonic models

International DEM Service (**IDEMS**) – *Director P. Berry (DeMontfort University, UK)*
Global Digital Terrain Models

Technical Center of the IGFS – *chief geodesist S. Kenyon (NGA St Louis, USA)*
Advise on global models, geoid and gravity, supplementing other services



Structure of the IGFS (International Gravity Field Service)

BGI has had its offices located in France since its creation. Today, it is a permanent service of the Observatoire Midi-Pyrénées (OMP) in Toulouse, accredited by the Institut National des Sciences de l'Univers (INSU) and supported by ten French organizations involved in the activities of BGI.

BGI in France

BGI has been hosted by French organizations since its beginning in 1951. Under his first director, Reverend Father Lejay, it operated at the premises of the Society of Jesus in Paris, and its main objectives were at the instrumental and network settlement levels. The second director, P. Tardy, transferred the activities to IGN where he put the emphasis on archiving (cataloguing at that time) gravity data, and contributing to the establishment of a worldwide network - which was done under the leadership of IGC (this led to IGSN71); the Bulletin d'Information was regularly published. His successor, J.J. Levallois, recognized the growing importance of surface gravimetry in the global modeling of the Earth's gravity field as an invaluable complement to satellite data, also in physical geodesy for the determination of the geoid; his impulse was also determinant in starting the digitization of the gravity measurements in 1976 - with the help of BRGM, which resulted in the first BGI computerized archives (on magnetic tapes) ; at that time the service had been moved to and supported by IPGP where gravity data were also used in studies of regional geophysical nature. In 1979, the Groupe de Recherche de Géodésie Spatiale (GRGS), a French federation of several teams working in the area of satellite geodesy, made a proposal to emphasize within BGI the synergy between satellite and surface gravity observations. This resulted, after the 17th General Assembly of IUGG (Canberra, Australia) at which this proposal was accepted, in the transfer of leadership to GRGS with the major support of BRGM, CNES and IGN (plus, a few years later, of INSU - a body of the French National Scientific Foundation: CNRS), and soon after to moving BGI to Toulouse in the premises of the technical Space Center of CNES. Since 1979, BGI has been housed in the Observatoire Midi-Pyrénées (OMP) for convenience and has been directed by G. Balmino (1979-1998) then by J-P. Barriot (1998-2007).

Since 1998, BGI has been supported by 10 French Organizations (see section 3) whose contributions to BGI over four year renewable periods are defined by a covenant.

1.2. BGI today

Tasks and objectives

The main task of BGI, as defined in the "Geodesist Handbook, 2004" is to collect, on a world-wide basis, all existing gravity measurements and pertinent information about the gravity field of the Earth, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes.

The data and products consist in: gravimeter observations (mainly location - three co-ordinates, gravity value, corrections, anomalies,...), mean free-air gravity values, gravity maps, reference station descriptions, publications dealing with the Earth's gravity. BGI also has access through his host agencies to satellite altimetry derived geoid heights (from Geos 3, Seasat, Geosat, ERS-1, ERS-2, Topex/Poseidon, etc.) and more recently to satellite derived gravity data (CHAMP, GRACE and soon GOCE); spherical harmonic coefficients of current global geopotential models; mean topographic heights. These data are sometimes used internally for data validation and geophysical analysis.

The data collection activities were especially conducted in the framework of large regional projects aimed to densify the world data coverage. BGI has put emphasis on the validation of received measurements, so as to improve the quality of the delivered information.

The current users of BGI services are:

- Geodesists (modeling of the earth gravity field, global and local geoid models, definition of the ocean mean surface, etc.)
- Geophysicists and geologists from universities, research laboratories, mining and petroleum companies (solid earth, oceanography, oil and mineral resources, resources hydrology, natural hazards, etc.)
- Industrials (developments of systems for inertial navigation, aeronautic, etc.)
- Developers of measuring instruments (balances, etc.)
- School and Universities (teaching)
- Military organizations

Main achievements

BGI has operated in a favorable context with the support of several French organizations. Thanks to this, permanent offices, permanent staff, logistics, computer equipment and time and travel money were provided. Details accounts of the achievements carried out at BGI along the last decades are given in reports from Balmino (1998) and Barriot (2004).

The main activities consist of :

- data collection,
- data archiving (ORACLE based, on a mainframe),
- data validation (thanks to various software packages developed in house, some with the contribution of Working Groups of IGC and of IAG scientists); this implies much scientific activity (e.g. use of satellite altimetry derived geoid heights, prediction methods, use of DEM,...),
- data distribution on CD-Roms, and via a server,
- maintenance of archives (reference stations, maps, bibliography) and their upgrades,
- provision of general information (data base contents, description of base stations, algorithms - and sometimes software, etc...) via a dedicated server (http://bgi.cnes.fr:8110/)
- publication of the Newton's Bulletin (in collaboration with ICET) with information on scientific or technical results in gravity and geoid, on meetings,...
- publication of data catalogues, of National Reports,
- education : providing tutorials put on the BGI server, contributig to summer schools,
- services such as performing the (cross-) validation of some data sets at the request of users or/and data contributors, gridding data sets, computing reference gravity from a global spherical harmonics model, etc...

A synthetic report in **Annex A** summarizes the main activities and major achievements of BGI for period 2003-2007.

2. NEW CHALLENGES AND PROPOSED ACTIONS

As mentioned above, the recent evolutions in gravimetry and geodesy methods and the launch within this decade of three satellite missions dedicated to the recovery of the earth gravity field have a direct impact on the activities of datacenters such as BGI. New interactions are required with different communities involved in gravimetry as for instance: with end-users of gravity data or products; with institutions involved in data acquisition as well as in research and development or educational activities; with other datacenters collecting complementary (satellite, airborne or ground based) gravity and geodetic data at regional or global scales. Up to now, BGI has been very reactive to consolidate and to improve its tasks and services to better match with such emergent constraints and opportunities.

According with the terms and references of BGI, we propose some specific actions to be continued or initiated for the next four years. They concern (i) tasks of service for data collection, validation and redistribution (section 2.1), (ii) activities of diffusion of gravity related information [section 2.2], (iii) educational activities [section 2.3] and (iv) research and development activities [section 2.4].

The main orientations consist in the following:

- to consolidate the terrestrial gravity databases (relative and absolute),
- to ease the consultation and diffusion of gravity data and products for end-users,
- to provide adequate data and services for both geodesists and geophysicists,
- to strengthen the contribution of BGI through its supporting organizations in educational, research and development activities aimed to maintain a high level of competence and its reactivity to external solicitations.

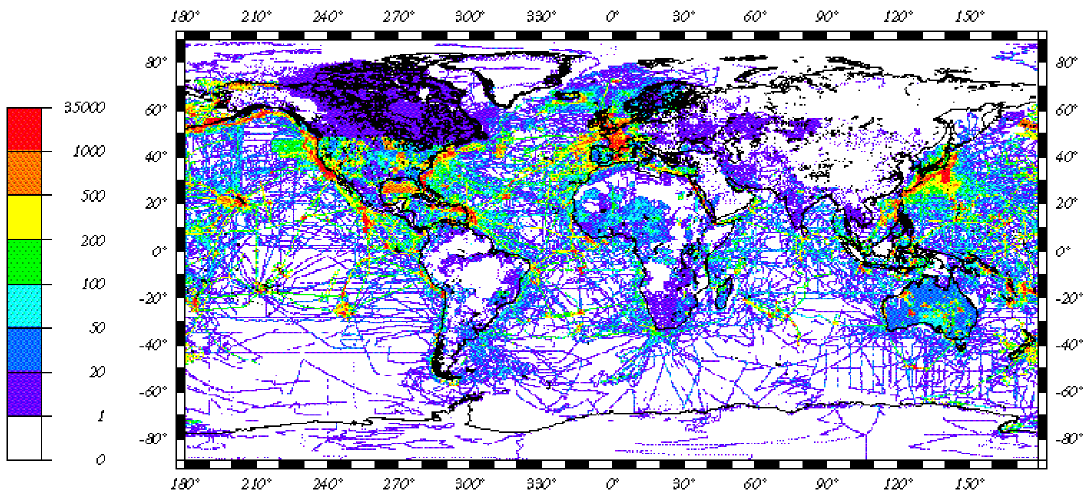
We briefly present hereafter the main actions we propose to be realized at BGI. Most of them have been initiated many years ago and are currently implemented by the BGI working group. Some others are new. The present-day status and the proposed new orientations are presented to enhance the way in which BGI could continue and improve its services and contribute to the synergy between national and international actors in gravimetry and geodesy.

2.1. Activities of service: data collection, validation and distribution

These activities remain the fundamental tasks of BGI. The main achievements consist in the relative gravity database, the database of reference gravity stations and the bibliography database. The Absolute gravity database and the airborne gravity database were insufficiently achieved due to the lack of man power in the past will be top prioritized in the next few years.

☐ ***"Relative gravity" database***

The BGI database contains today over 2,3 millions of land and 10,5 millions of marine gravity data. BGI has recently collected over 60000 data points from Belgium, Japan and Australia which are in process to be integrated into the database. This on-going effort of data collection of public or private data should be continued especially in regions where the BGI data coverage is poor with respect to the existing data (Russia, China, South America, etc.).



BGI relative on shore and off shore gravity database

As currently done, the new incoming datasets are validated using the standard procedures used, developed or updated at BGI. The conversion of the entire database into GRS80 system will be also achieved.

For many years, very few information was usually available on the reference datum systems for positioning, altitude or gravity. Thanks to the increasing use of GPS positioning in land or marine gravity campaigns, the recent surveys are better referenced in a global frame. The gravity stations coordinates and elevations are now determined with respect to given ellipsoid and datum. This contributes to enhance the reliability between terrestrial gravity data and global satellite observations (gravity-topography-altimetry) which can be processed and merged with respect to homogeneous geodetic reference systems. When possible, BGI will provide additional information on the reference ellipsoid and datum system used for coordinates and elevations. Global SRTM topography or bathymetry models will be also used to detect systematic shifts of station elevations for a given dataset as a tool for data evaluation and validation.

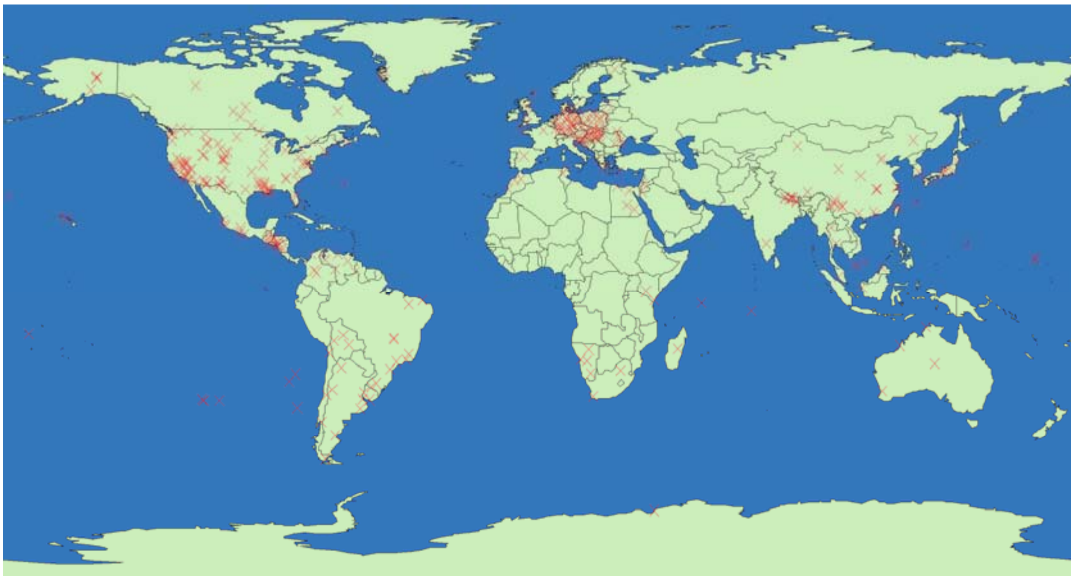
The procedures for data distribution will be simplified in order to make them more efficient and interactive for the BGI users. Up to now, the public data that are freely available or restricted data (data available under authorization of the owner institution) are sent on request to users by BGI through FTP or CD-Rom. We propose to implement new automated procedures in order to facilitate direct download of public data from the BGI Website as currently done by other IAG data centers (earth tide data, IGS GPS, etc.). Obviously, this will concern public data freely available only and not other restricted or confidential data.

Another challenge is to make more visible and accessible the overall available information for a given request. Other national or international datacenters or agencies have developed gravity databases of public, non-public or commercial data. Among these existing databases, complementary information (meta-data or numerical data) might be shared with the BGI database. An effort will be done to establish links or mirror sites between BGI database and other existing databases. In favorable cases, inter-connections and inter-operability functionalities between databases will be implemented in order to offer an overview of the existing information.

- ☐ ***"Absolute gravity" database***

The dramatic increase of absolute gravity measurements calls for a compilation of the existing absolute stations and to make accessible the related information to the scientific community. The constitution of a global Absolute Gravity database is recognized by the International Gravity Commission as one of the main tasks for BGI.

In the last few years, BGI has contributed to working groups within the IGC activities for the setting up of the International Absolute Gravity Base Network (IAGBN) and UEGN (Unified European Gravity Network). A standard format for archiving absolute gravity measurements has been defined[4]. In the same time, the commercial software "Absolute Gravity Data Acquisition and Processing Software" ("g") developed by Micro-g LaCoste (main manufacturer of absolute meters) became a standard within the absolute gravity community. The resulting data files derived from the absolute measurements can be used to share and exchange unified information (ASCII files containing the basic information related with the data acquisition and processing settings, binary files produced during data acquisition that can be post-processed with other settings).



Referenced absolute gravity measurements[5]

Both the defined AGMAF-03 format and the reference "g" software give a good support to consolidate a worldwide absolute gravity database. Several organizations belonging to the BGI working group (see section 3) will actively contribute in this task (data collection and archiving, database construction and management, definition of an ITRF-type coding number of stations, etc.). This will be one of the main objectives of BGI for the next years. Collaboration with BKG (Bundesamt für Kartographie und Geodäsie, Frankfurt) and NRC (National Resources Canada) which have also initiated prototypes of A-G data base is also proposed to make the database compatibles.

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[4] Barriot, J-P., Sarrailh, M., Liard, J., Boedecker, G. - "AGMAF-03: An archiving format for Absolute Gravity measurements" (G03/07P/D-062) presented at IUGG 2003, Sapporo, Japan.

[5] The number of absolute gravity determinations has been recently boosted. Complementing the standard laboratory-type FG5 meter (Micro-g LaCoste), new generations of portable and thermo-stated meters are now available (i.e. A10 meter). They are now commonly used in large scale surveys for measuring absolute gravity in most field conditions with accuracies in order or better than 10 microGal.

- ☐ ***"Airborne gravity" database***

The collection and diffusion of airborne gravity data in worldwide database is not as well developed as land or marine data whereas it is commonly used in mineral and oil exploration. Airborne gravimetry remains a powerful tool to produce accurate and homogeneous gravity data acquisition on inaccessible areas (mountains, volcanoes, tropical forests, deserts, islands, continental margins, coastal areas…). It has thus strong implications on the determination of the gravity field and geoid at regional and local scales providing information in intermediate wavelengths between ground and satellite measurements. An effort in the data collection and validation of new datasets at BGI is necessary to improve the knowledge of the earth gravity field (especially in continental margins or inaccessible areas).

- ☐ ***"Reference gravity station" database***

The global database of reference gravity stations has been finalized is accessible trough the BGI internet website. It contains more that 6000 reference stations for which the complete site information (coordinates, monography, scheme and photos) have been scanned. Tables of the corresponding gravity values (with their reference system) are also available. All the related information (monography and gravity values) can be directly downloaded. The consultation is done using interactive maps as for the relative gravity database. New reference gravity stations will be also provided through the absolute gravity database.

- ☐ ***"Bibliography" database (publications, maps…)***

The BGI bibliography database has been initiated in 2003 with the aim to inventory and to diffuse on a worldwide base, old and recent references related to gravimetry.

The database was developed under a standard and unified system (« Alexandrie » software) used by many others documentation centers in order to ease the integration of data, the database maintenance and the exchange of information between datacenters. This activity has been considerably consolidated within the last few years at BGI. The database now contains about 12300 references, ~3000 maps and 9350 textual (plus thesaurus of more than 400 terms and 6000 authors). The database can be consulted and interrogated by any user trough the BGI website. It is regularly updated with new references from scientific articles published in journals, proceedings of meetings, technical papers, national and international reports, etc.

This activity will be continued and implemented in collaboration with other IAG/IGFS datacenters (such as ICET) hosting bibliography databases in the field of gravimetry (links between ICET and BGI databases).

2.2. Activities of diffusion

- ***Website***

The internet website is the key interface between BGI and its users. New functionalities should be implemented in relation with the database management to perform direct downloads of data or products from the webpage and allow inter-operability between other sites hosting gravity-related databases. A new interface will be developed to add these new functionalities and present the whole BGI services and activities as presently done (http://bgi.cnes.fr:8110). An effort will be done to homogenize the BGI website (menus, graphic charts, etc…) with the other websites of centers belonging to the IAG/IGFS. Links between BGI and the FROG bureau (French resources for GOCE exploitation) hosted at the Institut de Physique du Globe de Paris will be proposed in order to display a unified and more complete information regarding the French resources in gravimetry.

- ***Diffusion of the Newton's Bulletin***

The Newton's Bulletin is published jointly by BGI and the International Geoid Service (IGeS) and contains papers about geoid estimation and gravity. This bulletin was born in 2003 from the merging of the BGI and IGeS bulletins and has one issue per year (first number has been issued in Dec. 2003). It is composed of two sections presenting "reviewed papers" and "communications and news". The submitted papers undergo a peer review process. The 3 issues are available in electronic form (full text version in PDF format) on BGI and IGeS websites (http://bgi.cnes.fr:8110; http://www.iges.polimi.it). Paper issues and CD are also published for diffusion to libraries and archiving centers. The Newton's Bulletin will be continued improving the co-operation with IGeS and enlarging its Editorial Board. BGI will encourage the publication of research or technical papers as well as proceedings of meetings dedicated to terrestrial gravimetry.

- ***Diffusion of public computer programs and software in gravimetry***

The diffusion of computer software developed (and in use) at BGI for the validation of land and marine gravity data has been initiated few years ago. As for other IAG services, it is recommended to maintain such activity that contributes to homogenize and standardize the validation and processing tasks in gravimetry. With this aim, BGI with its supporting organizations will intensify the compilation and diffusion of computer softwares related to the validation, processing and analysis of gravity data. Links to other databases or research centers compiling such computer programs will be done.

- ☐ ***Diffusion of gravity related information and products***

We propose to continue through the BGI website the diffusion of gravity database derived products such as geoid models, global or regional anomaly maps, etc. In addition, the diffusion of any product or information interesting the gravity community and users of BGI services is highly recommended (ex: procedures and results of data evaluation and validation, monthly GRACE solutions produced by GRGS, proceedings of gravity related meetings and workshop, national reports, etc.).

2.3. Contribution to educational activities

- ☐ ***Summer Schools and workshops***

BGI has been very active within these last few years in contributing to educational activities. Three Summer Schools, organized in the framework of IAG by ICET (International Center for Earth Tides) and IGeS (International Geoid Service) an BGI, were successfully realized in February 2000 (Malaysia)[6], September 2002 (Belgium)[7] and October 2005 (Canaria)[8]. The general purpose of these summer schools is to transfer theoretical and practical expertise in gravimetry towards graduate students, young scientists or employees of national agencies and services or industry staff. The February 2000 summer course was aimed to prepare the participants to use and to compute gravimetric geoids for the many scientific and technical applications we are met with in geodesy, primarily in transforming ellipsoidal (GPS) heights into orthometric heights. The two others were aimed to the training in gravimetric techniques of people involved in gravity and microgravity surveys with applications to

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[6] *"Geoid schools"*, Johor Bahru, Malaysia, Feb. 2000
[jointly organized by BGI, IGeS in cooperation with the Department of Survey and Mapping Malaysia].
[7] *"Terrestrial Gravity Data Acquisition Techniques"*, Louvain-la-Neuve, Belgium, September 4-11, 2002
[jointly organised by BGI/ICET in cooperation with the Catholic University of Louvain].
[8] *"Microgravimetry methods: static and dynamics aspects"*, Lanzarote (Canaria), October 23-28, 2005
[jointly organized by BGI/ICET in cooperation with the Institute of Astronomy and Geodesy, Spain].

geodesy, geodynamics, geophysics, geology or civil engineering (operating of relative gravity meters, gravity data handling and processing, etc.).

The international audience (announcements published in EOS) and the number of participants (up to 45 participants from 22 countries for one summer school) confirmed the interest of the international community in such events. Interest of scientists from emergent and developing countries in techniques of acquisition, processing and interpretation of gravity data has been also enhanced.

We believe that BGI must contribute to this on-going effort of the International Association of Geodesy of spreading the technical culture for the determination and use of the geoid and gravity data. We propose that BGI co-organize one or two similar events in the next four years (proposed topics: relative or absolute gravimetry, validation of satellite and ground data, processing software, etc.). A project of summer school is planed in 2008 with support of ECGS and University of Luxembourg (program, participants and conditions to be defined). Partnerships and sponsors from national and international research and educational organizations will be searched to keep the effort for organizing low cost summer courses and workshops and then encouraging the participation of students and young researchers from emergent and developing countries. As done for the recent summer courses, BGI will also publish a CD-ROM (with ISBN reference number) containing all the teaching material. Possible subjects for further summer schools in which BGI could be involved: relative or absolute gravimetry shools (methods for acquisition, reduction or analysis of data, processing tools for earth tide corrections or network adjustment…), geoid schools, schools on combination, validation and exploitation of satellite (GRACE, GOCE) and terrestrial gravity datasets…

☐ ***Tutorials and educational materials***

A series of tutorials in gravimetry and geodesy (mostly in French at that time) are accessible on line on the BGI website. Internet statistics reveal that the request for such tutorials is high. We propose that BGI put emphasis to collect more tutorials or lecture notes in gravimetry and geodesy from research and educational institutions. Efforts to diffuse texts in English language will be done.

2.4. Contribution to Research & Development activities

Even if it is not its main task, BGI has conducted to research activities mainly with its supporting research laboratories. Most of these activities valorize the current tasks of services and the global databases of BGI. They also contribute to maintain a good synergy between users, contributors and of databases.

In addition to the on-going projects in which BGI is already involved, new opportunities for BGI to increase his participation in processes for standardization, validation and valorization of gravity data and to strengthen his relationship with national and international organizations are also mentioned hereafter. The future activities will be mostly focused on federative projects that may have a significant impact for geophysicists and geodesists users of gravity data. They will be realized in strong collaboration with the supporting organizations of BGI and with other IAG datacenters.

☐ ***Contribution to the computation of regional geoids (EGG07, Ligure Sea)***

BGI has developed expertise in validation of gravity data, computation of geoid and gravity models and has participated as validation data center in various regional or global projects. The main projects in which BGI is currently involved are the realization of the new EGG07 European geoid (under leadership of Hanover University) and the development of methodologies for geoid computation at the sea-continent transition (case study on Ligure sea). It is also involved in the preparation of standard procedures for Global Gravity Field Validation in collaboration with IGeS and other national or international research groups.

☐ ***Contribution to evaluation and validation of satellite data (GRACE, GOCE)***

A contribution of BGI to the valuation and validation of the new satellite gravity data (GRACE and soon GOCE) might be also expected. In most scientific applications where high spatial or temporal resolution is required, it has been stated that such satellite data might be advantageously combined and validated by complementary ground information from terrestrial databases. BGI as one of the IAG/IGFS datacenter will contribute in preparing and providing relevant information from its databases (absolute or relative gravity measurements from ground, marine or airborne surveys, accurate time series from repeated or permanent monitoring networks, etc.). It might also contribute in the definition of standard methodologies aimed to combine ground and satellite data as well as to discriminate geodynamics or environmental gravity signals. On-going projects in which BGI is likely to be involved for data validation concerns the European, African and South-American continents. Expected fallouts are for instance: (i) the imaging of the solid earth at various scales, (ii) the continental hydrology (investigation of time varying signals related with the African monsoon), (iii) the natural hazards (investigations of vertical motions, mass or density changes induced by earthquakes or volcanic activities in subduction zones), (iv) the mineral resources in Africa.

- ***Contribution to the definition of absolute gravity standards***

In the last few years, the BGI working group gained experience in absolute gravimetry. Three instruments owned by French research groups (two FG5 and one A10 meters) are now available and are currently used for the establishment of reference networks in France, Europe or elsewhere (South America, Antarctica, etc.). Such absolute gravity networks will contribute to define a new reference frame of terrestrial gravity data. The validation and standardization of absolute gravity measurements is thus essential. A contribution of BGI to the definition and diffusion of procedures for the acquisition, reduction or validation of these measurements is required (contribution to the establishment of reference networks, to the inter-comparisons campaigns of absolute and relative gravity meters, to the publication of their results, etc.).

3. OPERATIONAL PLANS

We propose that BGI continue operating with its supporting organizations, in a new framework aimed at improving its efficiency and the quality of its services. This new framework (BGI working group) consists in topical teams pertaining to various French organizations, each team contributing with its expertise and means to one or several areas of gravimetry, as mentioned in section 2. As written in the foreword, it is anticipated that a covenant be established in due time between the partners to precisely define the inputs of each one to BGI as mentioned below.

BGI will also strengthen its relationships with other IAG services in order to harmonize its contribution with other international services.

3.1. BGI working group

The distribution of the different tasks among the different partners, contributing to the BGI activities, is the following (in alphabetic order).

- ☐ ***BRGM (Bureau de Recherches Géologiques et Minières)***

BRGM is an organization for research in geology and mineral prospecting (headquarters in Orléans, France). It has interests in the maintenance of networks and archiving of gravity measurements in France and overseas territories, and in the use of gravity for geological surveys and mineral prospecting.

BGRM will contribute to the modernization of BGI databases by implementing the required functionalities that will allow direct download of public data and interoperability facilities between other global gravity databases. It will also follow his participation in BGI research and teaching activities by bringing expertise on measurements and interpretation methods and will also contribute to the tutorials in gravimetry.

- ☐ ***CNES (Centre National d’Etudes Spatiales)***

CNES is the French space agency, which has its technical center located in Toulouse, France. It has major interests in global models of the Earth’s gravity field for various applications (especially very accurate orbit determination of some satellites, e.g. as required by altimetry for oceanographic studies).

CNES has provided a major support to BGI since 1979 (database construction and maintenance, management of BGI activities, data compilation and validation, software, tutorials, etc.). It currently hosts and maintains the BGI gravity database and server. It will follow his support to BGI in the data collection, validation, archiving and distribution (thanks to the expertise acquired since 1979 and to the developed software and existing facilities), as well as in the teaching and research activities of BGI. It will continue bringing its support to BGI by providing: staff; computer facilities (for data validation, archiving and distribution, also for maintenance of the server).

- ☐ ***EOST (Ecole et Observatoire des Sciences de la Terre)***

EOST is a school and an institute in Earth sciences located in Strasbourg, France. It has interest in the study of temporal and spatial variations of the earth gravity field for the study of the physical processes at global, regional and local scales (applications to physics of the earth, geodynamics and hydrology). It is experienced in the measure of precise gravimetry (it operates two national instruments: a super-conducting gravimeter and an absolute gravimeter [FG5 #206]) and has contributed in the establishing of absolute gravity networks mostly in French territories, Antarctica and Europa. It has also interest in the use and combination of both terrestrial and satellite (CHAMP, GRACE, GOCE) gravity data.

EOST will contribute to BGI in the absolute gravity data collection and compilation and in the achievement of the absolute gravity database of BGI. It will also follow his participation in BGI research and teaching activities by bringing expertise on the following areas: measurements, validation and interpretation methods, tutorials and summer schools in absolute gravimetry.

- ☐ ***ESGT-CNAM (Ecole Supérieure des Géomètres et Topographes)***

ESGT-CNAM is an engineering school of surveying and mapping located in Le Mans, France. It has interest in the use of gravimetry and geodesy. It has developed expertise in airborne gravimetry in the areas of instrumentation (development of gravity sensors), data processing and modeling. The ESGT-CNAM also seeks to further develop its competencies in geoid calculations.

ESGT-CNAM will follow his participation to BGI by bringing expertise in validation methods for gravimetric data based on geodesic information and in airborne gravity data acquisition and processing. It will participate, in the context of its educational role in applied geodesy and surveying, to research and teaching activities of BGI in the following areas: educative material including tutorials, summer schools.

- ☐ ***GM - UM2 (« Geosciences Montpellier » - Université de Montpellier 2)***

GM-UM2 is the laboratory of Geosciences of the University Montpellier, France. It has interest in the study of temporal and spatial variations of the earth gravity field for the study of the physical processes at regional and local scales (applications to geodynamics, hydrology, earthquakes). It has a long experience with gravity campaigns, reduction techniques and interpretation methods and has developed an expertise in airborne gravimetry thanks to a close collaboration with the ETH (Zurich, CH). It has also gained experience in absolute gravimetry (it operates one of the national FG5 instruments) and contributes in the establishing of absolute gravity networks for his research programs.

GM-UM2 will contribute to BGI in the absolute gravity data collection. It will also follow his participation in BGI research and teaching activities by bringing expertise on the following areas: measurements, validation and interpretation methods, tutorials and summer schools in absolute gravimetry.

- ☐ ***IGN (Institut Géographique National)***

IGN is the French national geographic and geodetic survey (Technical center in St Mandé, France). It has many interests in gravimetry for the establishment and the update of the gravity/geodetic reference frame and height systems, the computation of regional geoids and for the realization of regional gravity surveys. It has developed experience in relative and absolute gravity measurements and is co-owner with IRD and IPGP of the French portable absolute gravity meter [A10 #014]. Through his research laboratory in Geodesy (LAREG), it is involved in methodological and theoretical developments in the area of validation, interpretation and modeling of terrestrial and satellite gravity data with applications to geodesy, physics of the Earth, geodynamics, etc.

IGN has provided a major support to BGI since 1979 (database construction and maintenance, data compilation and validation, data diffusion, etc.). IGN will contribute to the modernization of the BGI databases by implementing the required functionalities that will allow direct download of public data and interoperability facilities between other global gravity databases. It will participate to the Absolute gravity database by providing new observations and by defining a unified international coding of the absolute gravity sites. It will also follow his participation in BGI research and teaching activities by bringing expertise in the following areas: methods for gravity data validation and interpretation, tutorials in gravimetry.

- ***CNRS/INSU (Institut National des Sciences de l'Univers)***

INSU is an organization within the French national scientific foundation (CNRS), dedicated to the sciences of the Universe. It supports scientific research laboratories or services. INSU supports BGI activities directly or through various research laboratories involved in gravimetry (mostly EOST, GM-UM2 and IPGP).

INSU has provided a major support to BGI since 1979 (database construction and maintenance, data compilation and validation, data diffusion, bibliography database, secretariat, etc.). It will follow his support to BGI through the recognition of his activities in France as one of his national observatory service (INSU label) and through the renewed contributions of his related research laboratories (see specific contributions of EOST, GM-UM2 and IPGP).

- ***IPGP (Institut de Physique du Globe de Paris)***

IPGP is the largest institute of physics of the Earth in France (located in Paris). It has many interests in gravimetry for the study of physical processes at global, regional and local scales (studies of the temporal and spatial variations of the earth gravity field applications to physics of the earth, geodynamics, volcanoes, earthquakes, hydrology, etc.). It is experienced in the measure and exploitation of land, marine and sea-bottom gravimetry and in the use and combination of both terrestrial and satellite gravity data. IPGP owns several gravimeters (Scintrex and LaCoste & Romberg) and manages the pool of INSU French relative gravity meters. It is also co-owner with IRD and IGN of the French portable absolute gravity meter [A10 #014].

IPGP will follow his long-term contribution to BGI activities by providing gravity observations from new campaigns established for his research purposes and expertise in interpretation methods for finer data validation, interpretation and modeling in geophysics. It will contribute to the development and the maintenance of software and educational material in gravimetry to be put on the BGI server. As hosting the French Bureau for the Coordination of Exploitation of GOCE data (Bureau FROG), it will also contribute to the validation of ground and space gravity.

- ***IRD (Institut de Recherche pour le Développement)***

IRD is the French institute conducting cooperative research and educational programs with emergent and developing countries (ex ORSTOM). It has many interests in the use of terrestrial, marine or space gravity data for his research programs applied to solid earth, hydrology and oceanography. It has a long term experience in the measure and interpretation of gravimetry and microgravimetry data with applications to structural geology, geodynamics, volcanic and seismic hazards. IRD owns a pool of gravimeters (Scintrex) and is co-owner with IGN and IPGP of the French portable absolute gravity meter [A10 #014]. It also currently contributes to the establishment of absolute gravity reference networks (ex: South America).

IRD has contributed to BGI through his land and marine gravity databases (mostly in Africa – over 300000 data points - and South West Pacific). It will follow his contribution to BGI by collecting gravity data (relative and absolute) acquired or compiled in overseas countries for his research programs. IRD will contribute to the achievement of the absolute gravity database of BGI. It will also support BGI research and teaching activities by bringing expertise in the following areas: measurements, validation and interpretation methods, contribution to summer schools in gravimetry and diffusion of software or educational materials in emergent and developing countries.

- ***SHOM (Service Hydrographique de la Marine)***

SHOM is the hydrographic and oceanographic service of the French navy (headquarters in Brest). This is where the highest expertise in marine gravimetry (instruments, campaigns, data taking and reduction) lies in France.

SHOM has contributed to BGI through his marine gravity databases and through his expertise in validation of marine gravity data. It will provide part time personal to help BGI to emphasize the collection and validation of marine data. It will contribute to BGI in data collection, data validation, and educational activities.

3.2. BGI directing board / Coordinating Committee

The BGI directing board will be composed of the BGI director and a deputy-director. The management and the secretariat of BGI are located at the same place (OMP Toulouse) for efficiency. A Coordinating Committee, composed of the representative of each supporting organization, will be established in France to help the Directing board in his task and to harmonize the contribution of the different groups.

The Directing board will be in charge of the international relationships with the International Gravity Commission and its Working Groups, with other IAG and FAGS services. It will coordinate the fluxes of information between the kernel and the different teams and ensure good links between the teams themselves according to the decisions of the Coordinating Committee.

ANNEX A

Endorsement letters

To be included

ANNEX A

Synthetic report on BGI activities for period 2003-2007

BGI mainly focused on the following topics related with its databases:

- Relative gravity data collection and validation (increasing of 10 % of new data)
- Online avalaibility of the bibliographic database, with entries added on a day to day basis.
- Online availability of reference gravity stations (scan of over 6000 descriptions and photos)
- Definition of an archiving format for absolute gravity data presented at the IUGG Sapporo meeting in 2003.

These actions where complemented by the continuation and development of other academic activities:

- Publication of the Newton's Bulletin, the Joint bulletin of the International Geoid Service and of the Bureau Gravimetrique International.
- Organization of summer schools
- Participation in the new IGFS (International Gravity Field Service), the unified service of IAG for the determination of the gravity field and figure of the Earth, federating BGI, IGeS and ICET.
- Communications presenting BGI activities at international meetings

In addition, research and development activities where also conducted in relationship with research laboratories.

Persons currently working at BGI :

- J.P. BARRIOT, CNES Ing., 47 years (50 %), BGI Director
- R. BIANCALE, Ing. CNES, 54 years - Director by interim (Sept. 2006-July 2007)
- M. SARRAILH, CNES Ing., 55 years (50 %), à 50 %, data collection and processing.
- B. LANGELLIER, IGN Ing., 57 years, (100 %), database maintenance.
- S. PECQUERIE, CNRS Ing., 50 years (80 %), bibliography

- N. LESTIEU, CNRS Technician, 51 years, (20 %), secretariat
- T. FAYARD, CNES Ing., 44 years, (50 %), data acquisition
- M. ABBASI, 30 years, (100 % in 2003-2006), Ph.D. student, processing of airborne gravimetry.

1. Relative gravity database

☐ ***Database archiving***

The BGI database contains today over 2.3 millions of land and 10.5 millions of marine gravity data. New sets of relative gravity corresponding roughly to 700000 points are being included into the BGI data base. The table here below presents the status of the process in three categories: already processed, under examination and still to do.

Location	**Number of points**	**Process status**
Southern Arabia	2965	td
West Antarctic	297000	ue
US-San Bernardino	615	td
US-Portland	127	td
Philippines	1025	ap
Patagonia	29	td
US-North Willamette	4153	td
US-Nevada	80000	td
Nepal	152	ue
US-Minesota	57905	td
Philippines	482	ap
US-Lassen volcano	384	td
Reunion	1181	ap
France-Ile de Groix	250	ue
US-Haiward Fault	400	td
Greenland	32	td
South America Gotze	6152	ap
Spain Goyau	2047	ue
Brazil	8871	ap
US Albuquerque	5562	td
Australia	1117055	ue
Japan	90298	ue

ap : already processed, ue : under examination, td : to do.

☐ ***Data requests***

The number of data requests is the following:

74 in 2003

94 in 2004

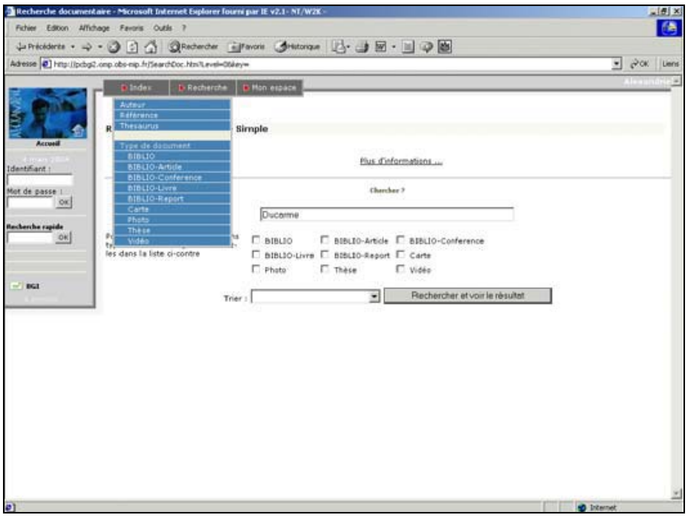
228 in 2005

123 in 2006

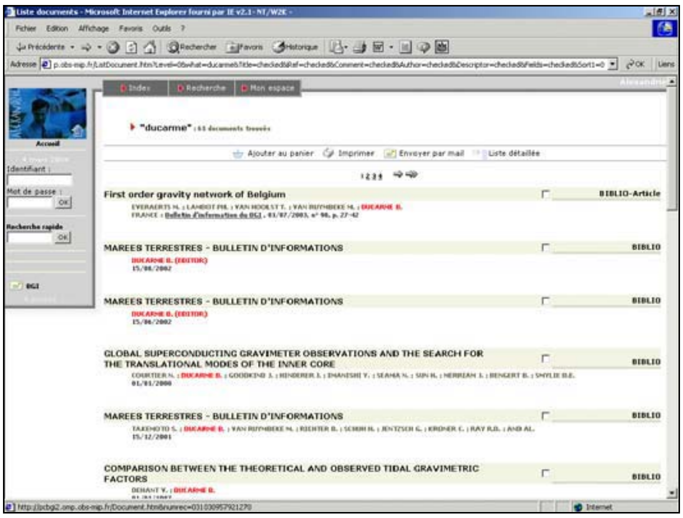
30 in 2007 (till June)

2. Bibliography database

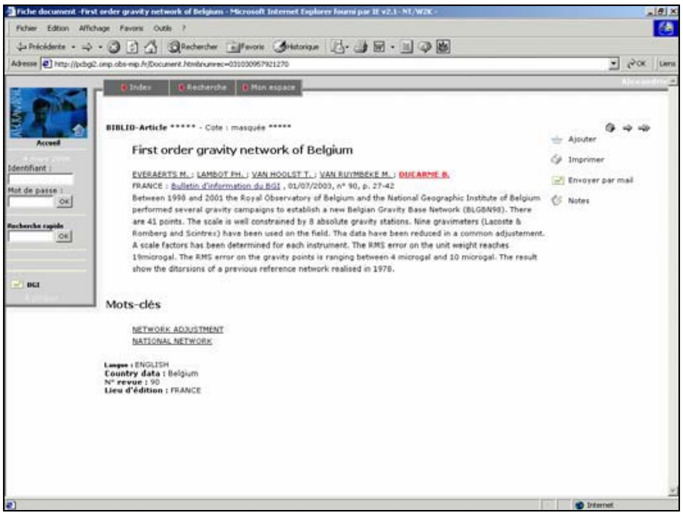
BGI maintains and develops its bibliography data base under the so called Alexandrie server. It contains 10300 paper references taken out from 150 publication or journal titles and includes 7232 authors and 429 thesaurus descriptors. Moreover 2950 map references and 200 digitalized maps are present. This base is on line at: http://bgi.cnes.fr. The total incurring cost was 7735 euros, a huge sum for BGI, which drained almost all our funds.



Example of request and with author name



Example of response



Example of response for a selected reference

3. Research and Development

☐ *Projects*

- Participation to the new european geoid EGG07 under the leadership of Université de Hanovre, as validation data center

- In the framework of hydrogeological studies in the Garonne basin (France), BGI has contributed to microgravity monitoring of the subsurface water table. For this project, BGI carried out field surveys and realized hardware developments. It has developed an electronic data acquisition system aimed to convert analogical data from Lacoste gravimeter output into digital data stored in memory on board. The data are then unloaded on a PC computer through an USB port under Windows OS which makes data filtering easier and allows a better detection of instrumental problems.

☐ *Details of software developments*

BGI has developed or renewed a few software packages for the preprocessing and the interpretation of gravity data, such as:

- A new software package for processing the airborne gravity data has been developed by Madjid Abassi in the framework of his PhD. This package is dedicated to the gravimeters of type Lacoste & Romberg air/sea model. On the contrary of classical methods used, this software processes aerogravimetric profiles in a global approach taking into account the intrinsic statistical characteristics. The computation procedure of the new method includes the following steps :

- computation of the aircraft induced accelerations and estimation of their variance-covariance matrices;
- removal procedure for subtracting the low frequency spectrum of the gravity disturbances;
- transfer of the vertical accelerations and its variance-covariance matrix through the damper/platform transfer function;
- construction of the a priori correlation matrix of the unknowns from the global geopotential models on the surveyed area;
- computation of the estimated values of the unknowns and of their variance-covariance matrix.

- Inversion of gravity field in finite elements with a simulated annealing algorithm: this software delivers the underground density distribution from a set of surface gravity observations according to an input of geophysical constraints.
- Sea gravity data adjustment package using a Singular Value Decomposition algorithm: this software detects and adjusts (by least squares method) crossovers between gravity profiles. It was used to calibrate marine data profiles in the Ligure Sea.
- A new versatile conversion tool for gravity data integration and validation, some software for gravity data preprocessing (drift removal…) and simulation as well.
- Interpret: this interactive package allows the determination of the gravity anomalies of 2D and 2.5D structures. It is mainly dedicated to educational training, but can be used professionally to estimate the gravity effects of given structures.

4. Summer schools

After the first joint BGI/ICET Summer School on terrestrial gravity data acquisition techniques held in Louvain-la-Neuve in 2002, BGI, associated with ICET and the Instituto de Astronomia y Geodesia (IAG), organised in October 2005 in Lanzarote, Canaries, a new Summer School on micro-gravimetric methods. The school program included courses about the instruments, the static and dynamic aspects and practical sessions. A total of 16 students and 15 teachers participated to the School.

5. Communications and publications of BGI for period 2002-2005

J.P. Barriot, Least Squares Processes and Imaging, XVIIIème Curso de Volcanologia, Lanzarote Island, June 14th, 2005.

M. Abbasi and J.P. Barriot, Différentiation de séries chronologiques et estimation des matrices de covariance associées. Application en gravimétrie mobile, Poster, 2ème Congrès National de Mathématiques Appliquées et Industrielles, Evian, France 23-27 Mai 2005.

M. Abbasi, J.P. Barriot, J. Verdun et H. Duquenne : Gravimétrie aéroportée : une méthode alternative de calcul par inversion intégrale, Poster, Journées de Gravimétrie Spatiale, Paris, CNES, 11 Mai 2005.

J.P Barriot, M. Sarrailh, B. Langellier, S. Pecquerie and T. Fayard, The database of the International Gravimetric Bureau an its Services, Geo-Siberia Fair and Conference, Novosibirsk, Russia, April 25-29th, 2005.

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M. Abbasi, J.P. Barriot, J. Verdun and H. Duquenne, Airborne Lacoste-Romberge gravimetry; an alternative computation approach, Geophysical Research Abstracts, Vol. 7, 00167, 2005 SRef-ID: 1607-7962/gra/EGU05-A-00167, Vienna, April 24-30th, 2005.

M. Abbasi, J.P. Barriot, J. Verdun and H. Duquenne, Data snooping, correction and reduction of the airborne gravimetry data acquired by a LaCoste-Romberg air/sea gravimeter, Poster, Ateliers d'Expérimentation et d'Instrumentation, Toulouse, France, 8 et 9 Février 2005.

T. Fayard, M. Sarrailh, J.P. Barriot et B. Massat, Mesures Micro-Gravimétriques en Hydrologie, Poster, Ateliers d'Expérimentation et d'Instrumentation, Toulouse, France, 8 et 9 Février 2005.

J.P Barriot, M. Sarrailh, B. Langellier, S. Pecquerie and T. Fayard, Present days Activities at BGI, in 2005 Geoid School « The determination and use of the Geoid », Budapest, Hungary.

Jan. 31-Feb. 04, 2005.

J. Chenal and J.P. Barriot, A simple anisotropic model of the covariance function of the terrestrial gravity field over coastal areas, Newton's Bulletin, Vol 2., Dec. 2004.

H. Denker, J.P. Barriot, R. Barzahi, R. Forsberg, J. Ihde, A. Kenyeres, U. Marti, I.N. Tziavos, Status of the European Gravity and Geoid Project EGGP., Proceedings of the Gravity, Geoid and Space Missions IAG International Symposium, Porto, Poster, Portugal, Aug. 30 –Sept. 3, 2004, submitted to the Proceedings.

J.P. Barriot, A new derivation of the least-squares collocation formula, Abstracts Journal Series : Geodesy and Aerial Survey, n° 2, 2004.

J.P. Barriot, S.Pecquerie, Services d'Observation : du nouveau. Inf'OMP, N° 20, 1er trimestre 2004.

J.P. Barriot, M. Sarrailh, T. Fayard, Monitoring of the Garona river Table By MicroGravimetry: results of the 2003-2004 Campaign, Poster RSTGV-A-00243, Réunion des Sciences de la Terre – Joint Earth Sciences Meeting, Sept. 20-25 2004, Strasbourg, France.

Abbasi M., Barriot J.P., Verdun J., Duquenne H, Data snooping, correction and reduction of the airborne gravimetry data acquired by a LaCoste-Romberg air/sea gravimeter, , Poster with CD Proceedings, Gravity, Geoid and Space Missions 2004, IAG International Symposium, Porto, Portugal, Poster, CD Proceedings, Aug. 30 –Sept. 3, 2004

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Barriot J.-P., Sarrailh M., Fayard T., Microgravimetry monitoring of the Garona River table near Toulouse during 2003-2004, Gravity, Geoid and Space Missions 2004, IAG International Symposium, Porto, Portugal, Poster, CD Proceedings, Aug. 30 –Sept. 3, 2004.

M. Abbasi,, J.P. Barriot, J. Verdun and H. Duquenne, Investigation of the Systematic Errors Contaminating Airborne Gravimetry Data Acquired by a Lacoste-Romberg Air/sea Gravimeter, Geophysical Research Abstracts CD, Vol. 6, 00099, 2004, ISSN 1029-7006, EGU General Assembly 2004, Nice, France, 25_30 April 2004.

J.P. Barriot, M. Sarrailh, Ajustement of Gravimetric Networks, Newton's Bulletin, n°1, Décembre 2003.

J.P. Barriot, M. Sarrailh et T. Fayard, Surveillance gravimétrique de la variation de la nappe phréatique superficielle associée à la Garonne au niveau de Portet, Colloque d'ouverture du GDR G2, 12-14 Nov. 2003, Paris.

J.P. Barriot, M. Sarrailh, T. Fayard and P. Pastor, Monitoring the Garona River water table by microgravimetry and GPS. Poster HW03/11A/D-002, Sapporo, UGGI General Assembly, July 2003.

J.P. Barriot, M. Sarrailh, J. Liard, G Boedecker, AGMAF-03, an archiving format for absolute gravity measurements. Poster G03/07P/D-062, Sapporo, UGGI General Assembly, July 2003.

L. Sliwa, J.P. Barriot. Establishment and Maintenance of a Gravity Network in the Carribean. Bulletin d'Information du Bureau Gravimétrique International. 91: Dec 2002

M. Sarrailh, J.P. Barriot. Gravity data validation and outlier detection using L1 norm. Bulletin d'Information du Bureau Gravimétrique International. 91: Dec 2002

JP Barriot and M. Sarrailh, J.L. Liard, G. Boedecker, Toward an unified format for the archiving of absolute gravity measurements at BGI. Instrumentation and Metrology in Gravimetry Workshop, Munsbach, Luxembourg. 28 Oct 2002

J.P. Barriot. General theory of the gravity field. Lecture given at the joint BGI/ICET Summer Course, Louvain-La-Neuve, Belgium. 4 Sep 2002

L. Sliwa, J.P. Barriot. Establishment and Maintenance of a Gravity Network in the Carribean. Third meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece. 1(28), 26 Aug 2002

M. Sarrailh, J.P. Barriot. Gravity data validation and outlier detection using L1 norm. Third Meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece. 1(13): 10, 26 Aug 2002

J.P. Barriot, B. Langellier, M. Sarrailh. Database management at the Bureau Gravimétrique International. Third Meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece. 1(12): 9, 26 Aug 2002

J.P Barriot. A new derivation of the least-squares collocation formula. Bulletin d'Information du Bureau Gravimétrique International. 90: pp. 43-51, Jul 2002

ANNEX B

CV of the new proposed Director

Curriculum Vitae

Dr. Sylvain BONVALOT
Born November 11, 1961 - Paris, France (French nationality)
Geophysicist (permanent research investigator at IRD, France)

Academic degrees

- Thèse de Doctorat en Géophysique de l'Université P. et M. Curie (Paris 6), Juin 1990
  « Mesures gravimétriques en Guinée et en Sierra-Leone. Modélisation structurale et étude du comportement mécanique de la lithosphère » (directed by P. Mechler)
- DEA en Géophysique de l'Université P. et M. Curie (Paris 6), Juin 1985
- 1er et 2ème cycles universitaires à l'Université P. et M. Curie (Paris 6), de 1979 à 1984

Professional positions

- Since 1991: Research investigator at IRD (ex-ORSTOM)
- 2002-2006: Associated research investigator at University of Chile
- 1995-2001: Associated research investigator at Institut de Physique du Globe de Paris
- 1986-1991: Ph-D student, voluntary nat. service, contracted young investigator at ORSTOM
- 1985: DEA student at Institut Français du Pétrole (Département de Géophysique marine)

Affectations

- Since 2007: University of Toulouse / Observatoire Midi-Pyrénées (LMTG, BGI)
- 2002-2006 : University of Chile (Fac. de Ciensas Físicas y Matematicas, Dep. Geofísica)
- 1995-2001: Institut de Physique du Globe de Paris (Lab. de Gravimétrie et Géodynamique)
- 1988-2001: IRD Bondy France (Lab. de Géophysique)
- 1986-1988: ORSTOM Dakar, Senegal (Lab. de Géophysique)

Research interests

Gravimetry and satellite Geodesy applied to solid earth studies (geodynamics, volcanoes, earthquakes)

- Volcanology: Detection and interpretation of mass transfer and volcanic ground deformations using microgravity, GPS and InSAR interferometry; Structural modeling of active volcanoes using gravity
- Tectonics: Detection and interpretation of crustal vertical motions in seismic zones using Absolute Gravity and permanent GPS
- Structural geology : Gravity study of geological structures at regional scales (West Africa, Andes)
- Methodology: protocols of data acquisition and processing in relative and absolute gravimetry, GPS and INSAR interferometry for monitoring active volcanic and tectonic zones

PI and Co-I of about 12 research projects in gravity and geodesy since 1990
with founding from national French (INSU, IRD) or Chilean (CONICYT) agencies
and from the European Space Agency (ESA Category 1 projects)

Field experience in gravimetry-geodesy

Regional and local surveys (relative gravimetry, GPS)

- Africa (1986-1988). Realization of regional gravity and GPS surveys of 7 countries of West Africa (Sierra Leone, Guinea, Mali, Guinea Bissau, Ivory Coast, Benin) as responsible for gravity data acquisition and processing (collaboration with IGN France and DMA USA).
- Active volcanic and tectonic zones (1991-2007): Realization of local surveys for structural study (1) on active volcanoes in Central and South America, Reunion, Indonesia and (2) on active tectonic zones in the Andes (Chile, Argentina, Bolivia).

High precision networks (absolute and relative gravimetry, GPS, CGPS)

- Installation of microgravity monitoring networks (1991-2007) : (1) Active volcanoes in Ecuador (Cotopaxi, Pichincha), Chile (Lascar, Lastarria), Peru (Misti), Nicaragua (Masaya), Reunion (Piton de la Fournaise), Italy (Vulcano) ; (2) Active tectonic zones in the Andes (Chile, Argentina, Bolivia)
- Participation to Inter-comparison campaigns at BIPM (since 1994)
- Microgravity and CGPS monitoring of a natural gaz storage (1999-2001)
- First GPS measurement of the altitude of Mont Blanc (1986)

Marine and sea-bottom surveys

- Participation to 3 oceanographic cruises (Atlantic, Pacific): (1) gravity study of the African continental margins (1987) ; (2) sub-marine gravity survey in the mid-Atlantic ridge (Nautile) ; (3) gravity study of a submarine volcanic caldera in Vanuatu Islands.

Scientific committees

- Member of « Comité de coordination du Bureau Gravimétrique International (BGI) » (since 1998)
- Member of « Comité français de pilotage du gravimètre absolu national FG5 » (since 1996)
- Member of « Comité français de pilotage du gravimètre absolu national A10 » (since 2005)
- Member of the working group for « Acquisition d'un gravimètre absolu national » (1988-1996)
- Member of the working group for « Renouvellement du gravimètre marin du N.O. l'Atalante » (1996)
- Member of gravity group of « Comité National de l'Information Géographique » (1995-1998)
- Member of « Conseil Scientifique de l'IRD (ex-ORSTOM) » (since 2004)
- Member of « Commission Scientifique Géologie-Géophysique de l'ORSTOM » (1995-1999)
- Member of « Commission Scientifique Géologie-Géophysique de l'ORSTOM » (1992-1995)

Other

- Referee of scientific papers for ISI journals (EPSL, Pure & Applied Geophysics, Journ. of Volc. and Geoth. Res., Tectonophysics, Geophysical Research Letters,…) and for AGU monographies
- Referee of scientific projects for national programs (INSU-France; CONICYT-Chile; NSF-USA)
- Membership of American Geophysical Union (AGU) and European Geophysical Union (EGU)
- Representative of IRD in Chile - by interim (2002-2006)
- Responsible of « laboratoire de géophysique du centre IRD Bondy » (1994 à 1996)

Teaching

- Co-Director of 3 Doctorate thesis in gravimetry/geodesy at IPG Paris (D. Remy, 2005; A. Pavez, 2005) and at Université de Savoie (J-P. Metaxian, 1994)
- Co-Director of master and licence thesis in gravimetry/geodesy (IPGP, Univ. Paris 6, Univ. of Chile)
- Lectures in Gravity / Geodesy at the University of Chile (2002-2006)

Languages

- French (native) / English / Spanish

Publications

Articles in ISI Journals

[23-2007] **Bonvalot, S.**, Remy, D., Deplus C., Diament, M., Gabalda, G. Insights on the March 1998 eruption at Piton de la Fournaise volcano (La Réunion) from microgravity monitoring. Submitted to *Journal of Geophysical Research.*

[22-2007] Remy, D., **Bonvalot, S**., Murakami, M., Briole, P., Okuyama, S., 2007. Inflation of Aira caldera (Japan) evidenced on Kokubu urban area using SAR interferometry data. *e-Earth Letters,* 2(1), pp.17-25.

[21-2007] Froger, J-L., Remy, D., **Bonvalot, S.**, Legrand, D., 2006. Dynamic of long term multi-scale inflations at Lastarria-Cordon del Azufre volcanic complex, central Andes, revealed from ASAR-ENVISAT interferometric data. *Earth and Planetary Science Letters,* doi:10.1016/j.eps.2006.12.012.

[20-2007] Peyrat, S., J. Campos, J.B. de Chabalier, A. Perez, **S. Bonvalot**, M.-P. Bouin, D. Legrand, A. Nercessian, O. Charade, G. Patau, E. Clevede, E. Kausel, P. Bernard, J.-P. Vilotte, 2006. The Tarapaca intermediate-depth earthquake (Mw 7.7, 2005, Northern Chile): A slab-pull event with horizontal fault plane constrained from seismologic and geodetic observations. *Geophysical Research Letters,* V33, LL22308, doi:10.1029/2006GL027710, 2006.

[19-2006] Pavez, A., Remy, D., **Bonvalot, S.**, Diament, M., Gabalda, G., Froger, J.L., Legrand, D., Julien, P., Moisset, D., 2005. Insight into ground deformations at Lascar Volcano (Chile) from InSAR, Photogrammetry and GPS data : implications on volcano dynamics and future space monitoring. *Remote Sensing of Environment*, Volume 100, Issue 3, 15 February 2006, pp 307-320.

[18-2005] Sepúlveda S., Lahsen A., **Bonvalot, S.**, Cembrano J., Alvarado A., Letelier P., 2005. Morpho-structural evolution of the Cordón Caulle geothermal region, Southern Volcanic Zone, Chile: insights from gravity and 40Ar/39Ar dating. *Journal of Volcanology and Geothermal Research*, Volume 148, Issues 1-2, 15 October 2005, pp 165-189

[17-2003] L. Vitushkin, M. Becker, Z. Jiang, O. Francis, T. M. van Dam, J. Faller, J.-M. Chartier, M. Amalvict, **S. Bonvalot**, N. Debeglia, S. Desogus, M. Diament, F. Dupont, R. Falk, G. Gabalda, C. G. L. Gagnon, T. Gattacceca, A. Germak, J. Hinderer, O. Jamet, G. Jeffries, R. Käker, A. Kopaev, J. Liard, A. Lindau, L. Longuevergne, B. Luck, E. N. Maderal, J. Mäkinen, B. Meurers, S. Mizushima, J. Mrlina, D. Newell, C. Origlia, E. R. Pujol, A. Reinhold, Ph. Richard, I. A. Robinson, D. Ruess, S. Thies, M. Van Camp, M. Van Ruymbeke, M. F. de Villalta Compagni, S. Williams. Results of the Sixth International Comparison of Absolute Gravimeters ICAG-2001. 2003. *Metrologia*, 39, 5, pp. 407-424.

[16-2003] Remy, D., **Bonvalot, S.**, Briole, P., Murakami, M. Accurate measurements of tropospheric effects in volcanic areas : application to Sakurajima volcano (Japan), 2003. *Earth and Planetary Science Letters*, Volume 213, Issues 3-4, 25 August 2003, Pages 299-310.

[15-2003] Gabalda, G., **Bonvalot, S.**, Hipkin, R., 2003 - CG3TOOL : An interactive computer program for Scintrex CG-3M gravity data processing. *Computers & Geosciences*, 29, 2, pp. 155–171.

[14-2002] Baldi, P., **Bonvalot, S.**, Briole, P., Gwinner, K., Coltelli, M., Puglisi, G., Marsella, M., Remy, D., 2002. Remote Sensing and GPS for the Derivation of Digital Terrain Models for Volcanic Modelling: Validation and Comparison of Different Techniques. *International Journal of Remote Sensing*. 23, 22, pp. 4783-4800.

[13-2000] Baldi, P., **Bonvalot, S.**, Briole, P., M. Marsella, M., 2000. Digital photogrammetry and kinematic GPS applied to the monitoring of Vulcano Island, Aeolian Arc, Italy. *Geophysical Journal International*, 142, 801-811.

[12-1998] **Bonvalot, S.**, Diament M., Gabalda G., 1998 - Continuous gravity recording with Scintrex CG-3M meters: a promising tool for monitoring active zones. *Geophysical Journal International*, 135, 470-494.

[11-1998] Ballu V., Dubois J., Deplus C., Diament M., **Bonvalot, S.**, 1998 - Crustal structure of the Mid-Atlantic Ridge in the MARK area from sea-floor and sea-surface gravity data – *Journal of Geophysical Research*, 103, B2, 2615-2631.

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[9-1995] Jousset, P., M. Van Ruymbeke, **S. Bonvalot**, and M. Diament, 1995. Performance of two Scintrex CG3-M Gravity Meters at the 4th International Absolute Intercomparison, Sèvres, France, *Metrologia*, 32 (Gravimetry), 32: 231-244.

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Centre International des Marées Terrestres
International Centre for Earth Tides

SCIENTIFIC ACTIVITY REPORT
for the period 2003-2007

by
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The staff of ICET, which is completely supported by the Royal Observatory of Belgium, our host Institution, is composed as follows:
Prof. B.Ducarme, Director(part time)
Mrs. L.Vandercoilden, technician(full time)

The Royal Observatory of Belgium is hosting ICET since 1958 and continues to provide numerous administrative and scientific facilities especially for the publication of the " Bulletin d'Information des Marées Terrestres" (BIM), for the tidal data processing and for the maintenance of the ICET WEB site.

The ICET directing board met in Ottawa (2004) and in Perugia (2007). The ICET director took part to several Federation of Astronomical and Geophysical data Services (FAGS) meetings in Paris and to the general assembly of the International Association of Geodesy (IAG) in Cairns (2005) and Perugia (2007). He attended all the meetings organised in the framework of the Earth Tides sub-commission: "15th International Symposium on Earth Tides", Ottawa (2004), workshop on "Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences", Jena (2006) and "First Asia Workshop on Superconducting Gravimetry", Hsinchu, Taiwan (2007).

1. Terms of reference

The terms of reference of the International Centre for Earth Tides (ICET) can be summarised as follows:
- *to collect all available measurements on Earth tides as World Data Centre;*
- *to evaluate these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the desired and needed geophysical information;*
- *to compare the data from different instruments and different stations distributed all over the world, evaluate their precision and accuracy from the point of view of internal errors as well as external errors;*
- *to help solving the basic problem of calibration by organizing reference stations or realizing calibration devices;*
- *to fill gaps in information and data;*
- *to build a data bank allowing immediate and easy comparison of earth tides parameters with different Earth models and other geodetic and geophysical parameters ;*

-to ensure a broad diffusion of the results and information to all interested laboratories and individual scientists.

These goals are achieved essentially by the diffusion of information and software, the data processing, the training of young scientists and the welcome of visiting scientists.

2. Main Commitments

It appears first that most geodetic measurements are affected by earth tides, as at the centimetre level the tidal displacement of the station is no more negligible. It will thus remain an important task for ICET to provide algorithms for tidal computation or analysis. For example the geophysicists, such as seismologists or volcanologists, who are measuring crustal deformations for natural hazards monitoring, are now conscious of the necessity of dealing properly with the tidal signals. In a similar way absolute gravity measurements require accurate tidal corrections that should take into account the local tidal parameters. These parameters have to be computed including oceanic tidal loading effects or even require in situ tidal gravity observations.

On the other hand the earth tidal scientific community is limited. The last International Symposium on Earth Tides, held in Ottawa, Canada from August 2 to 6, 2004 , brought together only a bit more than seventy participants. The groups are always very small and often marginally involved in tidal research. The papers dealing specifically with tidal studies are not fitting so well to international journals. It is thus very important to keep a specialized diffusion and information medium. It is the vocation of the "Bulletin d'Information des Marées Terrestres"(BIM). ICET is publishing one or two issues per year.

Which is the scientific challenge for global Earth tide studies now?

The mathematical modeling of the astronomical tidal forces as well as the elastic response of the Earth made decisive progress. It is now possible to model the astronomical tidal forces to within 0.05 $nm.s^{-2}$ in the time domain. The different mathematical techniques for the evaluation of the tidal response of the Earth do agree now to better than 0.1%. The most recent models include inelasticity in the mantle.

The last problems to be solved are linked to the fluid elements of our planet: liquid core resonance, oceanic loading, meteorological effects, underground water.

Among the ground based observations only gravity tides are able to give information valid at the regional level. The other components (tilt, strain, volume change) are heavily depending of the local parameters of the crust, including cavity or topography effects. These observations should be mostly used to monitor tectonic deformations and to study local tidal influence and correlations.

Tidal gravity observations are able to provide constrains on the liquid core resonance by means of very precise observations in selected sites. The same is valid also for the selection of the most realistic model for the elastic or inelastic response of the Earth. For that purpose it is essential to improve the calibration methods in order to achieve a 0.1% accuracy in amplitude and a 0.01^{o} accuracy in the phase determination. It is also necessary to use up to date oceanic tides models for tidal loading corrections. The determination of the amplitude factor of the polar motion effect on gravity will constrain the Earth viscosity at low frequency.

3. The Global Geodynamics Project (GGP)

These objectives are now directly addressed by the "Global Geodynamic Project" (GGP). A network of 25 stations equipped with cryogenic gravimeters is in operation since July 1997, using a similar hardware and the same procedures for data acquisition.

Besides tidal research, an important objective of GGP is to study the residues after elimination of the tidal contribution in order to detect inertial accelerations such as free oscillations of the Earth core and mantle with periods larger than 50 minutes, which are difficult to observe by means of conventional seismometers. In fact the cryogenic gravimeters are extra-large band instruments covering phenomena with period ranging from one second to more than one year.

It was a unique opportunity to obtain high quality well calibrated tidal observations. It is a reason why ICET has been interested to support this project since its beginning. ICET is responsible of the "Global Geodynamics Project-Information System and Data Centre" (GGP-ISDC, (http://ggp.gfz-potsdam.de) and firmed an agreement with the GeoForschungZentrum (GFZ) Potsdam which is physically hosting the data base. The data owners can upload themselves the original minute sampled data. The data are carefully preprocessed at ICET using a standard procedure, to correct for tares and spikes. The data are then decimated to one hour and analysed. The analysis results are directly communicated to the data owners. This follow up is required to detect as soon as possible the anomalies that could affect the data. Each year CD-ROM's are edited with the raw and corrected minute data as well as the log files and the auxiliary data, when available.

The archiving of the data is rather complex as the data are only released according to a strict time table. The constrain has been relaxed for the second GGP term beginning in 2003. The data are sent to ICET six months after their production. During one additional six months period the data are only available to the GGP members and can be freely accessed only after one full year. The software provided for the management of GGP-ISDC by the GFZ Potsdam is continuously updated.

With the collaboration of guest scientists ICET pushed forward researches using the GGP data sets and concerning for example the liquid core resonance, the determination of the pole tide and the detection of the inner core oscillations known as Slichter's mode (see bibliography). We have now more than 20 high quality data sets with a minimum length of six years and we can provide on request not only tidal parameters, oceanic loading corrections according to different models but also tidal residues to study non tidal effects such as core modes. These series, if they are well constrained by absolute measurements, will be also useful in the interpretation of satellite gravity data. To improve the tidal loading corrections ICET gathered the most recent ocean tides models.

4. Ongoing Activities

The “Bulletin d’Information des Marées Terrestres”(BIM) is printed in 300 copies. Some 275 copies are sent to libraries and individual scientists all over the world. It is devoted essentially to scientific papers concerning tidal research. From December 2003 until September 2006, six issues n° 138 to 142 have been published with a total number of 500 pages. In 2006 we had the opportunity to publish the proceedings of the workshop on “Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006”.All the published papers are immediately available on the ICET WEB site.

ICET is authorised to distribute freely the ETERNA tidal analysis and prediction software among the scientific community for non commercial purposes. Some forty CD-ROMS with ETERNA software are requested from ICET each year.

The ICET WEB site (http://www.astro.oma.be/ICET/) is continuously updated and developed. Besides general information including historical aspect and previous ICET reports, it proposes to the visitors an access to:

- the general bibliography on Earth Tides from 1870-1997 either by alphabetical order of the first author or following the decimal classification introduced by Prof. P.Melchior;
- the table of content of all the previous BIM, n° 1-142, and starting from BIM 133 an electronic version of the papers;
- tidal analysis and preprocessing software available from different WEB sites or on request from ICET.
- ocean tides loading computations and the predicted tidal gravity parameters for all the tidal gravity stations, more than 1,000 stations.

Most information requests (one per week minimum) concerned software. According to the internal GGP rules ICET is preparing annually CD-ROM's, with the raw and processed minute data. We already edited CD-ROM's for the 9 first years, 1997/07 to 2006/06, of the project.

5. Visitors

ICET welcomed more than 10 visitors. Besides visitors coming only for a short stay we must consider also guest scientists and trainees.

Prof. S. de Freitas ("Universidade Federal de Parana", Curitiba, Brazil) and Dr. Filippo Greco ("Istituto Nazionale di Geofisica y Vulcanologia, Sezione di Catania") visited ICET to discuss future cooperation.

The guest scientists bring their own know how or data to work at ICET during several weeks or even months. Prof. A.P.Venedikov (Institute of Geophysics, Bulgarian Academy of Sciences, Sofia) came in 2004, 2006 and 2007 to finalize its tidal analysis software VAV and extend its application to ocean tides. Some guest scientists worked on the ICET and GGP data banks, as Prof. H.P. Sun and his assistants X. D. Chen and J. C. Zhou (Institute of Geodesy and Geophysics, CAS, Wuhan, China). Others brought their own data sets to perform tidal analyses using the ICET software and computing facilities, as Prof. L.Brimich (Geophysical Institute, Slovak Academy of Sciences, Bratislava) and Dr. M. Benavent ("Instituto di Astronomia y Geodesia, CSIC-UCM", Madrid).

Mr. Daniel S. Costa ("Escola. Politécnica, Universidade de São Paulo, Brasil") and Mr. Stefano Panepinto ("Dipartimento di Chimica e Fisica della Tierra, Universita di Palermo") stayed during several months to receive intensive training on earth tide data processing and analysis.

As a follow up, many communications have been presented at International conferences and several papers have been published in international journals (see bibliography below).

ICET has been contacted by the Department of Technical support (Topographic Service) of the European Nuclear Research Center (CERN) in connection with the installation the Large Hadron Collider (LHD). The persons in charge have to monitor on line the tilt of the ground. As a first step our expertise is required to determine the most appropriate tidal parameters from theoretical models as well as from clinometric measurements. In a second step we should provide software for the real time prediction of the tidal tilts.

6. Summer School

In the framework of the International Gravity Field Service (IGFS), an International School on "Micro-gravimetric techniques: static and dynamics aspects", has been organised jointly by the "Bureau Gravimétrique International" (BGI) and ICET. It took place at Lanzarote (Canarias, Spain) from October 24 to 28, 2005.

7. Future of ICET

As the ICET Director is retiring at the beginning of 2008, it was necessary to prepare the transfer of the Service. As early as in 2004, the ICET director contacted all Scientific Institutes with a tradition in Earth Tides research. The requirements to host ICET were clearly explained in a document "Requirements to host the International Centre for Earth Tides (IAG Service and World Data Center)". The GGP group discussed this matter and sent an official letter with his view of the future of ICET. Finally IAG issued an announcement of opportunity which has been widely circulated.
Two institutions presented an official candidature:

- the "European Center for Geodynamics and Seismology", Luxembourg, Grand Duchy of Luxemburg;
- the University of French Polynesia at Papeete.

The ICET Directing board evaluated the candidatures on scientific grounds and selected the University of French Polynesia. This choice was accepted by the Earth Tide sub-commission and the IAG executive bureau during the XXIVth General Assembly of the IUGG.

The main task of the new Director will be to convert the ICET WEB site into a real "Virtual Observatory" on Earth Tides and to provide an interactive "portal" to answer specific questions.

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Submitted to Proceedings of IAG Symposium GS003, Earth rotation and Geodynamics

International Earth Rotation and Reference Systems Service (IERS)

Report to IAG, 2003-2007

1 Publications and web sites

The following IERS Technical Notes were published between 2003 and 2007:
No. 30: B. Richter et al. (eds.): Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids, 2003.
No. 31: C. Boucher, Z. Altamimi, P. Sillard, and M. Feissel-Vernier: The ITRF2000, 2004.
No. 32: D.D. McCarthy and G. Petit (eds.): IERS Conventions (2003), 2004.
No. 33: B. Richter et al. (eds.): Proceedings of the IERS Workshop on site co-location, 2005.
No. 34: Jean Souchay and Martine Feissel-Vernier (eds.): The International Celestial Reference System and Frame 2006.

The IERS Annual Reports give information about activities of all IERS components, as well as on IERS structure, Terms of Reference and contact addresses.

For rapid information, the Central Bureau issues IERS Messages which are being sent to about 2000 users.

Earth orientation data are distributed in IERS Bulletins A, B, C, and D.

The IERS components run about 20 web sites to present general information, data and publications. The central web site www.iers.org maintained by the Central Bureau provides information about IERS in general, its components and Earth rotation and reference systems as well as links to other servers. The web site contains also online versions of all publications since 2000.

2 Workshops

The IERS organized four Workshops:

- *IERS Workshop on site co-location* (Matera, Italy, October 23-24, 2003). More than 30 participants from Australia, South Africa, USA and Europe discussed various examples, analysis methods and survey strategies. Finally guidelines for co-location site surveys and report templates were proposed. The potential availability of survey teams as well as the planning for surveys were investigated and important recommendations were given. The Proceedings were printed as IERS Technical Note No. 33 and are available also online through IERS's website.

- *IERS Workshop on the Combination Pilot Project* (Napa, CA, USA, December 11, 2004). To discuss the future aspects and consequences of the IERS Combination Pilot Project experts of the IERS Working Group on Combination, the participants in the Combination Pilot Project together with representatives of the Technique Services - in total 23 persons - came together. The following topics were discussed:
  1) Combination Pilot Project and CONT'02 ("Weekly" SINEX);
  2) Long Time Series and their combination (ITRF, IERS200x, ...);
  3) Database and Information Systems.

- *IERS Workshop on Combination* (Potsdam, Germany, October 10-11, 2005). The workshop brought together nearly 60 experts from the fields of Terrestrial Reference Frame, Celestial Reference Frame and Earth Orientation Parameters to discuss the combination and validation strategies, the present status of combined intra- and inter-technique products, their development and adoption in the future. The Proceedings will be printed as IERS Technical Note No. 35.

- *IERS Workshop on Global Geophysical Fluids* (San Francisco, CA, USA, December 6-7, 2006). The goal of the workshop was to determine whether the GGFC was adequately addressing the needs of the community and what should be the priorities for changes. 25 specialists took place.

3 Activities of the IERS components

3.1 Central components

The *IERS Directing Board* (DB) met once or twice each year:

- Meeting No. 38 in San Francisco, December 8, 2003;
- No. 39 in Sèvres, September 23, 2004;
- No. 40 in Vienna, April 28, 2005;
- No. 41 in San Francisco, December 5, 2005;
- No. 42 in Vienna, April 8, 2006;
- No. 43 in San Francisco, December 11, 2006; and
- No. 44 in Vienna, April 15, 2007

to decide on important matters of the Service like minor structural changes, overall strategy, creating working groups, launching projects, changing Terms of Reference, etc.

Among the most important decisions made by the DB in 2003-2007 were the following:

- Creation of the IERS Working Group on Combination;
- Creation of the IERS Working Group on Site Survey and Co-location;
- Launching the EOP Prediction Comparison Campaign;
- Creation of the IERS Working Group on Prediction;
- Creation of the IERS/IVS Working Group on the Second Realization of the ICRF.

The *Central Bureau* coordinated the work of the Directing Board and the IERS in general, organized meetings and issued publications. It developed the IERS Data and Information System based on modern technologies for internet-based exchange of data and information. The system provides general information on the structure and the components of the IERS and gives access to all products.

The work of the *Analysis Coordinator* focused on initiating and coordinating the Analysis Campaign to align EOPs to ITRF2000 / ICRF, the SINEX Combination Campaign, and the Combination Pilot Project. He also issued new versions of the SINEX data format.

3.2 Technique Centres

The Technique Centres are autonomous independent services, which cooperate with the IERS.

The *International GNSS Service* (IGS), formerly the International GPS Service, is committed to provide the highest quality data and products as the standard for global navigation satellite systems (GNSS). Current GPS and GLONASS products support scientific objectives including realization of the ITRF, monitoring Earth rotation, and many others. Pilot Projects have been launched to develop new products and services.

The *International Laser Ranging Service* (ILRS) is responsible for the coordination of SLR/LLR missions, technique development, operations, analysis and scientific interpretation. Since mid-2003, it has been producing weekly time-series of solutions for station coordinates and Earth orientation parameters.

The *International VLBI Service for Geodesy and Astrometry* (IVS) has continues to fulfil its role as a service by providing necessary products for the densification and maintenance of the Celestial Reference Frame as well as for the monitoring of Earth Orientation Parameters. On average, a total of more than 1000 station days per year were used in about 180 geodetic sessions during the year as the observational basis for the IVS products.

The *International DORIS Service* (IDS) was created by the International Association of Geodesy in July 2003 as the result of a successful DORIS Pilot experiment. The main contribution of IDS to Earth rotation studies is the production of series of daily pole coordinates and weekly Terrestrial Reference Frames. The quality of these results has improved with time.

See also the individual reports of these Services to IAG.

3.3 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. The Centre has set up interactive Web tools for selecting, plotting, analysing time series of the Earth orientation and its atmospheric excitation. Starting from June 2007, the consistency of the EOP series with the International Reference Frames is at a better level of accuracy.

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. A lot of work has been dedicated to improvement of the centre's products, which includes the development of new strategies.

The *Convention Centre* released the electronic edition of the IERS Conventions (2003) in November 2003, and the corresponding paper edition was published in 2004. A new web site includes a discussion forum and pages for the Conventions updates. Several updates to the Conventions have been published since 2004.

The *ICRS Centre* has been working on validation of individual reference frames by comparison with ICRF-Ext.1, on monitoring source structure to assess astrometric quality, on the maintenance of the Hipparcos link, on linking the ICRF to frames at various wavelengths, and on other studies. The Centre published its Report for 2001-2004 as IERS Technical Note 34.

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. A new ITRS Web site was developed. In cooperation with the ITRF combination centres (DGFI and NRCan), the ITRS Centre finalized the ITRF2005 in October 2006.

The *Global Geophysical Fluids Centre* (GGFC) 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. During the last three years, the amount of data and their quality have significantly improved in several cases.

3.4 Combination Centres and Working Groups

Eleven *Combination Research Centres* worked on the development of methods and software for the combination of data and products from different techniques. Three *ITRS Combination Centres* are responsible to provide ITRF products by combining ITRF inputs. Several of these Combination Centres took part in the Combination Pilot Project.

The *Working Group on Site Survey and Co-location* coordinates a Site Survey and Co-location Pilot Project with the intention of developing future recommended IERS standards for site survey and co-location. The major task of the *Working Group on Combination* is the coordination of the IERS Combination Pilot Project. The *Working Group on Prediction* is 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 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.

Chopo Ma, Chairman of the IERS Directing Board,
Bernd Richter, Director of the IERS Central Bureau,
Wolfgang Dick, IERS Central Bureau.

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International Geoid Service Report (2003-2007)

Since the IAG/IUGG General Assembly held in Sapporo, IGeS actively continued its educational and research mission on geoid estimation.
In 2005 and 2006, IGeS organized two new schools on "The determination and Use of Geoid". These schools continued the tradition of IGeS, which in the past has organized five geoid Schools: Milano (Italy - 1994), Rio de Janeiro (Brasil - 1997), Milano (Italy -1999), Johor (Malesia - 2000), Thessaloniki (Greece - 2002).
The first one took place in Budapest, from January 31st to February 4th 2005. It was hosted by the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BUTE) in cooperation with the Research Group for Physical Geodesy and Geodynamics of the Hungarian Academy of Science (HAS).
The courses have been given by Fernando Sansò (A compendium of physical geodesy in view of geoid computation and related height questions), Riccardo Barzaghi (The Global Geopotential Models), Christian C. Tscherning (Geoid Determination by least-squares collocation using GRAVSOFT), Michael G. Sideris (Geoid Determination by FFT Techniques) and Ilias N. Tziavos (The Terrain Effects in Geoid Estimation). One seminar on "Present Day Activities of the International Gravimetric Bureau (BGI)" was presented by M. Abbasi and Th. Fayard from BGI, France.
The Lecture Notes on Global Geopotential Models was prepared by Peter Schwintzer (GeoForschungsZentrum, Potsdam), who passed away before the School. His Lecture Notes titled as "The gravity field of the Earth: global gravitational potential models" is dedicated in memory of Peter Schwintzer.
All courses, but for the first one, have been followed by computer exercises based on the available software programs. 49 participants attended the School. They come from 19 countries: Canada (3), Croatia (3), Czech Republic (1), Denmark (3), France (3), Germany (3), Greece (1), Hungary (5), Italy (3), Malaysia (1), Pakistan (8), Poland (4), Portugal (1), Saudi Arabia (3), Slovakia (1), Slovenia (1), Spain (2), Turkey (2) and Ukraine (1).
In June 19th-23rd 2006, the second geoid school was organized in Copenhagen. It was hosted by the Niels Bohr Institute at the University of Copenhagen. The teachers were Fernando Sansò (General introduction to Physical Geoid and general theory on geoid computation), Niko Pavlis (The Global Geopotential Models), Christian C. Tscherning (The collocation method in Physical Geodesy), Michael G. Sideris (FFT methods in Physical Geodesy) and Rene Forsberg (The Terrain Effects in Geoid Estimation). One seminar on "Geoid, gravity and sea-level from radar atimetry" was presented by Ole Andersen by the Danish National Space Center.

All courses, but for the first one, have been followed by computer exercises. 20 participants attended this School. They come from 13 countries: Brazil (1), Denmark (5), Egypt (1), Italy (2), Morocco (2), Mexico (1), Norway (1), Portugal (1), Romania (1), Spain (3), Switzerland (1), Turkey (1), USA (1).
As done in the previous schools, lecture notes and software for geoid computation have been distributed to the students.
On the scientific side, IGeS is participating to the project aimed at estimating the new European geoid, a Commission Project which is chaired by Heiner Denker. In this framework, IGeS has carried out the validation of the SRTM DTM and of the NOAA 1'× 1' bathymetry in the Mediterranean area. Also, the gravity data base covering the Western/Central part of the Mediterranean has been checked using the collocation filtering technique and will be used in the European geoid project. Furthermore, within this project, IGeS is in charge for the computation of the terrain effect (using an original approach) and for the estimation of the residual geoid component by means of collocation.
Also, a new project will soon be started to test for different geoid estimation methods using a common and reliable data base (kindly supplied by H. Duquenne).
Furthermore, IGeS is strongly involved as a member of the European GOCE Gravity Consortium (EGG-C) in the GOCE High-level Processing Facility (GOCE HPF) whose activities started in April 2004.
Within the GOCE Ground Segment, the HPF is one of the Core Elements (ESA-controlled), and it is charged with the generation of L2 products and acquisition of the external (auxiliary) data needed to generate these products, the delivery of these products (auxiliary, intermediate and final) to the PDS/DPA (Payload Data Segment/Data Processing Archive) and/or the LTA (Long Term Archive) and the generation of QLP (Quick Look Products) and ECP (External Calibration Products) for the purpose of the activities of the CMF (Calibration and Monitoring Facility).

Members of the GOCE HPF are:
- IAPG Institute of Astronomical and Physical Geodesy, Technical University Munich, Germany (Principal Investigator);
- AIUB Astronomical Institute, University of Bern, Switzerland;
- CNES Centre National d'Etudes Spatiales, Groupe de Recherche de Géodésie Spatiale, Toulouse, France;
- FAE/A&S Faculty of Aerospace Engineering, Astrodynamics & Satellite systems, Delft University of Technology, Delft, The Netherlands;
- GFZ GeoForschungsZentrum Potsdam, Department 1 Geodesy and Remote Sensing, Potsdam, Germany;
- ITG Institute of Theoretical Geodesy, University Bonn, Germany;
- IGeS- POLIMI, DIIAR – Sezione Rilevamento, Politecnico di Milano, Italy;
- SRON National Institute for Space Research , Utrecht, The Netherlands;
- TUG Institute of Navigation and Satellite Geodesy, Graz University of Technology;
- UCPH Department of Geophysics, University of Copenhagen, Denmark.

Within the GOCE HPF, the establishment of a sub-processing facility for GOCE data and the retrieval of the gravity field with the space-wise approach is under responsibility of IGeS-POLIMI as contractor, with UCPH as sub-contractor. In addition ITG is participating as science consultant. The sub-processing facility will be developed at two sites, namely at IGeS-POLIMI and UCPH, and operated at one facility at IGeS-POLIMI.
The software to perform the space-wise approach will be made up of already existing modules developed at UCPH (GRAVSOFT) and modules developed at IGeS-POLIMI for the purpose

(based on existing routines). This software will be integrated and tested as a whole, so that the data stream from GOCE will flow smoothly through it, in a unique processing chain implemented in a Sub-Processing Facility (SPF) located at IGeS-POLIMI.

IGeS web has been also updated and renewed during the last four years and contains at present 28 geoid data files and a collection of 11 global geopotential models. Furthermore, the CD containing the software on geoid computation (the same distributed at the geoid schools) can be requested through the IGeS web, under the same restrictions applied when distributing it during the geoid schools (freely available after a declaration stating for non commercial use of this software).

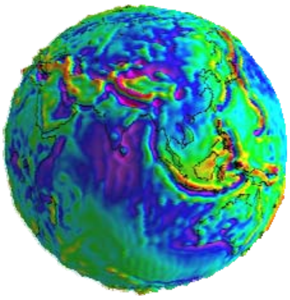
The editorial activity, which started in 1993, is now continuing in a new form. From December 2003, the IGeS and the BGI Bulletins have been merged in the new Newton's Bulletin. The Newton's Bulletin is a reviewed scientific journal collecting paper on geoid and gravity. Three issues are available, in electronic form, on the IGeS web page, together with 13 issues of the previous IGeS Bulletin.

IGeS also promoted, together with BGI, NIMA, ICET and GFZ, the creation of a new IAG service named International Gravity Field Service (IGFS). IGFS is a unified IAG service aiming at collecting, validating and distributing data and software for the purpose of determining, with various degrees of accuracy and resolution, the gravity potential of the Earth, or any of its functional, and the surface of the Earth. This new service has been approved by the IAG Executive Committee during the last IAG-IUGG Assembly in Sapporo.

In this framework, IGFS actively participated in organizing the 1st IGFS General Assembly which was held in Istanbul, August 2006.

Besides, IGeS, as an official IAG service, is involved in the Global Geodetic Observing System (GGOS) project which aims at collecting geodetic data and integrating them to "provide the scientific and infrastructure basis as geodesy's significant contribution to global change research in Earth sciences"

On the national Italian side, IGeS has estimated the new high precision Italian geoid and it is cooperating with the Italian Space Agency (ASI), the Istituto Geografico Militare (IGM), the Agenzia del Territorio (Italian National Cadastre), the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS).



Status report 2003-7
International Gravity Field Service

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Structure, working groups and mission

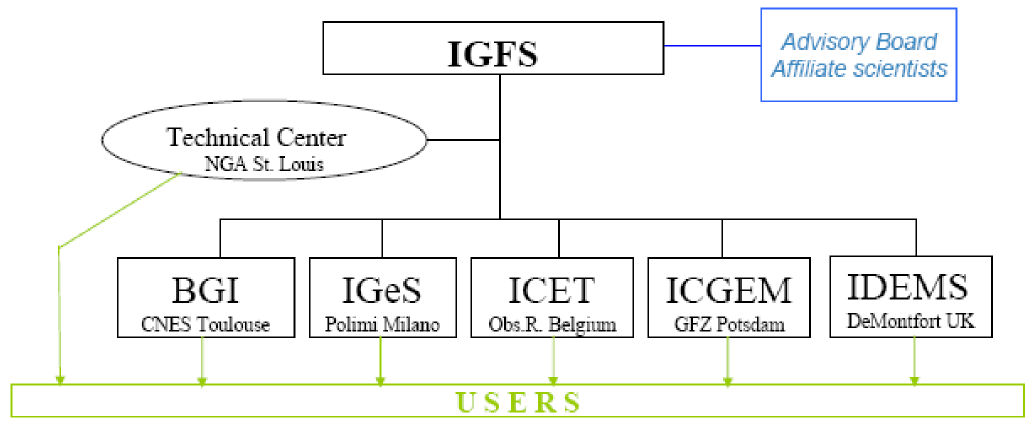
The International Gravity Field Service (IGFS) was established at the IUGG in Sapporo 2003. The purpose of the IGFS is to act as an "umbrella" service over the existing gravity field services:

- BGI (Bureau Gravimetrique International)
- IGeS (International Geoid Service)
- ICET (International Center for Earth Tides)

New gravity field services and project groups would be set up as required. Since Sapporo the following services has been initiated:

- ICGEM - International Centre for Global Earth Models
- IDEMS - International DEM Service

The new services are both online, and information can be linked via the IGFS home page, www.igfs.net. The National Geospatial-Intelligence Agency has taken a special role in the IGFS acting in part as a parallel gravity field data service, not least in securing the development of high-resolution gravity field models (EGM07). The overall structure of the IGFS for the start-up phase 2003-7 is shown below:



So far there has been no direct interaction with users via IGFS; this interaction is ongoing via the "Level-1" services and the Technical Center at NGA.

In addition the IGFS has the following working groups:

- Joint Working Group on Evaluation of Global Earth Gravity Models (especially EGM07), joint group with IAG Gravity Field Commission (*chairman: Jianling Huang, NRCan, Canada)*.
- Working Group on Absolute Gravimetry (*chairman: H. Wilmes, BKG, Germany)*

The working group on absolute gravimetry was established in Istanbul, September 2006, and will as special role have the coordination and standardization of global absolute gravity campaigns. GGOS has e.g. identified a unified global absolute gravity network as a major element missing in the long-term basic GGOS network.

The advisory board consists of 12 scientists, among them directors of IGFS services and chairman of working groups, as well as members for major regional projects and satellite gravity missions, see www.igfs.net.

The overall long-term goal of IGFS is to coordinate the servicing of the geodetic and geophysical community with gravity field-related data, software and information. The combined data of the IGFS services data will include both satellite-derived global models, terrestrial, airborne, satellite and marine gravity observations, earth tide data, GPS leveling data, digital models of terrain and bathymetry, as well as ocean gravity field and geoid from satellite altimetry. Both the static and the temporal variations of the gravity field will be covered by the IGFS. A special purpose of the IGFS will be to coordinate the gravity field services in relation to GGOS – the Global Geodetic Observing System – and take initiatives to cover missing elements, e.g. the provision of "combination solutions" of gravity field related quantities, analogous to e.g. IERS.

IGFS will make special efforts in trying to secure release of data from national and international institutions holding data on the spatial and temporal gravity variations, geoid and the surface heights of the Earth, to make them widely available to the scientific community. For this purpose the IGFS has also initiated some regional conferences on gravity and geoid.

Activities for 2003-7

The IGFS has set up its web page – www.igfs.net. This is a minimal web page at present. There has been plans to improve the web page with resource information on gravity field science etc, to serve as a more useful entry to the Level-1 services (BGI, IGeS etc.), especially for the non-geodetic user. This has not been done due to limited time resources.

Advisory Board meetings were held at:

- 2004 EGS meeting in Nice, France.
- 2005 IAG General Assembly in Cairns
- 2006 IGFS 1st Symposium in Istanbul

The Advisory Board has approved the activities of the IGFS, such as the arrangement of conferences and workshops, and discussed new initiatives. The Advisory Board meetings were usually only with a limited attendance. Minutes are at www.igfs.net.

Workshops and meetings organized by the IGFS include:

- Workshop on Height Systems, Geoid and Gravity of the Asia-Pacific Ulaanbaatar, Mongolia, June 6-8, 2006.
- 1st International Gravity Field Service Symposium, Istanbul, Aug 28 - Sep 1, 2006.
- International Workshop Gravity and Geoid in South America, Buenos Aires, Sep. 25-29, 2006.

The Mongolia workshop attracted approx. 35 participants from the region, and aided in the future sharing of data across the borders, as well as in the formulation of various new cooperative projects, e.g. cross-border geoid projects and a proposed cooperation between Taiwan and Mongolia on superconducting gravimetry.

The Symposium in Istanbul was a large meeting with more than 220 presentations (oral papers and posters). The presentations was grouped into 10 sessions:

- Gravity field modeling from combinations of local and satellite data
- Regional geoid projects
- Vertical datum and height systems
- New Earth Geopotential Models (EGM06)
- Satellite Gravity Missions
- Satellite Altimetry
- Airborne Gravity
- Global terrain models for physical geodesy
- Absolute Gravity and gravimetric networks
- Geodynamics and gravity change

The Symposium was hosted by the Turkish National Geodesy Commission and Turkish General Command for Surveying and Mapping. The local organizing committee was under the leadership of A. Kilicoglu. Proceedings are currently nearing final production, and will be published as a special volume of Turkish Journal of Surveying.

The South American workshop, hosted by the Istituto Geographic Militar, were attended by about 25 scientists from 6 countries, and were mainly held in Spanish. The discussions focussed very much on local geoid models, the joint South American geoid and the possibilities for defining a unified vertical datum, as well as discussions on improving the gravity data coverage in accessible regions such as the Andes and Amazon, e.g. by airborne gravity projects.

Service cooperation within IGFS

With the individual gravity field services, funded by national funding agencies, the enthusiam of some “Level-1” services to enter into a more formal cooperation under the IGFS umbrella has – understandably – been somewhat limited, and communication sometimes relatively slow. This has in part been due to changes in the “old” services due to reorganization and the changing of directors. All services have, however, contributed to IGFS meetings and also acknowledged the usefulness of a coordinating body like the IGFS. In addition joint service activities has included “Newton’s Bulletin” (journal of the BGI and IGeS) and de-facto joint schools (geoid and microgravimetry schools).

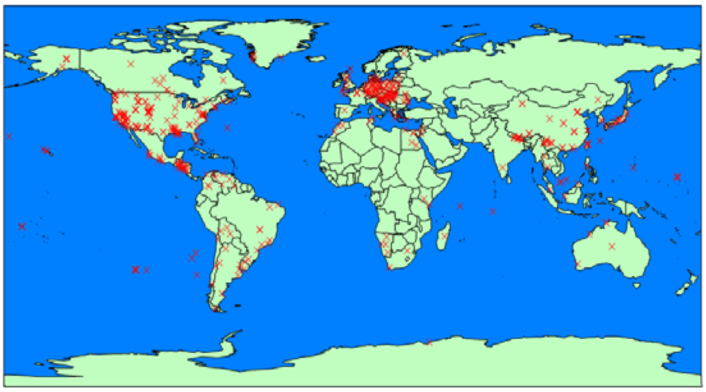
There seems to be a need for some more formalized cooperation for the upcoming period 2007-11, not least from a general user and GGOS point of view, to truly let the gravity field take the role of a “third pillar” of geodesy, looking into the success of the cooperation of the geometric services (IERS, IGS, ILRS, IVS etc ..). Developments in satellite geodesy should, however, make a case for improved cooperation and coordination of gravity field services in the near future, given the need for combining e.g. static and temporal gravity field satellite models, as well as high-resolution combination models, into a single unified “GGOS product”. Other new developments, such as the adaption of a global vertical datum (W_0), and the increased absolute accuracy of satellite-derived geoid models, would also enforce a need for much closer cooperation on standardization of corrections to gravity field data.

There is therefore a clear need for the IGFS also in the coming period (but maybe with a different organization, e.g. a Central Bureau).

Rene Forsberg, DNSC
June 28, 2007

Some examples of gravity field activities, with global coordination via the IGFS??

Coordination of absolute gravity:



Current NGA global points (courtesy S. Kenyon, NGA)

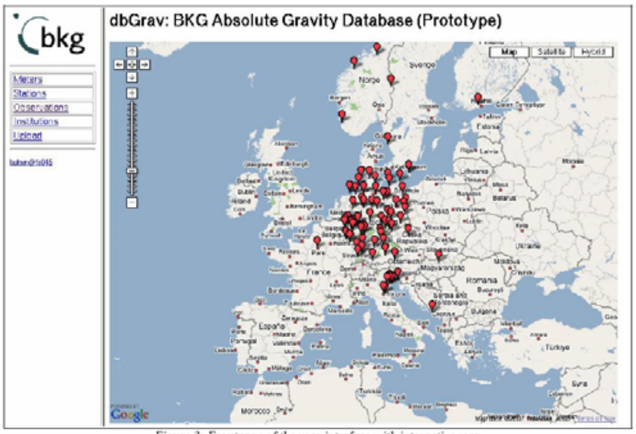
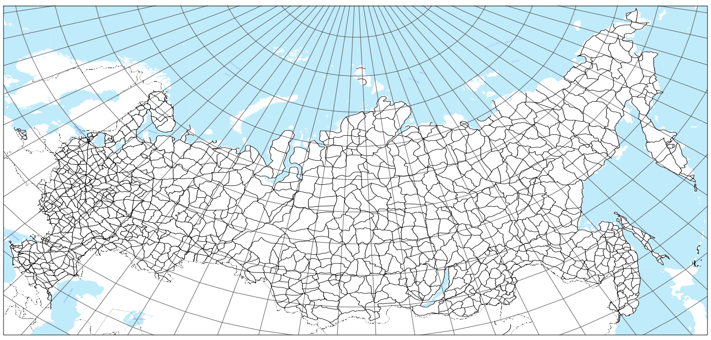


Figure 3: Frontpage of the user interface with interactive map

Absolute gravimetry data base (courtesy H. Wilmes, BKG)

GPS-levelling global, standardized data sets:



Example of (GPS) levelling of Russia (courtesy G. Demianov)

INTERNATIONAL LASER RANGING SERVICE (ILRS)

M. R. Pearlman[1], C. E. Noll[2], W. Gurtner[3], E. C. Pavlis[4]

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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 ultrashort laser pulse to and from a retroreflector array on a satellite, which are reduced for orbital and positioning products, once corrected

for atmospheric delays and spacecraft center-of-mass. 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 geocenter 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 Subnetworks
- Operations Centers
- Global and Regional Data Centers
- Analysis and Associate Analysis Centers
- Central Bureau

The ILRS Tracking Stations range to a constellation of artificial satellites, the Moon, 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 Center. 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 Center. Each Tracking Station is typically associated with one of the three regional subnetworks: National Aeronautics and Space Administration (NASA), EUROpean LASer Network (EUROLAS), or the Western Pacific Laser Tracking Network (WPLTN).

Operations Centers 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 Center. Operational Centers 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 Center themselves.

Global Data Centers are the primary interfaces between the Tracking Stations and the Analysis Centers and outside users. They receive and archive ranging data and supporting information from the Operations and Regional Data Centers, and provide these data on-line to the Analysis Centers. They also receive and archive ILRS scientific data products from the Analysis Centers and provide these products on-line to users. Regional Data Centers reduce traffic on electronic networks and provide a local data archive.

Analysis Centers retrieve data from the archives and process them to produce the official ILRS products. They are committed to follow designated standards and produce on a routine basis for delivery to the Global Data Centers and the IERS. Analysis Centers 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 Centers also provide a second level of data quality assurance in the network. Analysis and Associate Analysis Centers produce station coordinates and velocities, geocenter 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 Centers are also encouraged to perform quality control functions through the direct comparison of Analysis Center products and the creation of "combined" solutions using data from other space geodetic techniques. Lunar Analysis Centers produce LLR products such as lunar ephemeris, lunar libration, and Earth rotation (UT0 - UT1). In the field of relativity, LLR is used for the verification of the equivalence principle, estimation of geodetic precession, and examination of the relative change in G.

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 AND WORKING GROUPS

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 2006 at the 15th International Workshop on Laser Ranging in Canberra Australia.

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, and (4) Analysis. A fifth WG on Transponders for lunar and planetary ranging was established in 2006. The Ad-Hoc Signal Processing WG, organized to provide improved satellite range correction models to the analysts, has now been subsumed into the Networks an Engineering WG. 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 four standing 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.

Table 1. ILRS Governing Board (as of June 2007)

Hermann Drewes	Ex-Officio, President of IAG Commission	Germany
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
Hiroo Kunimori	Appointed, WPLTN	Japan
Vincenzia Luceri	Elected, Analysis Representative, Analysis Working Group Deputy Coordinator	Italy
Erricos Pavlis	Elected, Analysis Representative, Analysis Working Group Coordinator	USA
Wolfgang Seemueller	Elected, Data Centers Rep., Data Formats and Procedures WG Coordinator	Germany
Juergen 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 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 has developed and implemented the new Consolidated Prediction Format (CPF) for a much wider variety of laser ranging targets including (1) Earth-orbiting retroreflector 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 maneuver files. Within the WG, the Refraction Study Group has made significant advances in updating the refraction correction model and in proposing novel techniques for further improvement. The new model is now accepted as part of the IERS Conventions. The WG has developed a new format for ranging data to accommodate extraterrestrial targets and transponders in addition to SLR satellite data.

The Network and Engineering WG has organized a special kHz SLR workshop in Graz, to motivate and assist other stations to switch to this promising technique; slight adaptations in the existing normal point format were implemented to accommodate kHz SLR data. Programs to quality check normal points at the SLR station before transmission to operations centers were distributed to all stations. The SR620 Stanford counters, which have been used during the past year at several stations, are now measured for recently discovered non-linearities, to be able to apply possible range corrections on already measured SLR data. In addition, the EDF (Engineering Data File) system has been established in order to verify and intercompare SLR system functions at the hardware level. The Signal Processing Ad-Hoc WG is working on improved center-of-mass corrections and signal processing techniques for SLR satellites.

The Analysis WG completed its pilot projects to assess and resolve differences among analysis products from the Analysis and Associate Analysis Centers. Seven centers have qualified as Analysis Centers; two additional centers are in the qualifying process. A Combination Center and a Backup Combination Center 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 1993-2005 reanalysis of the LAGEOS data was provided to the IERS in support of the development of ITRF2005. Work is underway to add additional official ILRS products including precision orbits and certified data corrections. A new reanalysis that includes the historical SLR data back to at least 1983 is in process.

The newly formed Transponder Working Group has begun to form a list of recommendations for the future development of interplanetary laser transponders for centimeter ranging and sub-nanosecond time transfer. Activities are underway at SLR sites in Europe and the US to conduct simulated interplanetary experiments using the current SLR satellite constellation. Such experiments would have a beneficial impact on interplanetary optical communications as well.

ILRS NETWORK

Satellite Laser Ranging (SLR) Network

The SLR technique is now over forty years old, having originated in 1964 with ranging to Beacon-B from GSFC. Systems have evolved from a manually operated mount with meter-level ranging systems to automated and semi-autonomous systems with sub-centimeter ranging accuracies.

The present ILRS network, as shown in Figure 1. The last four years have witnessed considerable activity within the ILRS. After some discouraging cutbacks in 2003-5, the ILRS network has had some resurrection. NASA and the University of San Agustin reopened the TLRS-3 system at Arequipa in late 2006. A rededication ceremony was held in early 2007. Fortunately the GPS receiver has been in operation since SLR closure in 2003, so some continuity has been provided during the intervening period. Several upgrades including the “restricted tracking capability” have been added to the system to enhance operations. The Mt. Haleakala station has also been reopened with the TLRS-4 at a new site about 100 meters from the old site. The system began producing data also in late 2006. A rededication of this site was held in late January 2007. Both stations have produced sufficient LAGEOS data to verify their performance. Staffing reductions persist at the MLRS (McDonald) and MOBLAS-7 (GSFC) and to a lesser extent at MOBLAS-4 (Monument Peak). The partner stations at Yarragadee, Hartebeesthoeck, and Tahiti are unaffected.

Figure 1. ILRS network (as of June 2007)

The Mt. Stromlo station has been fully operational since its reconstruction after the forest fire in early 2003. The station is now the second largest data producer in the ILRS network after Yarragadee. The two Australian stations together produced about 14,000 passes in 2006.

The Chinese SLR network continues its very strong support for the ILRS network. The Changchun station maintained its exceptional performance with activities underway now to help strengthen daylight ranging. The new Shanghai station is now in operation after relocation; data yield is steadily improving. The new Chinese SLR station in San Juan, Argentina has performed impressively since beginning operations in March 2006 and has risen to one of the six largest producers of data in the network. This station has helped a great deal in the laser ranging coverage in Southern Hemisphere.

Improvements have also been realized in other stations in the ILRS network. The station in Riyadh, Saudi Arabia continues its impressive tracking operations. This is the only station that in the ILRS located on the Arabian Peninsula, so its importance cannot be understated. The TIGO system in Concepción, Chile has undergone substantial repairs and is now back in operation. Data yield has steadily increased over the last few years, but the station is fighting difficult weather conditions. The location of this station in South America should help greatly in the Southern Hemisphere coverage. The Graz system continues its impressive performance with 2kHz operation, a technology that will most likely become more prevalent in the network as time goes on. A 2kHz laser has also been purchased for implementation into the Herstmonceux station; several other stations are seriously considering this upgrade. The TIGO system in Concepción, Argentina and the upgraded Zimmerwald station continue with two-wavelength ranging using a titanium-sapphire laser operating at 423nm and 846nm to test this as a means for improving the atmospheric refraction correction. The station at Grasse, France has temporarily closed for major upgrading. The French Transportable Laser System (FTLRS) is now being readied for relocation to Burnie, Tasmania) to support altimeter calibration and validation. The storm damage has been repaired the GUTS facility in Tanegashima, Japan and operations have been underway, but data yield is still sparse.

Lunar Laser Ranging (LLR) Network

During the Apollo missions the astronauts deployed laser retro-reflectors near their landing sites, which are in continued use up to the present day. Today, the results from Lunar Laser Ranging (LLR) are considered among the most important science return of the Apollo era. The lunar laser ranging experiment has continuously provided range data for more than 37 years. The main benefit of this geodetic technique is the determination of a host of parameters describing lunar ephemeris, lunar physics, the Moon's interior, various reference frames (the terrestrial and selenocentric frame, but also the dynamic realization of the celestial reference system), the Earth-Moon dynamics as well as the verification of metric theories of gravity and gravitational physics, such as the equivalence principle or any time variation of the gravitational constant.

The site operated by the Observatoire de la Côte d'Azur (OCA), France has collected the majority of the LLR data in recent years. The LLR station at the McDonald Observatory in Texas, USA is another major provider of the LLR data. Until 1990, the Haleakala laser ranging station on the island of Maui (Hawaii, USA) contributed to LLR activities with its 40cm telescope. Other stations with promising potential in lunar ranging are Wettzell, Matera, and Mount Stromlo. The new APOLLO lunar ranging station at the Apache Point Observatory (New Mexico, USA) took some data in 2006 with very impressive results. This station is designed for mm accuracy ranging. Today, MLRS (and OCA) are the only currently operational LLR sites achieving a typical range precision of 18-25mm, hopefully further sites may provide lunar data on a routine basis soon. Current LLR data is collected, archived and distributed under the auspices of the International Laser Ranging Service (ILRS).

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.

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

Missions are added to the ILRS tracking roster as new satellites are launched and as new requirements were adopted. New missions included ANDE-RR, an atmospheric modeling satellite, and GIOVE-A the first engineering test satellite for the Galileo series. The network also supported a short calibration campaign on the ALOS satellite with optical sensors for terrestrial mapping. The ETS-8 synchronous satellite was also launched to a location over the western Pacific, but tracking was delayed until early 2007 while the satellite underwent engineering readiness tests. Missions for completed programs were deleted from the ILRS tracking list. The TOPEX/Poseidon project ended in 2006 after a remarkable 13 years of service, with SLR providing the sole source of POD during its last year of operations. SLR was the sole means of POD for the SAGE experiment on Meteor-3M which ended in 2006. The GP-B 18-months campaign also ended in 2006.

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 retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 3 along with their sponsors, intended application, and projected launch dates.

Table 2. ILRS Tracking Priorities (as of June 2007)

Satellite Priorities					
Priority	**Mission**	**Sponsor**	**Altitude (km)**	**Inclination (degrees)**	**Comments**
1	TerraSAR-X	Infoterra/DLR/ GFZ/CSR	514	97.44	First priority for acquisition phase only
2	GRACE-A, -B	GFZ/JPL	485-500	89	Tandem mission
3	CHAMP	GFZ	429-474	87.3	
4	GFO-1	US Navy	790	108.0	Altimetry/no other tracking technique
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	
8	ANDE-RR Active	NRL	400	51.6	
9	ANDE-RR Passive	NRL	400	51.6	
10	Larets	IPIE	691	98.2	
11	Starlette	CNES	815-1,100	49.8	
12	Stella	CNES	815	98.6	
13	Ajisai	NASDA	1,485	50	
14	LAGEOS-2	ASI/NASA	5625	52.6	
15	LAGEOS-1	NASA	5850	109.8	
16	Beacon-C	NASA	950-1,300	41	
17	Etalon-1	Russian Federation	19,100	65.3	
18	Etalon-2	Russian Federation	19,100	65.2	
19	GLONASS-99	Russian Federation	19,100	65	Replaced GLONASS-86 on 03/20/2003
20	GLONASS-95	Russian Federation	19,100	65	Replaced GLONASS-87 on 01/12/2007
21	GLONASS-102	Russian Federation	19,100	65	Replaced GLONASS-84 on 08/26/2005
22	GPS-35	US DoD	20,100	54.2	
23	GPS-36	US DoD	20,100	55.0	
24	GIOVE-A	ESA	29,601	56	

Lunar Priorities			
Priority	**Retroreflector Array**	**Sponsor**	**Altitude (km)**
1	Apollo 15	NASA	356,400
2	Apollo 11	NASA	356,400
3	Apollo 14	NASA	356,400
4	Luna 21	Russian Federation	356,400

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 (e.g., TerraSAR-X in 2007) 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.

Table 3. Upcoming Missions (as of June 2007)

Mission	Sponsor	Planned Launch Date	Mission Duration	Altitude (km)	Inclination (degrees)	Application
GIOVE-B	ESA	2007		23,916	56°	Radio navigation satellite system
GOCE	ESA	2007		250	96.5°	Earth's gravity field and geoid modeling
Jason-2	NASA, CNES, Eumetsat, NOAA	June 2008		1,336	66	Oceanography, T2L2
LRO-LR	NASA	October 2008		Lunar	N/A	POD for LRO
NPOESS	NOAA, NASA, DoD	2013		833	98.7°	Sea surface height
PROBA-2	ESA	December 2007		721	98	Technology validation

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 Centers (AC) and Combination Centers (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 2007. Each weekly solution is obtained through the combination of weekly solutions submitted by the official ILRS Analysis Centers:

ASI, Agenzia Spaziale Italiana
BKG, Bundesamt für Kartographie und Geodäsie
DGFI, Deutsches Geodätisches Forschungsinstitut
GA, Geosciences Australia
GFZ, GeoForschungsZentrum Potsdam
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 Center (ASI) and the official Backup Combination Center (DGFI) follow strict timelines for these routinely provided products.

In addition to operational products, solutions have been provided covering the period back to 1993. A current effort is underway to extend the time series as far back as the mid 1970s. The ILRS products are available, via ftp from the official ILRS Data Centers CDDIS/NASA Goddard (*ftp://cddis.gsfc.nasa.gov/*) and EDC/DGFI (*ftp://ftp.dgfi.badw-muenchen.de*).

ILRS Contribution to ITRF2005

The time series of weekly solutions from 1993 to 2005, produced by the Primary Combination Center, was delivered to IERS/ITRS as an official ILRS contributed data set for ITRF2005. 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 final version of the combined ILRS time series was submitted in December 2005. Figures 2 and 3 show the origin and scale differences with respect to the old ITRF realization, ITRF2000.

These time series are essentially equivalent to the ones that have been generated operationally since after January 2007 and those to be soon reissued for the period of 1993-2006 and only differ from that in the applied tropospheric model (Marini-Murray for the old vs. Mendes-Pavlis for the new series) and the modelling of a range bias due to Stanford event timers' non-linearities for a subset of stations. The description of the official contribution to ITRF2005 is available at *http://itrf.ensg.ign.fr/ITRF_solutions/2005/doc/ILRS_ITRF2005_description.pdf.*

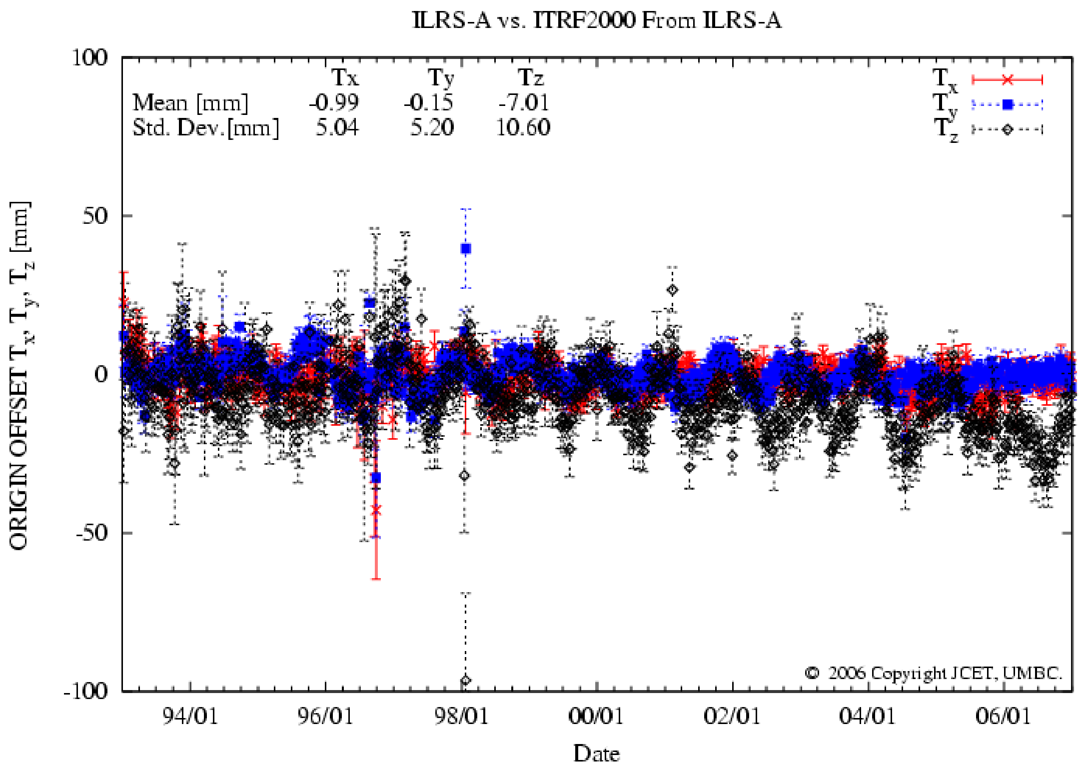

Figure 2. Origin offsets from the official weekly ILRS product with respect to ITRF2000.

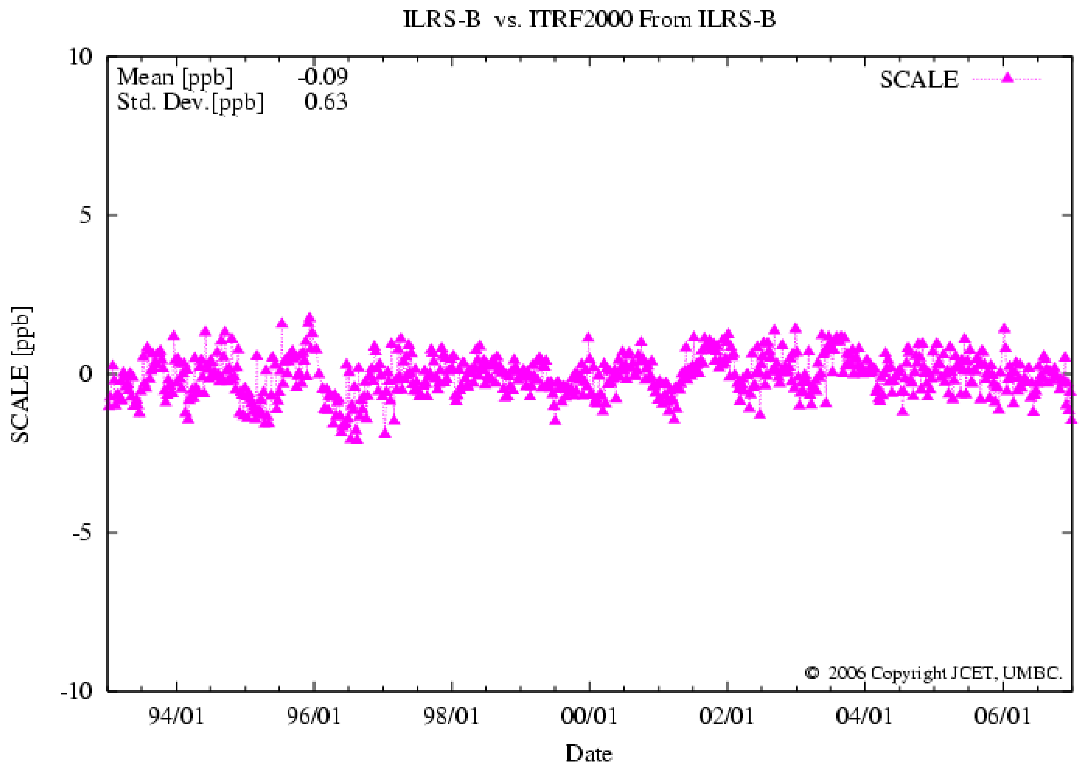

Figure 3. Scale factor from the official weekly ILRS product with respect to ITRF2000.

Comparison of the ILRSA and ILRSB Combinations

The official ILRSA combination solution produced by ASI is routinely compared with the backup combined solution ILRSB produced by DGFI following a fundamentally different approach. The results show a good agreement between the two solutions and absence of any systematic differences. The tables and figure below briefly show this agreement in terms of:

1. mean 3D wrms of the site coordinates residuals with respect to ITRF2000 (Table 4 and Figure 4);
2. mean differences of the translation and scale parameters with respect to ITRF2000 computed using the two time series ILRSA and ILRSB (Table 5);
3. EOP residuals with respect to EOPC04 (Table 6) for the year 2006.

Table 4. 3D wrms of the site coordinates residuals w.r.t. ITRF2000

	ILRSA(mm)	ILRSB(mm)
All sites (mean)	21.5	26.0
Core sites (mean)	8.0	10.1

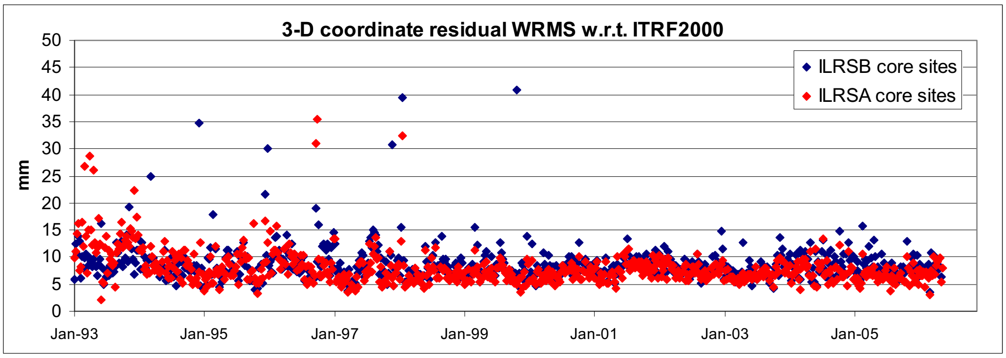

Figure 4. 3D wrms of the core site coordinates residuals with respect to ITRF2000.

Table 5. Translation and scale (with respect to ITRF2000) differences between ILRSA and ILRSB

	TX(mm)	TY(mm)	TZ(mm)	Scale(mm)
Weighted Mean	1.14±0.18	-0.24±0.18	-0.10±0.41	0.05±0.26
WRMS	3.14	2.27	4.03	3.13

Table 6. EOP daily residuals with respect to EOPC04 for ILRSA and ILRSB

	ILRSA		ILRSB	
	WMEAN	WRMS	WMEAN	WRMS
EOP-X (mas)	-0.055	0.153	0.020	0.175
EOP-Y (mas)	0.193	0.153	0.244	0.197
LOD (ms)	0.003	0.047	-0.003	0.054

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/*.

MEETINGS AND REPORTS

The ILRS organizes semiannual 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 ILRS meetings is shown in Table 7. Detailed reports from past meetings can be found on the ILRS Web site.

Table 7. Recent ILRS Meetings (as of June 2007)

Timeframe	Location	Meeting
October 2003	Kötzing, Germany	ILRS Technical Workshop "Working Toward the Full Potential of the SLR Capability"
April 2004	Nice, France	Analysis Working Group Meeting
June 2004	San Fernando, Spain	14th International Workshop on Laser Ranging 10th ILRS General Assembly and WG Meetings Analysis Working Group Meeting
October 2004	Graz, Austria	ILRS Technical Workshop "kHz SLR Technology"
April 2005	Vienna, Austria	ILRS Working Group Meetings Analysis Working Group Meeting
October 2005	Eastbourne, UK	ILRS Technical Workshop "Observations Toward mm Accuracy" 11th ILRS General Assembly and WG Meetings Analysis Working Group Meeting
April 2006	Vienna, Austria	ILRS Working Group Meetings Analysis Working Group Meeting
October 2006	Canberra, Australia	15th International Workshop on Laser Ranging 12th ILRS General Assembly and WG Meetings Analysis Working Group Meeting
April 2007	Vienna, Austria	ILRS Working Group Meetings Analysis Working Group Meeting
July 2007	Perugia, Italy	Analysis Working Group Meeting
September 2007	Grasse, France	ILRS Technical Workshop "Challenges for Laser Ranging in the 21st Century" 13th ILRS General Assembly and WG Meetings Analysis Working Group Meeting

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 Center 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 centers. 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.

International VLBI Service for Geodesy and Astrometry (IVS)

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1. Introduction

This report summarizes the activities of the International VLBI Service for Geodesy and Astrometry (IVS) during 2003−2007 reviewing the results and progress made. IVS is an approved service of the International Association of Geodesy (IAG) since 1999 and 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 nearly 40 years. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing the quasar positions as the best approach to an inertial reference frame, VLBI significantly contributed to the tremendous progress made in geodesy over the last decades. VLBI was a primary tool for understanding the global phenomena changing the "Solid Earth". Today VLBI continuously monitors Earth orientation parameters as well as crustal movements in order to maintain global reference frames, coordinated within the IVS. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI's technical limitations. VLBI, as the unique technique for providing a celestial reference frame and for deriving the full set of Earth rotation parameters, plays the fundamental role of generating the basis for many applications and research in the 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. Figure 1 shows the global distribution of the IVS components. More information can be found on the IVS Web site at http://ivscc.gsfc.nasa.gov.

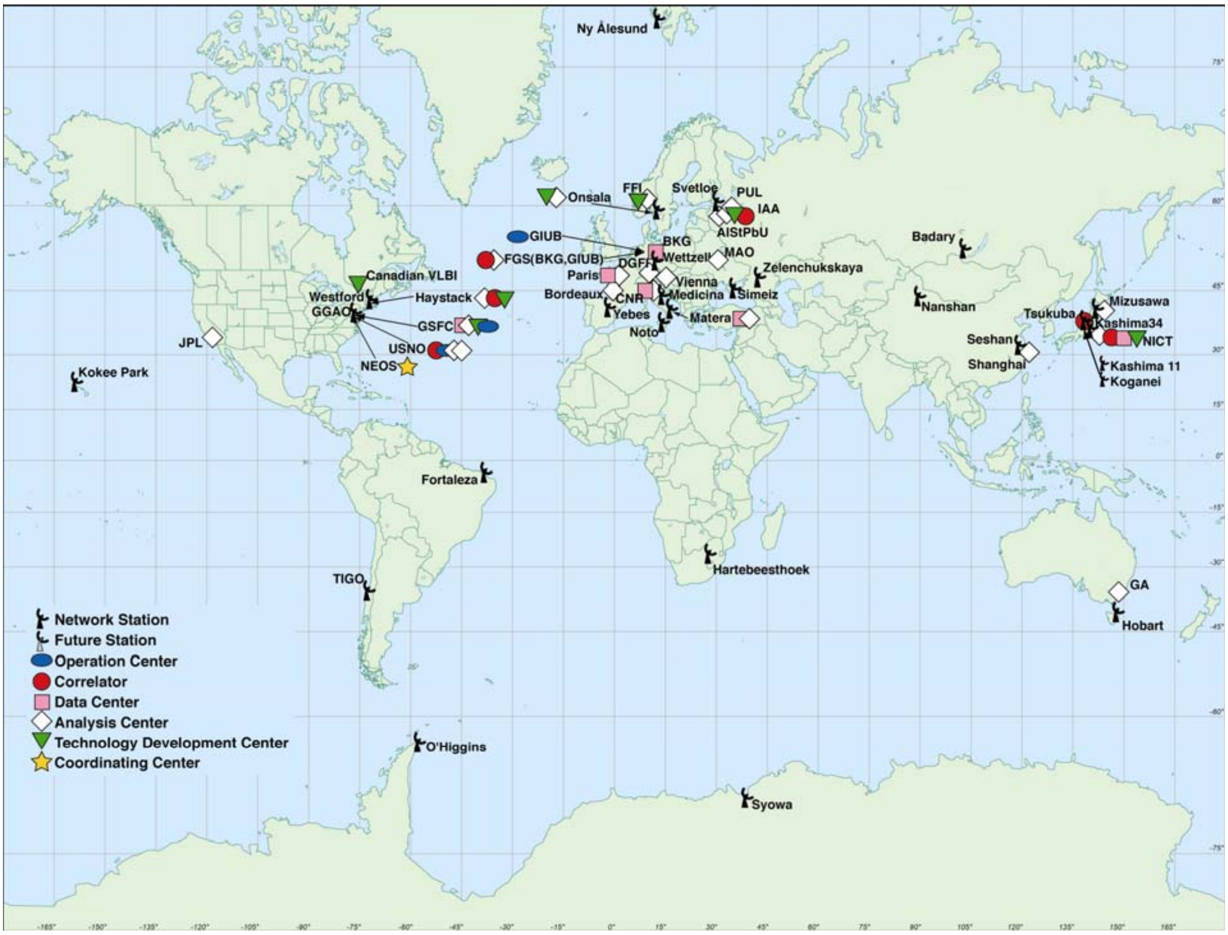

Figure 1. Global distribution of IVS components.

2. Highlights of IVS Activities

Digital recording systems. In the report period a significant improvement was achieved by completely switching from tape-based observing to disk-based observing. Starting in 2003, the tape drives have been successively replaced by the disk-based digital data recording systems Mark 5 and K5. Using digital recording systems the large amount of VLBI raw data can be handled at lower cost and with more reliability. The digital data recorders are the basis for the development of e-VLBI, in which raw VLBI data is transmitted via high-speed networks from the recording stations to the correlators. It also has to be pointed out that the work at the correlator has improved significantly and the correlation procedure, in particular the re-correlation, can now be done much faster. The transition from Mark 4 to Mark 5A went very smoothly, and all observing stations and the correlators are now equipped with disk-based digital recorders.

Observing program. The observing program for 2003–2007 included the following sessions:

- EOP: Two rapid turnaround sessions each week, mostly with 7 stations, some with 6 or 8 stations depending on station availability. These networks were designed with the goal of having comparable x_p and y_p results. Data bases are available no later than 15 days after each session. Daily 1-hour UT1 Intensive measurements on five days (Monday through Friday) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA) and on weekend days (Saturday and Sunday) on the baseline Wettzell (Germany) to Tsukuba (Japan). The daily sessions are recorded using Mark 5 (Wettzell-Kokee) and K5 (Wettzell-Tsukuba) technology. Comparisons of the two series showed good agreement with the IERS C04 series.
- TRF: Monthly (2003, 2004), bi-monthly (2005, 2006), and quarterly (2007) TRF sessions with 16 stations using all stations at least two times per year. The increase from 8 stations in the observing years

2002/2003 to 16 stations in 2004−2007 is largely due to the deployment of the Mark 5 technology, which sped up the correlator processing time significantly. The limiting factor has shifted from correlator to station availability.

- CRF: Bi-monthly RDV sessions using the Very Long Baseline Array (VLBA) and 10 geodetic stations, plus astrometric sessions to observe mostly southern sky sources where the sessions were increased from 8 in 2003, over 10 in 2004, to 16 in 2005−2007.
- 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 S2 or K5 technology had the same accuracy and timeliness goals as those using Mark 5. On average, a total of more than 1000 station days per year were used in about 180 geodetic sessions during the year increasing the average days per week which are covered by VLBI network sessions to 3.5.

CONT05. In September 2005, a 15-day continuous VLBI observation campaign called CONT05 was observed. The network consisted of eleven IVS stations. The participating stations conducted extensive testing of their equipment prior to the campaign. The resultant data set is of excellent quality and will likely be used by numerous groups for studies of inter-technique comparisons, searches for geophysical signals, and technique improvement. This is in particular so, as the other geodetic space techniques (GPS, SLR, DORIS) undertook a concerted effort to observe the best possible data sets for the same time and locations.

VLBI Standard Interface. Further developments have been carried out for the VLBI Standard Interface (VSI). Hardware has been built and the VSI software interface was released, which is very important for the combination of the different recording techniques. The Mark 5B recording systems are being developed, which will result in a step forward, as formatters will become obsolete, the problems with the Mark 4 correlator station units will be overcome, and compatibility of the technology will be supported by the integration of VSI.

ICRF-2. 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.

VLBI2010. The IVS Working Group 3 (WG3) prepared a final report titled “VLBI2010: Current and Future Requirements for Geodetic VLBI Systems”. This report is a strategic paper and a road map for IVS to motivate new developments and to encourage investments towards the next generation VLBI system. Internally it supports the coordination of the activities to be done by the IVS supporting agencies; externally it documents the continued need for VLBI in the future and provides arguments to request financial support. It also demonstrates that IVS takes seriously its responsibility for preparing the service towards future requirements. Such requirements will arise with the program “Global Geodetic Observing System (GGOS)” of the International Association of Geodesy. GGOS aims at realizing a precise reference frame consistent for decades and consistent with respect to geometric and physical parameters. IVS, as the service which uniquely provides the CRF and the complete set of EOP and which contributes strongly to the TRF, will play a key role in GGOS. As a consequence of the VLBI2010 report the IVS Directing Board established at its 14th meeting held in September 2005 in Washington, DC, the VLBI2010 Committee, which is tasked with promoting the ambitious goals set by the VLBI2010 report.

The VLBI2010 Committee worked on designing and implementing the next generation VLBI system. The work concentrated on Monte Carlo type simulations to investigate the performance of network configurations, schedules and observing scenarios, and on the broadband delay approach. The broadband approach involves the use of broadband feeds (2–15 GHz) and multiple IF channels to reliably resolve RF phase, even at low signal-to-noise ratios. It will enable extremely precise delay measurements to be made while using comparatively small and cost effective 12-m class antennas. The lower cost of these antennas will make replacement of existing, old antennas and the addition of new stations more affordable.

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 Centers was changed from a combination on the level of EOP results to a combination on the basis of datum-free normal equations in SINEX format. The new approach improved the robustness and quality of the combination product significantly. Today, the input of the Analysis Centers agrees to better than 60 microarcseconds, while the combined IVS polar motion results agree with the IGS pole at the 100−130 microarcsecond level.

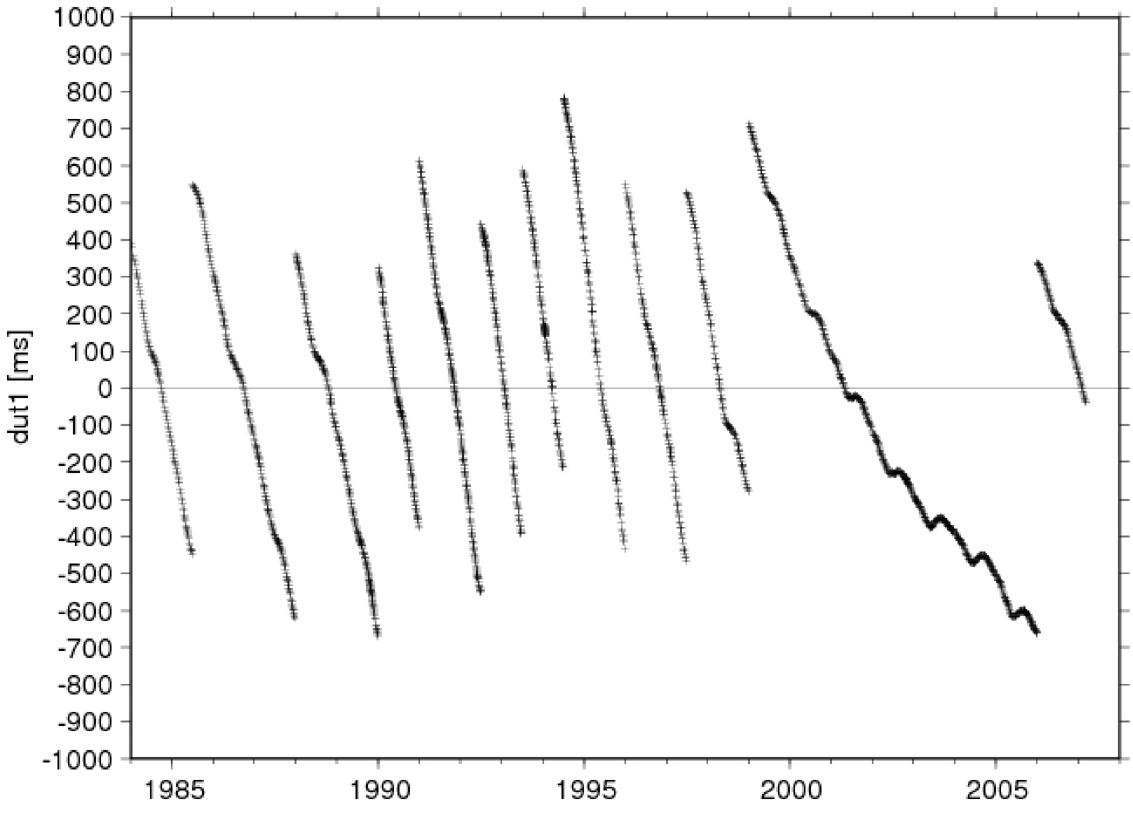

Figure 2. UT1−UTC time series from 1984 to 2007.

Troposphere parameters. The main goal of this product is to obtain reliable tropospheric zenith delay estimates from VLBI data analysis for climate studies and for integrity check with other IAG services, in particular with the IGS. Troposphere parameters turned out to be a valuable indicator for inter-technique and intra-technique analysis inconsistencies. The IVS provides two tropospheric products: short-term results from eight Analysis Centers are available in a series of weekly files with combined tropospheric zenith delay estimates derived from all IVS-R1 and IVS-R4 sessions since January 2002. Until June 2003 the files were created in the IVS Pilot Project phase, whereas starting with July 2003 the combined zenith delay estimates became regular IVS products. Long-term series of tropospheric zenith delays cover all types of VLBI sessions from 1984 until the end of 2004. With over 20 years of data at some stations, it is possible to obtain significant trends of tropospheric zenith delays, which can be directly related to changes of atmospheric water vapour—one of the most important greenhouse gases. Long-term series of tropospheric parameters from eight individual Analysis Centers and a combined series determined at the Institute of Geodesy and Geophysics, Vienna University of Technology, are accessible from the IVS Data Centers.

Baseline Lengths. Within the framework of the IVS Pilot Project "Time Series of Baseline Lengths" five Analysis Centers provide their results in a special file format to the Data Centers. From these files, baseline lengths and their standard deviations are being computed for the submitting Analysis Centers as well as for a combined series (see example in Figure 3). A graphical user interface was prepared at the Analysis Coordinator's office which assists the user in getting baseline length results and accuracies in numerical and graphical form. After a successful testing phase, the time series of baseline lengths have become an official product of IVS in September 2006.

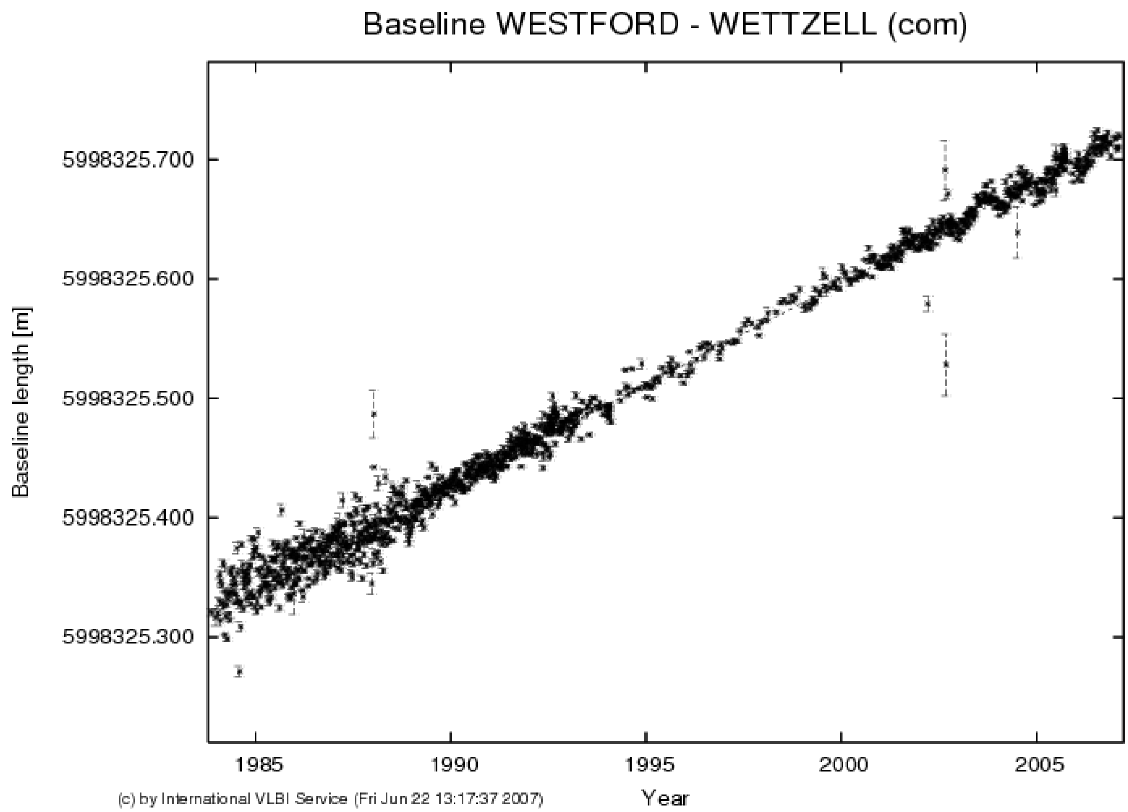

Figure 3. Baseline length evolution of the baseline Westford−Wettzell from the IVS combination solution.

Operations cessation. In 2006, IVS had to face two events that had an impact on the service products. First, the Network Station at Gilmore Creek discontinued its VLBI operations in January 2006 and the telescope—located in Fairbanks, Alaska—was mothballed for an undetermined period of time. The second event was the cessation of the Canadian VLBI operations by Natural Resources Canada in October 2006. In both events, various reasons contributed to the termination of the observations; however, the costs for required upgrades of the worn-out telescopes played a major role in both cases. Today's VLBI network is not sufficiently robust to simply compensate such events without an impact on the final products. Due to the location on the North American continent, the "lost" stations have been of extreme importance to the IVS and, accordingly, their contribution to the IVS observing program was significant. The influence on the product quality could be mitigated to some extent with stations that came online recently such as Zelenchukskaya, Russia.

Upcoming antennas. Projects are under way in several corners of the world to establish several new VLBI sites. In the southern hemisphere, Geoscience Australia is planning to construct three new next generation VLBI antennas (upgrading one existing site and creating two new sites), and Auckland University of Technology, New Zealand will establish one new site. Other projects to be mentioned are running in Korea (Korea Astronomy and Space Science Institute, National Geographic Information Institute), Germany (Federal Agency for Cartography and Geodesy), and India (Indian Space Research Organization).

3. Organization and Meetings

The Directing Board determines policies, adopts standards, and approves the scientific and operational goals for IVS. The Directing Board exercises general oversight of the activities of IVS including modifications to the organization that are deemed appropriate and necessary to maintain efficiency and reliability. During the report period two Directing Board elections took place: December 2004/January 2005 and December 2006/January 2007. At the 17th Directing Board meeting in Wettzell, Germany the new board (see Table 1) elected Prof. Harald Schuh as new chair of IVS. Harald Schuh followed Wolfgang Schlüter, who was the IVS chair since the inception of the service in 1999.

Table 1. Members of the IVS Directing Board during the report period (2003−2007).

a) ***Current Board members (June 2007)***

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 2007 − Feb 2009
Yoshihiro Fukuzaki	Geographical Survey Institute, Japan	Networks Representative	Feb 2007 − Feb 2011
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	—
Arthur Niell	Haystack Observatory, USA	Analysis and Data Centers Representative	Feb 2005 − Feb 2009
Ray Norris	CSIRO Australia Telescope Nacional Facility, Australia	FAGS Representative	—
Axel Nothnagel	University of Bonn, Germany	Analysis Coordinator	—
Bill Petrachenko	Natural Resources Canada	Technology Development Centers Representative	Feb 2005 − Feb 2009
Harald Schuh	Technical University Vienna, Austria	IAG Representative, Chair	—
Oleg Titov	Geoscience Australia	At Large Member	Feb 2007 − Feb 2009
Alan Whitney	Haystack Observatory, USA	Technology Coordinator	—
Xiuzhong Zhang	Shanghai Astronomical Observatory, China	At Large Member	Feb 2007 − Feb 2009

b) ***Previous Board members in 2003−2007***

Roy Booth	Hartebeesthoek Radio Astronomy Observatory, South Africa	FAGS Representative	—
Yasuhiro Koyama	NICT, Japan	At Large Member	Feb 2005 − Feb 2007
Zinovy Malkin	Institute of Applied Astronomy, Russia (till Sep 2006); Pulkovo Observatory, Russia	At Large Member	Feb 2005 − Feb 2007
Franco Mantovani	INAF Bologna, Italy	At Large Member	Feb 2005 − Feb 2007
Shigeru Matsuzaka	Geographical Survey Institute, Japan	Networks Representative	Feb 2003 − Feb 2007
Wolfgang Schlüter	BKG, Germany	Networks Representative, Chair	Feb 2003 − Feb 2007

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 2 gives an overview of the recent IVS meetings.

Table 2. IVS meetings during the report period (2003-2007).

Time	**Meeting**	**Location**
3-4 April 2003	4th IVS Analysis Workshop	Paris, France
22-26 September 2003	2nd IVS Technical Operations Workshop	Westford, MA, USA
9-11 February 2004	3rd IVS General Meeting	Ottawa, Canada
12 February 2004	5th IVS Analysis Workshop	Ottawa, Canada
21-22 April 2005	6th IVS Analysis Workshop	Noto, Italy
9-12 May 2005	3rd IVS Technical Operations Workshop	Westford, MA, USA
9-11 January 2006	4th IVS General Meeting	Concepción, Chile
12 January 2006	7th IVS Analysis Workshop	Concepción, Chile
15 September 2006	1st VLBI2010 Working Meeting	Westford, MA, USA
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

4. References

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N.R. Vandenberg, K.D. Baver (editors): IVS 2003 Annual Report, NASA/TP-2004-212254, Greenbelt, MD, USA, 2004. (http://ivscc.gsfc.nasa.gov/publications/ar2003/)

N.R. Vandenberg, K.D. Baver (editors): IVS 2004 General Meeting Proceedings, NASA/CP-2004-212255, Greenbelt, MD, USA, 2004. (http://ivscc.gsfc.nasa.gov/publications/gm2004/)

Report by the Permanent Service for Mean Sea Level (PSMSL) for the Period 2003-2007 to the XXIV General Assembly of the IUGG, Perugia, Italy, July 2007

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1. Introduction

This report reviews briefly the work of the Permanent Service for Mean Sea Level (PSMSL) during 2003-2007. In this period, the PSMSL has continued with its main duty, of data banking of sea level information for the scientific community. In addition, it has taken a major role in the development of the Global Sea Level Observing System (GLOSS), and has contributed to important international working groups and conferences on climate change and geophysics.

The PSMSL is operated at the Proudman Oceanographic Laboratory (POL) under the auspices of the International Council for Science (ICSU), and is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). In December 2004 the PSMSL (together with other groups in POL and the British Oceanographic Data Centre, BODC) relocated from Bidston Observatory to a new building on the campus of Liverpool University with minimal disruption to normal work.

The PSMSL reports to the International Association for the Physical Sciences of the Oceans Commission on Mean Sea Level and Tides (IAPSO/CMSLT) and has an Advisory Board consisting of scientists expert in each area of sea level research. Annual reports on the work of the PSMSL are circulated each year to the International Association of Geodesy (IAG), the Intergovernmental Oceanographic Commission (IOC), IAPSO, FAGS, and other relevant bodies and are available publicly via the web at:

http://www.pol.ac.uk/psmsl/

This same web page also serves as a source of PSMSL data and ancillary information.

2. PSMSL Staff and Funding

The main PSMSL scientific staff concerned with the collection and analysis of monthly MSL data include Philip Woodworth, Simon Holgate and Svetlana Jevrejeva. They were joined in 2005 by Kathy Gordon whose responsibility is sea level data management. Alongside the monthly MSL collection, the PSMSL together with BODC, is responsible for an archive of delayed-mode higher-frequency sea level data (e.g. hourly values) from the GLOSS network. This activity has so far included Lesley Rickards, Elizabeth Bradshaw and other colleagues. In 2006, proposals were accepted for the merger, so far as possible, of these two delayed-mode Liverpool-based sea level activities. As a consequence, Lesley Rickards took over the Directorship of an enlarged PSMSL in April 2007.

The stimulus for this merger was the PSMSL application in 2005 to the UK Natural Environment Research Council (the parent body of POL and BODC) for continued and modestly expanded funding for the period 2007-2012 under a process called ‘Oceans2025’. The proposal was graded as ‘alpha-5’, the highest possible, which provides a clear way forward. The PSMSL has since been able to recruit a scientist (Mark Tamisiea) with an established international reputation in geophysics and geodesy. Mark will expand the range of Sea Level Science undertaken at POL and will be able to help the PSMSL play a more active role in activities such as the Global Geodetic Observing System (GGOS). Trevor Baker retired from POL in 2005. Trevor represented the PSMSL on many occasions, and lectured at GLOSS training courses, and his expertise continues to be available on an informal basis.

3. PSMSL MSL Data Receipts for 2003-2007

On average, approximately 1500 station-years of MSL data were entered into the PSMSL database during each year of the period. This compares well to rates obtained in previous years. Most data originated from Europe, North America and Japan, but all regions are represented in the receipts at some level. Important data gaps in South America, Africa and parts of Asia are receiving special attention as part of the GLOSS and ODINAFRICA programmes (see below). Figure 1 indicates the locations from which data were received during 2003-2007.

4. PSMSL DM HF Data Receipts for 2003-2007

Approximately 686 site years of high-frequency delayed-mode were received during the period 2003-2007. Data have been added from new tide gauge installations in poor coverage areas, such as the data from the Odin Africa tide gauges. There have also been important datasets received from other data sparse regions, such as Indonesia, and South America (a large amount of data was submitted for Venezuela). Significant historic datasets have also been included. Data have been received from Norway, extending back to 1927 in one case, from the gauge at Tregde. Long time series have also be acquired for two of the French GLOSS sites, with the record from Brest beginning in 1860. Figure 2 provides an overview of DM HF received.

5. GLOSS Activities

The Global Sea Level Observing System (GLOSS) is a project of the Joint Commission for Oceanography and Marine Meteorology (JCOMM) of the Intergovernmental Oceanographic Commission (IOC) and World Meteorological Organisation (WMO). One of the main aims of GLOSS is to improve the quality and quantity of data supplied to the PSMSL. GLOSS has been one of the first components of the Global Ocean Observing System (GOOS). GLOSS network status as perceived by the PSMSL is reviewed each year and can be found at http://www.gloss-sealevel.org. Status reports are also presented to meetings of the GLOSS Group of Experts, which is the management committee for the programme. These meetings are held approximately every two years with the latest held in June 2007 alongside a workshop on new tide gauge technology.

GLOSS training courses have been held in many countries since the mid-1980s. In 2003, a most successful course was held at the Hydrographic and Oceanographic Service of the Navy (SHOA) in Valparaiso, Chile in which the Philip Woodworth gave several lectures on sea level science and technology. In 2004, another excellent course was held in Malaysia organized by the Department of Survey and Mapping, in which the PSMSL was represented by Simon Williams from POL. He presented a set of lectures on tides and sea and land level changes, and gave instructions in tidal analysis software packages.

Two courses were held in 2006. The first was in Tokyo, Japan and was attended by Simon Holgate. It included background information provided by the PSMSL. The second course, which the PSMSL took a lead in organizing, was at the IOC facility in Oostende, Belgium. This course was attended by participants from African countries, several of whom are to receive new tide gauges as part of GLOSS development or the ODINAFRICA programme. Training was provided in the technology of tide gauges, the software used for tidal analysis, and in the science of sea level change. A less formal course focused on Africa was held at POL in mid-2007. In addition, several African tide gauge specialist have received individual training POL during the past four years.

6. Tide Gauge Network Building

During the period, the PSMSL took the lead in the technical specification of new gauges to be installed in Africa and the western Indian Ocean as part of the Ocean Data and Information Network for Africa (ODINAFRICA) initiative of the Government of Flanders and IOC, and of Indian Ocean Tsunami Warning System developments. Following the Sumatra tsunami of December 2004 and the Katrina floods of August 2005, there is a recognition that all new gauges must be capable of real-time reporting and be able to serve operational requirements as well as scientific ones. New gauges have been provided through PSMSL for installation in Mozambique, Pakistan, Mauritania, Ghana, Cameroon, Congo, Djibouti and Yemen with up to 6 others planned in 2007-8.

An important component of the network building was a 4th edition of the IOC Manual on Sea Level Measurement and Interpretation, which was finally published in 2006 and can be obtained in electronic form from the PSMSL training web pages. Of equal importance to the tide gauge hardware itself is the form of telemetry employed to send data to centres. The PSMSL and IOC 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. 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. BGAN-enabled tide gauges similar to those described above for ODINAFRICA should be installed in late-2007.

7. International Polar Year

The PSMSL took the lead during 2005 in the preparation of a proposal for sea level measurements in the Arctic and Antarctic as part of the International Polar Year activities. The proposal was accepted enthusiastically by the international programme and has formed the basis for national bids for funding by GLOSS partners.

8. Altimetry and Gravity Field Activities

Participation has continued in European and US altimeter working groups during the period. Philip Woodworth is a Principal Investigator for the US/French altimeter missions (TOPEX/POSEIDON and JASON-1) and of particular interest to the PSMSL is the symbiosis between altimetry and tide gauge measurements with gauges being used extensively by the project to calibrate the altimeter data set. Philip Woodworth and Chris Hughes of POL have during the period been members of the Mission Advisory Group (MAG) of the European Space Agency (ESA) Gravity Field and Steady State Ocean Circulation Experiment (GOCE) mission which is planned for launch at the end of 2007. This is a major development for ocean circulation and sea level studies in the next decade. POL scientists are also involved in the use of data from the US-German Gravity Recovery And Climate Experiment (GRACE).

9. Geodetic Fixing of Tide Gauge Benchmarks

For the last two decades the PSMSL and the International GNSS Service (IGS) have led workshops and facilitated reports on the subject of operating GPS receivers at tide gauges in order to decouple land and sea level change. This led to the establishment of the TIde GAuge (TIGA) pilot project of the IGS which has the aim of studying the particular problems of operating receivers at gauge sites. The state of the art in this topic was reviewed in the Royal Society meeting referred to below. As part of what is called 'CGPS@TG' work, regular surveys have been conducted on behalf of the PSMSL and other organisations on the availability of permanent GPS stations near to tide gauges by Guy Wöppelmann of the University of La Rochelle.

10. Publications

The PSMSL has a responsibility to not only collect and redistribute sea level information, but also to analyse data and publish scientific results. The main papers published each year are listed in PSMSL Annual Reports. However, three important ones may be mentioned here. The first is the Fourth Assessment Report (4AR) of the Intergovernmental Panel on Climate Change (IPCC) which was published during 2007 with a chapter on ocean and sea level changes with Philip Woodworth as a Contributing Author.

The second follows the World Climate Research Programme workshop on Understanding Sea-Level Rise and Variability, held at UNESCO in Paris, France during 6-9 June, co-organised by Philip Woodworth, John Church (CSIRO, Australia), Stan Wilson (NOAA, USA) and Thorkild Aarup (IOC). This major event attracted over 150 attendees and reviewed the entire field of past and future sea level changes (including extreme sea level as well as mean sea level), together with the reasons for change, and with methods for better monitoring and modelling them. A book is near completion with chapters based on position papers written before the workshop and on the presentations and discussions during it.

In February 2004, the PSMSL helped to organize a two day 'Celebration of UK Sea Level Science' at the Royal Society in London, which was attended by approximately 100 UK scientists. This meeting marked the establishment of the UK National Tidal and Sea Level Facility. A Theme Volume of Philosophical Transactions of the Royal Society, containing papers based on presentations at the meeting, was published in 2006. The meeting was attended by Christian Le Provost, a long-standing friend of PSMSL and Chairman of the GLOSS Group of Experts. Christian died shortly after the Royal Society meeting and the Theme Volume was published in his memory.

11. GLOUP

The PSMSL is responsible to the IAPSO Commission on Mean Sea Level and Tides for the maintenance of the data base of pelagic (bottom pressure recorder) information. This data base, called GLOUP (Global Undersea Pressures), was maintained during the period by Chris Hughes and will receive a major update in the near future. It can be inspected at: http://www.pol.ac.uk/psmslh/gloup/gloup.html

12. Publicity

The opportunity has been taken whenever possible to publicise the work of the PSMSL in newspapers and on radio and TV. Presentations were given in the period in all three media in several countries and details can be found in the PSMSL Annual Reports.

Summary

It can be seen that 2003-2007 has been a further active period with regard to important workshops and conferences, and a busy one with regard to data acquisition and analysis. The functions provided by the PSMSL are in as much demand as ever, and plans are already in place to celebrate the 75th anniversary of the Service in 2008, when Liverpool will itself be celebrating its recognition as European Capital of Culture. Particular thanks as usual go to PSMSL staff, and also to the staff of POL and BODC who help us to provide the community with an extended Service.

Lesley Rickards and Philip Woodworth (July 2007)

Distribution:

Dr. Nicole Capitaine, President Federation of Astronomical and Geophysical Data Analysis Services (FAGS)
Dr. Niels Andersen, Danish National Space Centre, Secretary FAGS
Dr. Patricio Bernal, Secretary Intergovernmental Oceanographic Commission (IOC)
Dr. Keith Alverson, Director GOOS Office IOC
Prof. Andrew Willmott, Director Proudman Oceanographic Laboratory
Prof. John Huthnance, Deputy Director, Proudman Oceanographic Laboratory
Prof. Philip Woodworth, President IAPSO Commission MSL and Tides
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- Dr. Gary Mitchum, University of South Florida, USA
- Prof. Bruce Douglas, Maryland, USA
- Dr. David Pugh, Liverpool University, UK
- Dr. John Church, CSIRO, Australia
- Dr. Per Knudsen, Danish National Space Center
- Dr. Richard Bingley, Nottingham University, UK
- Dr. Thorkild Aarup, IOC/GLOSS
- Dr. Juan Fierro, SHOA, Chile

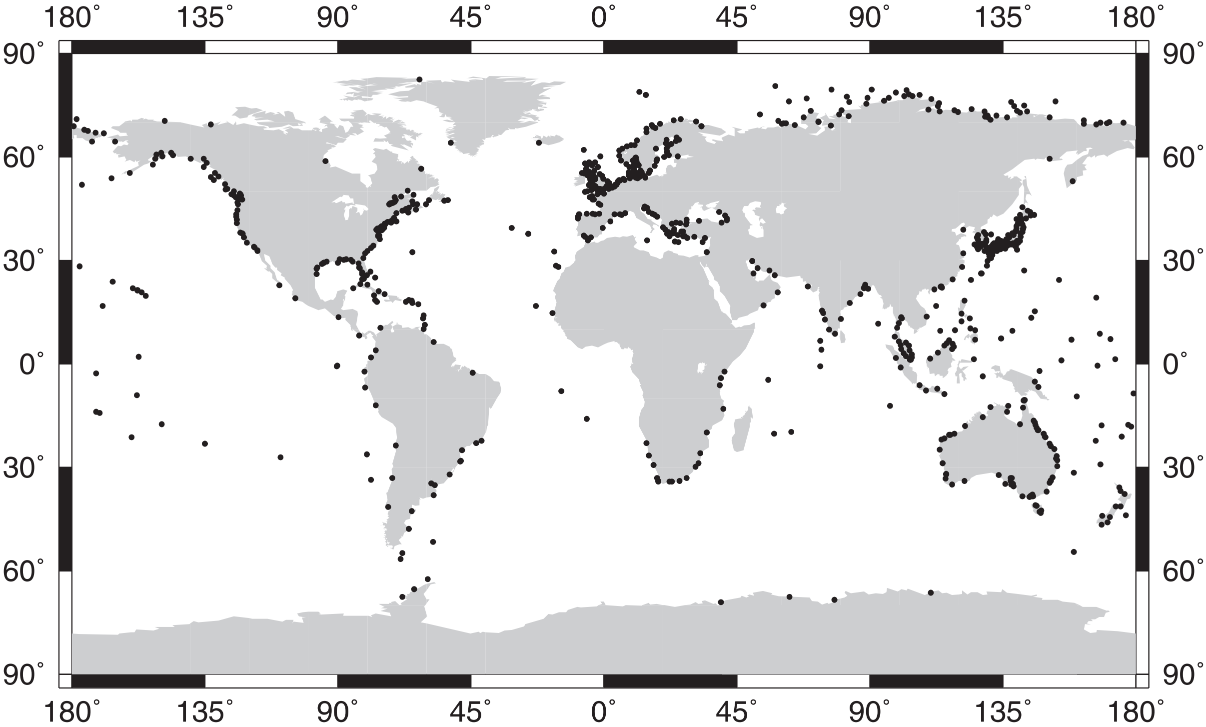


Figure 1: New PSMSL MSL Data 2003-2007

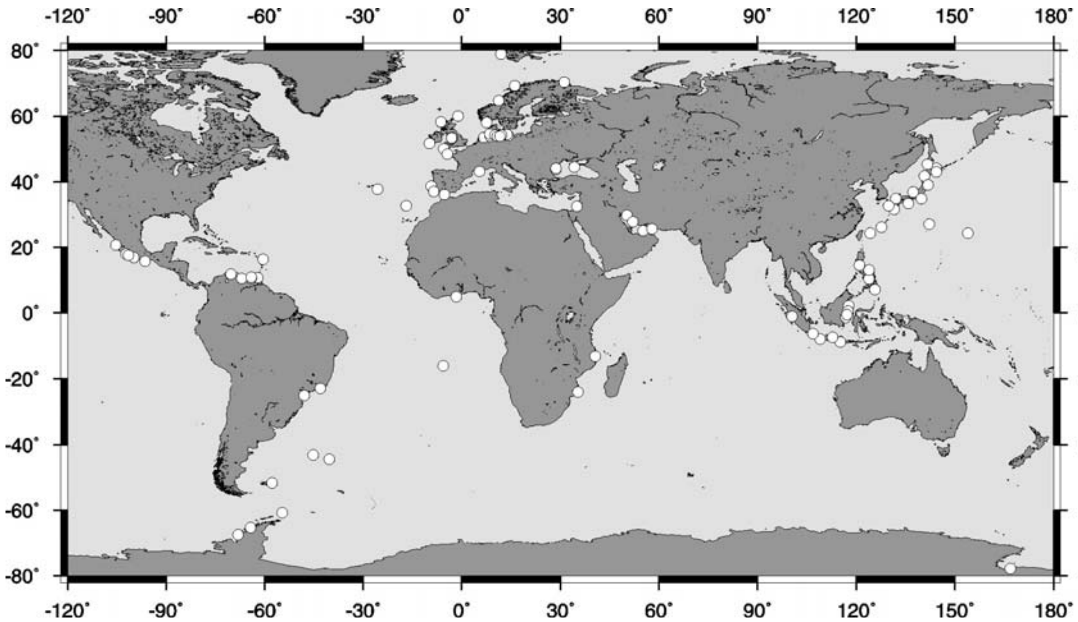


Figure 2: New HF DM Data 2003-2007

Quadrennial Report on the Contribution of the Communication and Outreach Branch (COB)

1. Introduction

In the past period (since the 2003 IUGG in Sapporo, the founding event of the COB), the infrastructure investment indicated in our proposal for the Executive Committee Meeting in Nice (April 2003) has been fully realized. Thus the technological background of the COB at the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BME) has been fully realized and is supported by the department and the Research Group for Physical Geodesy and Geodynamics of the Hungarian Academy of Sciences. All administrative work for the registration of the new IAG Website address (www.iag-aig.org) has been done.

The Terms of Reference and program of activities of the COB, and a short report on the IAG website, were published in the Geodesist's Handbook 2004 (pp. 677-678, pp. 576-577, respectively).

The COB's Steering Committee held meetings six times in the last four years:

a) Sapporo, Japan, 8 July, 2003;
b) Nice, France, 29 April, 2004;
c) Budapest, Hungary, 1 February, 2005;
d) Cairns, Australia, 23 August, 2005;
e) Vienna, Austria, 2 April, 2006.
f) Vienna, Austria, 15 April, 2007.

2. Status of the new IAG website

A new Compaq server has been purchased and the backend of the website has been developed. Hence all of the documents can be edited and maintained through a simple web browser. The documents are stored in a MySQL database, which enables fast data retrieval and also searching in documents. The graphical front-end is also ready.

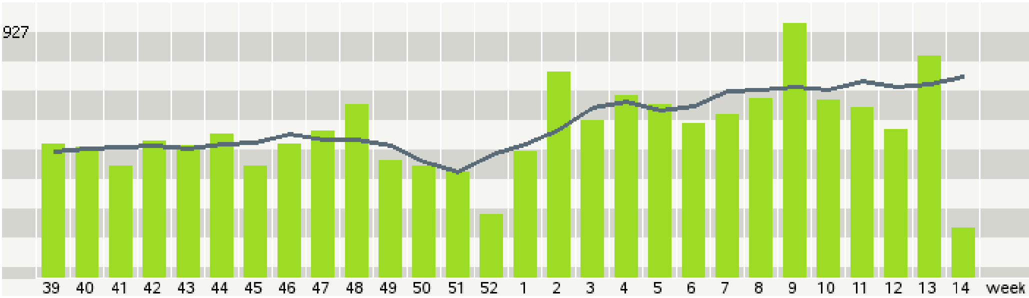
After providing the IT background for creating and maintaining the web content, the editing of the old web content has been started. All the old documents must have been partially re-edited in order to fit into the new structure of the IAG website. Due to this, the migration of the old website to the new one went a bit slower than previously expected. The Geodesist's Handbook 2000 has also been migrated to the new website.

The layout of the website has been changed a few times according to suggestions made at the Steering Committee Meetings. Direct links to services, old sections, commissions, etc. have been added to the front page. The event calendar has been shortened; it now contains only five upcoming events. Additional advertisements have been also added to the front page. The recent Membership Application Form, as well as the IAG Newsletters, can be downloaded from the opening page.

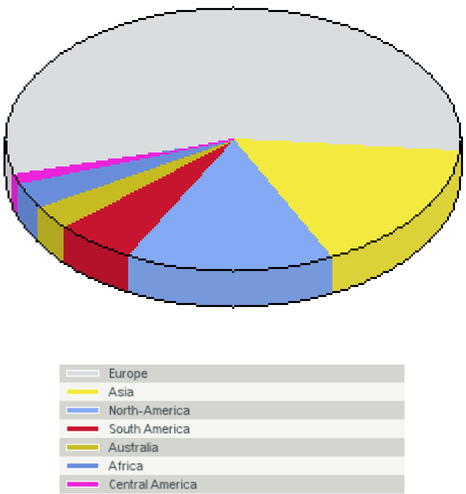
The number of visitors is steady, about 600 per week. The geographical distribution of the visitors shows that the webpage is mostly visited from Europe (52,271), Asia (15,302) and North America (13,914) out of the total 94,918 visits since May 28, 2003. Only 2935 visits came from the African continent.

Visitors are registered from 153 countries worldwide. The list can be found at http://webstats.motigo.com/s?tab=1&link=3&id=2359395&cou=all .

The IAG website includes a Members' Section, which can be accessed by IAG Members only. IAG Members have received a password to enter this restricted area. Each IAG Member is entitled to read articles in this area, as well as to query the contact database of the IAG members. The Members may update their own contact details, and specify their fields of interests, too.



Weekly number of visits (since 24 September, 2006)



Geographical Distribution of visitors

3. The IAG Newsletters

Altogether, 39 IAG Newsletters have already been published (up to March 2007) and can be accessed on the IAG new website in HTML, HTML print version and in PDF formats. The web addresses in the text can now be reached also from the PDF file. The IAG Individual Members received it monthly in PDF and text attachments, with a link in the e-mail message to access the actual HTML Newsletter on the IAG website. A new subscriber list of the Newsletter for developing countries was set up in a web-based database, independently from the IAG Individual Members' subscriber list for promoting interest in the activities of IAG. Now the electronic IAG Newsletter is distributed to these e-mail addresses as well. Selected contents of the electronic Newsletters were compiled and were sent to Springer for publication in 25 issues of the Journal of Geodesy (Vol. 77/12-81/4).

4. Membership development and outreach activities

The Membership Application form (MAF) has been updated and placed in the new IAG website. It contains all the information for payments by credit card and it can be filled using Adobe Acrobat Reader.

Initially, about 2600 e-mail addresses were stored in a database. The validation of e-mail addresses as well as the web integration for future mailing lists management is currently taking place. Many duplicate and invalid e-mail addresses had to be removed from the aforementioned database.

The COB designed a short brochure for promoting the IAG to the geoscientific community. The main objective of this brochure is to introduce the activities of IAG to the geoscientific community and to encourage individuals to become a member of the Association. In the first run, 1500 copies have been printed. The brochure was available at the IAG, AGU, EGU Assemblies and at different IAG Symposia.

The Communication and Outreach Branch in cooperation with the Department of Geodesy and Surveying, Budapest University of Technology and Economics, and the Research Group for Physical Geodesy and Geodynamics of the Hungarian Academy of Sciences organized the 6^{th} International IGeS School on "The Determination and Use of the Geoid" in Budapest, Hungary, 31 January- 4 February, 2005, which was attended by 49 students from 19 countries.

József Ádám, Szabolcs Rózsa, Gyula Tóth
IAG Communication and Outreach Branch

Report on the activities of ABLOS 2003-2007

The Advisory Board of the Law of the Sea (ABLOS) was created in 1994 by the International Hydrographic Organisation (IHO) and IAG to provide advice and, guidance and, where applicable, offer expert interpretation of hydrographic, geodetic and other technical aspects of the Law of the Sea to parent organisations, their member states or to other organisations on request.

The IAG representatives in ABLOS for the current period were Don Grant, Chris Rizos (chairman 2003-2005) and Lars Sjöberg.

Four annual business meetings were held (all in Monaco except one in Canberra, October 2004). One of the main activities was the revision of the Technical Aspects of the Law of the Sea to the 4^{th} TALOS manual (www.iho.shom.fr: publication S51 (free to download)). This task required that some of the members gathered at additional editorial meetings. The other major activity was the preparation and conducting of two ABLOS conferences, namely

- *Difficult Issues in UNCLOS,* Monaco, 28-30 October 2003, and
- *Marine Scientific Research and the Law of the Sea: the Balance between Coastal State and International Rights,* Monaco, 10-12 October 2005.

More details on ABLOS' activities with minutes of meetings and conference papers can be found at ABLOS homepage: www.gmat.unsw.edu.au/ablos/