Commission 2 – Gravity Field

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

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

Structure

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Sub-commission 2.2:	Spatial and Temporal Gravity Field and Geoid Modelling
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Study Group 2.2:	High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results
IC Working Gr. 2.1:	Absolute Gravimetry
IC Working Gr. 2.2:	Evaluation of Global Earth Gravity Models

Overview

This report covers the period of activity of the entities in Commission 2 for the year 2007 to Middle of 2009. Commission 2 consists of five sub-commissions, six projects, two study group and several inter-commission projects, working groups, study groups. The sub-commissions cover following science themes; terrestrial, airborne, ship borne gravimetry and relative/absolute gravity networks; spatial and temporal gravity field and geoid modelling; dedicated satellite gravity missions; regional geoid determination and satellite altimetry. It is clear that some entities of the Commission were significantly more active than others, but most if not all made progress in their stated objectives. Each of the chairs of the entities was asked to summarize their activities and here summarized the important highlights of these reports.

1. GGEO2008

One of the most important events of Commission 2 for the last 2 years was the International Symposium on Gravity, Geoid and Earth Observation 2008 (GGEO2008), which took place in Chania, a beautiful city in a Mediterranean island, Crete, Greece, 23-27 June, 2008. It was expertly organized by the members of the Laboratory of Geodesy and Geomatics Engineering, Department of Mineral Resources Engineering, the Technical University of Crete. The title of the symposium "Gravity, Geoid and Earth Observation" is currently very pertinent and points the direction to which the commission 2 as well as the new IAG are pursuing. Studies of the gravity fields, in particular, temporal variations of the gravity fields, are closely related to the various phenomena which occur in Earth Systems. Gravity field studies or the geodesy in general today, should contribute to the Earth observation.

GGEO 2008 brought together 210 scientists from 36 countries to discuss the state-of-the-art topics in 9 scientific sessions which cover the traditional research areas of Commission 2, as well as interdisciplinary topics relate to geoid, gravity modelling, geodynamics and the new challenges towards the Earth observation. All components of the Commission were well represented at the symposium not only in terms of participants but also by attracting 88 oral and more than 200 poster presentations. The Proceedings of the Symposium including 91 peer-reviewed papers will be published in the IAG Symposia series by Springer Verlag.

2. Gravimetry and Gravity Networks

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

The Study Group 2.1 (SG 2.1) reported that the evaluation of the results of the 7th International Comparison of Absolute Gravimeters (ICAG) -2005 was completed and the 8th ICAG-2009 in September-October 2009 at the Bureau International des Poids et Mesures (BIPM) in Sèvres, France is in the process of organization. The increasing number of participating absolute gravimeters (27 in 2009 relative to 15 in 2001) indicates the growing demand for confident and reliable absolute gravity measurements.

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

3. Spatial and Temporal Gravity Field and Geoid Modelling

There is no doubt that satellite gravity missions, in particular GRACE, become indispensable for gravity field modelling. The SG 2.2 focuses on the application of forward gravity modelling techniques for high-resolution gravity field recovery with the specific aim to assist in processing data from current and future satellite gravity missions. To make its objective clearer, the SG 2.2 has slightly modified its title from "High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results" to "High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results".

One of the most significant improvements over the Global Earth Gravity Models was the official release of EGM2008. The ICWK 2.2 has successfully coordinated the evaluation of EGM2008 and the first evaluation results were presented by the working group members at GGEO2008. These results provide a thorough external assessment of EGM2008, using a variety of geodetic data and testing methodologies.

4. The gravity field satellite missions

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

5. Regional Geoid Determination and Commission Projects

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

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

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

6. Satellite Altimetry

Sub-commission 2.5, "Satellite Altimetry" has been newly established as a sub-commission of Commission 2 with a like to Commission 1, following the discussion made in the IAG Executive Committee meeting held in San Francisco, Dec. 2007. It is certainly reasonable to have a sub-commission on satellite altimetry within the IAG organization, because this technique contributes to all the three pillars of geodesy; the gravity field, the geometry and the rotation of the Earth. It was also decided, in the EC meeting, to establish the International Altimetry Service (IAS) and the SC-2.5 has been maintaining a close link with IAS. Mainly due to a lack of time, the sub-commission activities have not been significant. Nevertheless the SC2.5 has organized the scientific sessions on satellite altimetry in GGEO 2008 and IAG 2009 in Buenos Aires as well.

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

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

Sub-Commission 2.1: Gravimetry and Gravity Networks

President: Leonid F. Vitushkin (BIPM)
Vice-President: Gerd Boedecker (Germany)

1. Terms of Reference and Objectives

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

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

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

Program of Activities

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

Steering committee

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

2. Activities

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix 1-1

Report on the activities in Relative Gravimetry

Reported by M. Becker

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

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

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

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Appendix 1-2

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

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

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

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

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

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

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

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

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

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

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Appendix 1-3

Absolute gravity measurements in the Fennoscandian Postglacial Rebound area

Reported by Jaakko Mäkinen, Finnish Geodetic Institute

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

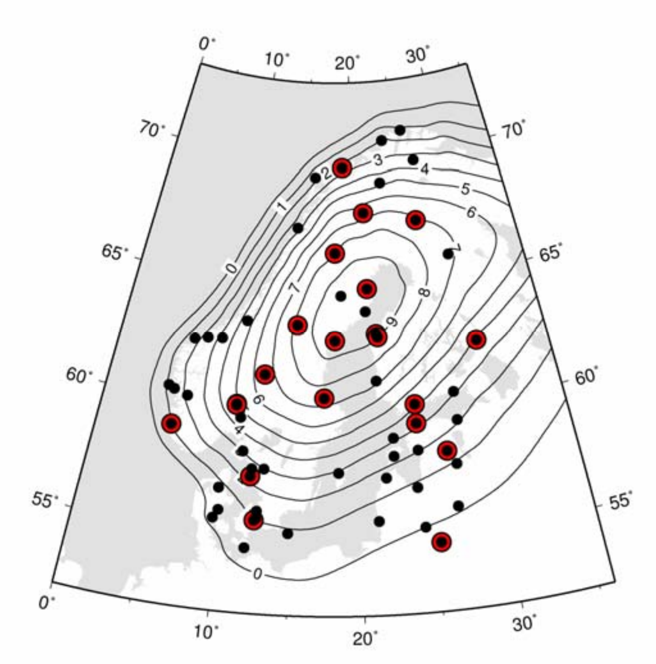

Figure 1. Absolute gravity stations in the Fennoscandian Postglacial Rebound area. Stations with a rim have repeats with a sufficient time span to determine a gravity trend. In addition to the stations depicted in the Nordic and Baltic countries, measured in the cooperation described here, stations in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

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

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

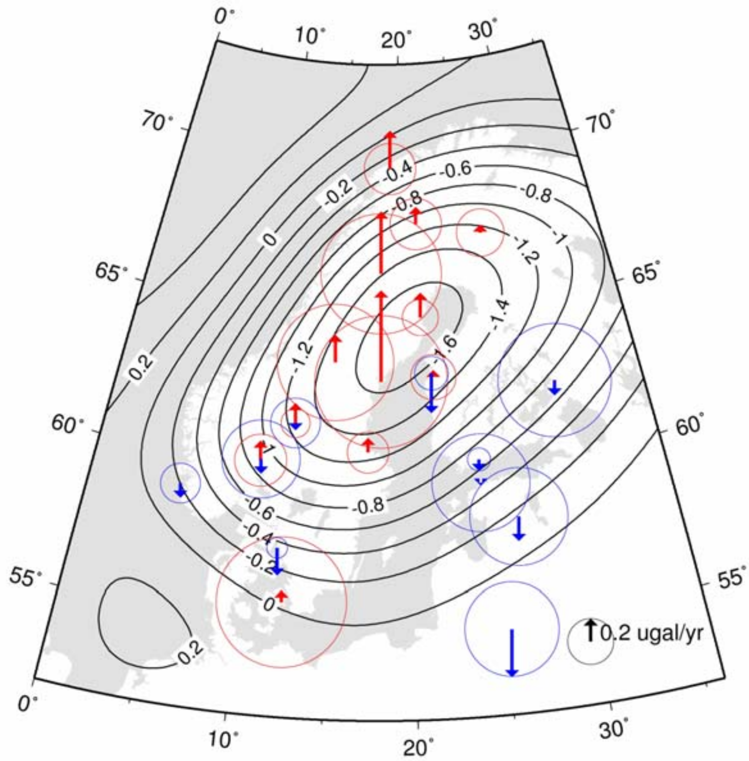

Figure 2. Comparison of observed gravity change rates with predictions from the model of Glacial Isostatic Adjustment by Milne et al. (2004). The isolines give the predicted gravity rates, obtained from predictions of vertical motion by multiplying them with –0.154 µgal/mm. The arrows give the residual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

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

President: Martin Vermeer (Finland)

Terms of Reference

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

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

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

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

Activities

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

The SG 2.2 focuses on the application of forward gravity modelling techniques for high-resolution gravity field recovery with the specific aim to assist in processing data from current and future satellite gravity missions. To make its objective clearer, the SG 2.2 has slightly modified its title from "High-Resolution Forward Gravity Modelling for Improved Satellite Gravity Missions Results" to "High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results". The first focus of the SG is on the assessment of space-domain forward gravity modelling techniques/software with the particular view on both theory and practical determination. For this purpose the chair prepared a sample topography DEM data set over parts of Australia.

The ICWG 2.2 has successfully coordinated the evaluation of both PGM2007 and EGM2008. This evaluation project was carried out through three phases: the implementation and testing of the NGA software for spherical harmonic synthesis using ultra-high degree geopotential models (2006-2007), the evaluation of the PGM2007 model (2007-2008), and finally the evaluation of the official EGM2008 model (2008-2009). Phase 3 started right after the official release of EGM2008 at the EGU General Assembly in April 2008. The first results of the EGM2008 evaluation tests were presented by the working group members in a dedicated session during the GGEO 2008 symposium.

Sub-Commission 2.3: Dedicated Satellite Gravity Mapping Missions

President: Roland Pail (Austria)

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

1. generation of static and temporal global gravity field models based on observations by the satellite gravity missions CHAMP, GRACE, and GOCE, as well as optimum combination with complementary data types (SLR, terrestrial and air-borne data, altimetry, etc.), both on a global and a regional/local scale;
2. investigation of alternative methods and new approaches for gravity field modelling, with special emphasis on functional and stochastic models and optimum data combination;
3. identification, investigation and definition of enabling technologies for future gravity field missions: observation types, technology, formation flights, etc.;
4. communication/interfacing with gravity field model user communities (climatology, oceanography/altimetry, glaciology, solid Earth physics, geodesy, ...).

In the following, a brief report on the activities, main results, and a selection of key references related to these subjects is given for the reporting period 2007 to mid 2009.

1. Static and temporal global gravity field models

Activities and results

Sub-commission members are involved in the derivation of new releases of global gravity field models based on GRACE and CHAMP mission data, applying updated background models, processing standards and improved processing strategies (e.g.: EIGEN-5S, GGM03S, ITG-Grace03, AIUB-GRACE01S). Special emphasis has been given to the de-aliasing from short-term tidal and non-tidal gravity signal contributions, in order to reduce the unrealistic meridional striping patterns (e.g., [5], [7], [9]). In addition to improved static gravity field models, also monthly and even weekly GRACE solutions (CNES-GRGS, GFZ) have been derived (e.g., [3], [4], [11]). A combination with complementary gravity field information derived from terrestrial and air-borne data, satellite altimetry, and satellite laser ranging led to the generation of high-resolution combined gravity field models, such as EGM2008 (degree 2190), EIGEN-5C (degree 360), GGM03C (degree 360). These models have been thoroughly validated and inter-compared (e.g., [6], [16]), and are now extensively used by a wide geo-scientific community.

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

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2. Alternative methods for gravity field modelling

Activities and results

Sub-commission members have actively contributed to the development and investigation of alternative methods of global and regional gravity field modelling, e.g. using space localized base functions ([21], [24]). Another key issue is the optimum combination of different ground and satellite gravity data types. As an example, this problem has been investigated by setting up a generalized remove-restore procedure in the frame of the least squares collocation concept, which also takes into account the global model error covariance ([23]).

Several Sub-commission members execute projects dealing with the optimum inclusion of global gravity field information for the improvement of regional gravity field (geoid) solutions, as an example [19], [22]. The most recent high resolution European quasigeoid model EGG2008 was computed within the framework of the European Gravity and Geoid Project (EGGP; [20]).

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3. Future gravity field missions

Activities and results

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

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

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

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

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

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4. Interfacing with user communities

Activities and results

The workshops discussed above ([27], [29]) represent an important platform to involve all relevant user groups of gravity field products in the planning of satellite gravimetry missions and the definition of their requirements.

Several national platforms have been set-up or are maintained by Sub-commission members to interface with user communities, exemplarily, the German GOCE Project Office ([33]) or GOCE-ITALY. Sub-commission members are also involved in joint projects with representatives of various user communities in many fields of applications, such as mantle dynamics (e.g., [31]), glacioisostatic adjustment (e.g., [34]) or cryospheric modelling (e.g., [30]).

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

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Sub-Commission 2.4: Regional Geoid Determination

President: Urs Marti (Switzerland)

Terms of Reference

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

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

Gravimetric geoid modelling techniques and methods, available software

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

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

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

Objectives

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

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

The Continental Gravity and Geoid Projects

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

Project 2.1: European Gravity and Geoid Project (EGGP), chaired by Heiner Denker (Germany)

Project 2.2: North American Geoid, chaired by Daniel R. Roman (USA)

Project 2.3: African Geoid, chaired by Hussein Abd-Elmotaal (Egypt)

Project 2.4: Antarctic Geoid (AntGP), chaired by Mirko Scheinert (Germany)

Project 2.5: Gravity and Geoid in South America (GGSA), chaired by Maria Cristina Pacino (Argentina)

Project 2.6: South Asian and Australian Geoid, chaired by William Kearsley (Australia)

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

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

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

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

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

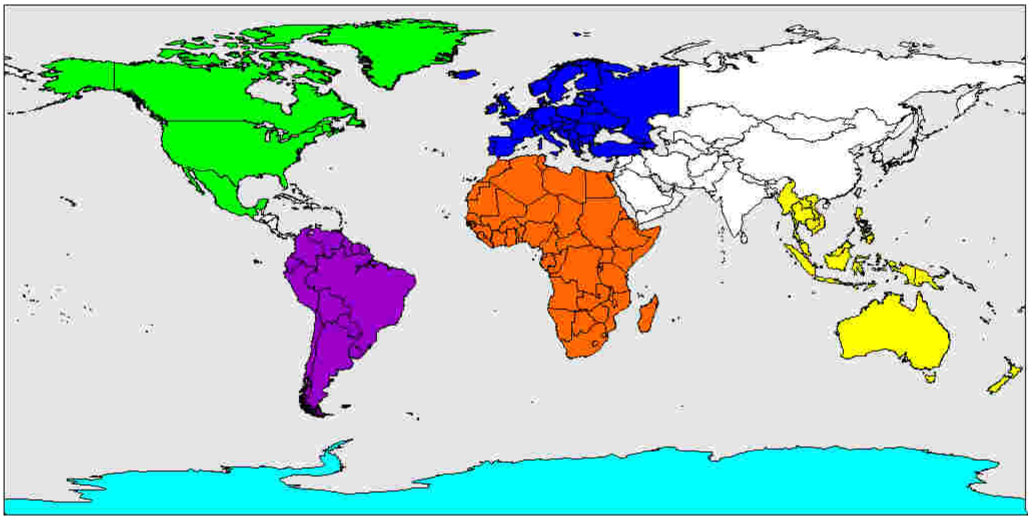

Figure 1: Coverage Areas of the Commission 2 geoid projects

Activities of the Continental Gravity and Geoid Projects

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

The projects in Europe, North-America, South-America and Antarctica are advancing well and first results are available. The collaboration of National authorities works rather well.

For the African geoid project, a result was presented in 2007 by Charles Merry but a further improvement is difficult due to poor collaboration of countries, missing data and funding. An important step was the airborne gravity mission over Ethiopia. Some countries (Algeria, Egypt) advance well on the national level.

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

Other regional geoid projects

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

Important national activities in countries that are not covered by a commission 2 project include Russia, Japan, China, Korea, Mongolia, Iran, Saudi Arabia and others. The main goal of these activities is usually to present a national geoid model which can be used in practice for height determination with GPS. Many activities include as well the introduction of GPS/leveling in geoid determination and the comparison of local models with global models.

Other activities

Sub-commission 2.4 is active in the assistance of the organization of symposia such as the GGEO2008 in Chania (2008) or the IAG scientific Assembly in Buenos Aires (2009). The sub-commission supports education and gives assists local authorities in their geoid and gravity projects. In the last years there have been activities in Azerbaijan, Kosovo, Sri Lanka, Jordan and Guatemala.

Sub-Commission 2.5: Satellite Altimetry

President: Cheinway Hwang (Taiwan)

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

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

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

The current focus (2007-2009) is to promote applications of satellite altimetry over land and coastal zones. To this end, the "International Workshop on Gravity, GPS and Satellite Altimetry Observations of Tibet, Xinjiang and Siberia (TibXS)" will be held from August 20 to 22, 2009, in Urumqi, Xinjiang, China. (see http://space.cv.nctu.edu.tw/altimetryworkshop/ TibXS2009/TibXS2009.htm). Tibet, Xinjiang and Siberia (TibXS) are regions with active plate tectonics. This workshop will bring together scientists to present their research results and thoughts in the fields of geodynamics, climate change, hydrology, over Tibet, Xinjiang and Siberia using the tools of satellite altimetry, plus gravimetry and GPS. Evidences from satellite gravimetry and altimetry show the hydrological evolutions over these regions are sensitive to global climate change. Inter-annual lake level changes over Tibet and Xinjiang from satellite altimetry are found to be connected to El Nino Southern Oscillation (ENSO). Lakes in central Asia originating from Xinjiang and lakes in eastern Siberia show sharp changes in lake levels that can be explained by climate change. Satellite altimetry is a potential tool to study vertical displacement and permafrost thawing and changes in the active layers in Siberia and Tibet. IAG SC2.5 will again organize an altimetry workshop in 2010 to promote altimetric applications.

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

Chair: Heiner Denker (Germany)

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

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

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

Regarding the evaluation of the gravimetric geoid and quasigeoid models, the EUVN_DA project lead by A. Kenyeres contributed an important set of GPS/levelling control points (Kenyeres et al., 2008a – 2008d). In total, about 1500 European high precision GPS/levelling stations were collected within the framework of the EUVN_DA initiative. These control points agree with the gravimetric quasigeoid EGG2008 at the level of about 0.08 m, just considering a constant bias parameter to account for different zero level definitions. Only two areas show larger discrepancies. The first area is Great Britain, where the levelling heights are suspected to contain significant systematic errors; in this case, the removal of a north-south and east-west trend in the comparisons reduces the RMS difference from about 0.15 m (bias case) to 0.05 m (bias and tilt case). The second area with larger discrepancies is Italy, where the situation is less transparent, as the differences exhibit wavy structures without a clear trend; further investigations with Italian colleagues are underway. In the end, the EUVN_DA GPS/levelling data shall also be combined with the gravimetric quasigeoid.

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

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

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

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Commission Project 2.2: North American Geoid

Chair: Dan Roman (US) – dan.roman@noaa.gov

Bottom Line Up Front

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

Meeting Activities

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

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

Data Improvement

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

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

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

Planned Implementation

Canada remains in the lead with implementation planned in 2013 for use of a gravimetric geoid height model in conjunction with GNSS to provide a vertical reference system. The USA remains committed to a goal of 2018. Canada looks towards a semi-dynamic datum that will likely be updated at the time of the implementation of a common geoid height model for the USA. At the 2009 Joint Assembly meeting, representatives from Canadian and USA agencies as well as Canadian Academia discussed topics related to this implementation. For consistency with IAG rules, a Tide-Free system will be adopted. Additionally, a W_0 value will likely be adopted that is consistent with that selected by the IAU and endorsed by the IAG. Determination of this value must confirmed by November 2012 to ensure that the Canadian implementation (which occurs first) will be consistent with the later USA implementation. The determination of the working group was that the "true" value would continue to be refined over time and that customers (surveyors, GPS users, mapping agencies, etc.) would better be served by adopting a value that is nearly correct but doesn't change often. As long as the offset to the currently adopted best value is known, this can be applied as need to get to the selected value.

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

International Great Lakes Datum of 2015 (IGLD15)

A unique aspect of cooperation between Canada and the USA will be the development of a replacement for the existing dynamic height datum employed on the common shared Great Lakes. IGLD85 is scheduled for replacement in 2015. The existing model was developed from geopotential numbers developed as a part of the North American vertical Datum of 1988 (NAVD 88). While Canada did not adopt NAVD 88 as a vertical reference system they did allow for its use in development of dynamic heights across the Great Lakes.

As both Canada and the USA move towards a common gravimetric geoid height model as the basis for a vertical reference system, it is imperative that this effort be synchronized. Separate meetings of the International Great Lakes Commission involve many of the same people involved with this project. The intention of members of this project is to ensure that IGLD15 is based on geopotential values determined from the common geoid height model. As a part of GRAV-D, airborne collection and data cleaning will occur early on (2011) to permit analysis and model development by both national agencies as well as academic groups interested in evaluating modelling theory and techniques.

The goal is to develop separate approaches and evaluate them together. Ideally, several different approaches should result in similar models with error allowances. The likely implementation date for IGLD15 will be around the time of the release of the gravimetric geoid height model for a new vertical reference system in 2018 (IGLD85 actually was released in 1988).

Collaboration with Other Groups/Projects/Commissions

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

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

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

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

Outlook

Funding is likely in place to start airborne data collections next year, surface data cleaning and the melding of these disparate data sets into a common seamless gravity field. Theoretical improvements continue that will serve as the basis for future USA models. Canadian and other researchers will have access to this data to test their own theoretical approaches. NGA, USAID, and the World Bank are being sought as partners in this effort to help expand this project into a truly regional effort for a common North American Geoid to serve as a uniform vertical reference system for scientific and coastal/emergency management applications. Future meetings are scheduled to discuss these results. The likely timeline for the activities will be beyond the end of the current four-year cycle and will necessitate a continuation of efforts in the future.

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

Commission Project 2.3: African Geoid

Chair: Hussein Abd-Elmotaal (Egypt)

1. Primary Objectives

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

The objectives of the project are summarized as follows:

- Identifying and acquiring data sets - gravity anomalies, DTM's, GPS/levelling.
- Training of African geodesists in geoid computation.
- Merging and validating gravity data sets, producing homogenous gravity anomalies data set ready for geoid computation.
- Computing African geoid**.**
- Evaluating the computed geoid using GPS/levelling data.

2. Main activities (2007–2009)

This document presents the status report of IAG African Geoid Project (Commission Project 2.3) since 2007. During the period 2007–2009 the AGP established its terms of references, organized its membership structure and is currently working on the main objectives of the project. It is acknowledged that this report can only cover the main activities of the AGP as per information provided by its members and that there are likely more activities within as well as outside the AGP.

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

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

Benahmed Daho et. al (2009) has focussed on study of the impact of the new GRACE derived Geopotential Model and SRTM data on the Geoid modelling in Algeria. A revised geoid model, incorporating the SRTM and GRACE data, for Algeria was computed. A new investigation on the choice of the tailored geopotential model in Algeria has been carried out by Benahmed Daho et. al (2008).

Different models for corrector surfaces between the gravimetric and GPS/levelling geoids were evaluated and the best geopotential models were investigated for Algeria by Zeggai et. al (2008).

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

3. Future Activities

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

4. Problems and Request

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

5. Membership Structure

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

- Hussein Abd-Elmotaal (Egypt) – Chairman (abdelmotaal@lycos.com)
- Charles Merry (South Africa) – Past chairman (cmerry1@gmail.com)
- Addisu Hunegnaw (Ethiopia) (Addisu.Hunegnaw@ed.ac.uk)
- Adekugbe Joseph (Nigeria) (nigeria.ipost@skannet.com)
- Albert Mhlanga (Swaziland) (sgd@realnet.co.sz)
- Benahmed Daho (Algeria) (d_benahmed@hotmail.com)
- Chuku Dozie (Ethiopia)
- Francis Aduol (Kenya) (fwoaduol@uonbi.ac.ke)
- Francis Podmore (Zimbabwe) (podmore@science.uz.ac.zw)
- Godfrey Habana (Botswana) (ghabana@gov.bw)
- Hassan Fashir (Sudan) (fashir@lycos.com)
- Jose Almeirim (Mozambique) (jose.carvalho@tvcabo.co.mz)
- Joseph Awange (Kenya) (J.awange@curtin.edu.au, joseph.awange@gmail.com)
- Karim Owolabi (Namibia) (kowolabi@namibia.com.na)

- Ludwig Combrinck (South Africa) (ludwig@hartrao.ac.za)
- Peter Nsombo (Zambia) (pnsombo@eng.unza.zm)
- Prosper Ulotu (Tanzania) (pepulotu@gmail.com)
- Saburi John (Tanzania) (saburi@uclas.ac.tz)
- Solofo Rakotondraompiana (Madagascar) (sorako@syfed.refer.mg)
- Tsegaye Denboba (Ethiopia) (ema@telecom.net.et)

6. Publications

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

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

Abd-Elmotaal, H. (2007c) High-Degree Geopotential Model Tailored to Egypt. Proceedings of the 1st International Symposium of the International Gravity Field Service, Istanbul, Turkey, August 28 – September 1, 2006, Harita Dergisi, Özel Sayı, Vol. 18, 187–192.

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

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

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

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

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

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

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

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

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

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

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

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

Commission Project 2.4: Antarctic Geoid

Chair: Mirko Scheinert (Germany)

Short Review

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

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

It is one of the main tasks of AntGP to improve the availability of gravity data in Antarctica. It is anticipated to finally deliver a suitable grid of terrestrial gravity data and of the regional geoid.

The coverage of gravity data in Antarctica has been continuously improved by new surveys. In this respect, the International Polar Year 2007/2008 (IPY, March 2007 – February 2009) played an important role. Within a number of IPY projects gravity observations have been carried out, mainly aerogravimetric surveys, but also terrestrial relative gravimetry or tidal gravimetry. The following IPY projects should be mentioned: Project 67 “Origin, evolution and setting of the Gamburtsev sub-glacial highlands (AGAP)", project 97 “Investigating the Cryospheric Evolution of the Central Antarctic Plate (ICECAP)", project 42 “Sub-glacial Antarctic Lake Environments (SALEUNITED)", project 152 “Trans-Antarctic Scientific Traverses Expeditions (TASTE-IDEA)", project 185 “Polar Earth Observing Network (POLENET)".

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

With regard to new gravity surveys in Antarctica, aerogravimetry provides the most powerful tool to survey larger areas. In this context, airborne gravimetry forms a core observation technique within an ensemble of aero-geophysical instrumentation. This aspect has been addressed by a workshop “Aerogravimetry: Techology and Applications”, recently held in Dresden, June 4 and 5, 2009. A number of AntGP members actively took part in this workshop. This workshop provided an excellent opportunity for exchanging information and also to discuss the progress of AntGP.

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

Future plans and activities

Future activities are well defined following the "Terms of Reference". Since any Antarctic activity call for a long-term preparation the main points to be focused on do not change. New surveys will be promoted, nevertheless, due to the huge logistic efforts of Antarctic survey campaigns, coordination is organized well in advance and on a broad international basis. Within AntGP, the discussion on methods and rules of data exchange is in progress and has to be followed on. Compilations of metadata and databases have to cover certain aspects of gravity surveys in Antarctica (large-scale airborne surveys, ground-based relative gravimetry, absolute gravimetry at coastal stations). The main goal is to finally deliver a suitable grid of terrestrial gravity data and of the regional geoid.

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

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

Membership

(active members)

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

(corresponding members)

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

Selected conferences and workshops with participation of AntGP members

- IUGG General Assembly, Perugia, July 2-13, 2007.
- X International Symposium on Antarctic Earth Sciences, Santa Barbara, August 26-31, 2007.
- XXX SCAR Meeting and Open Science Conference (jointly with IASC), St. Petersburg, July 4-11, 2008.
- Earth Tide Symposium 2008 "New Challenges in Earth's Dynamics", Jena, September 1-5, 2008.
- International Workshop "Aerogravimetry: Technology and Applications", Dresden, June 4-5, 2009.

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

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

Activities

1. Introduction

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

Due to the big efforts undertaken by the different organizations in the last few years to improve the gravity data coverage all over the countries there are available at the moment approximately 924,600 point gravity data in the continent, including Central America. Figure 1 shows new and old gravity data distribution.

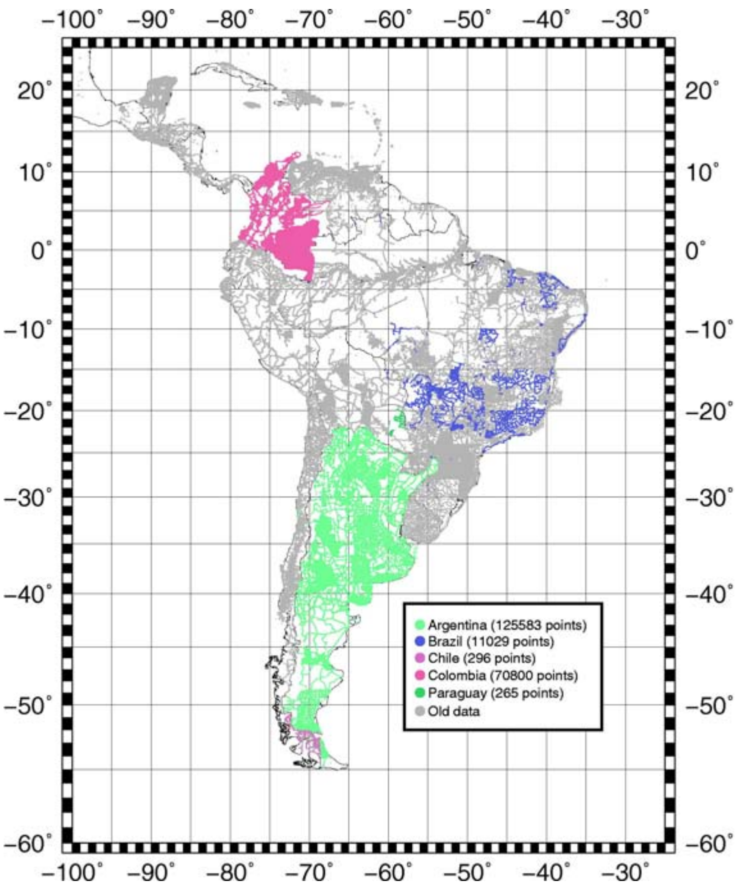
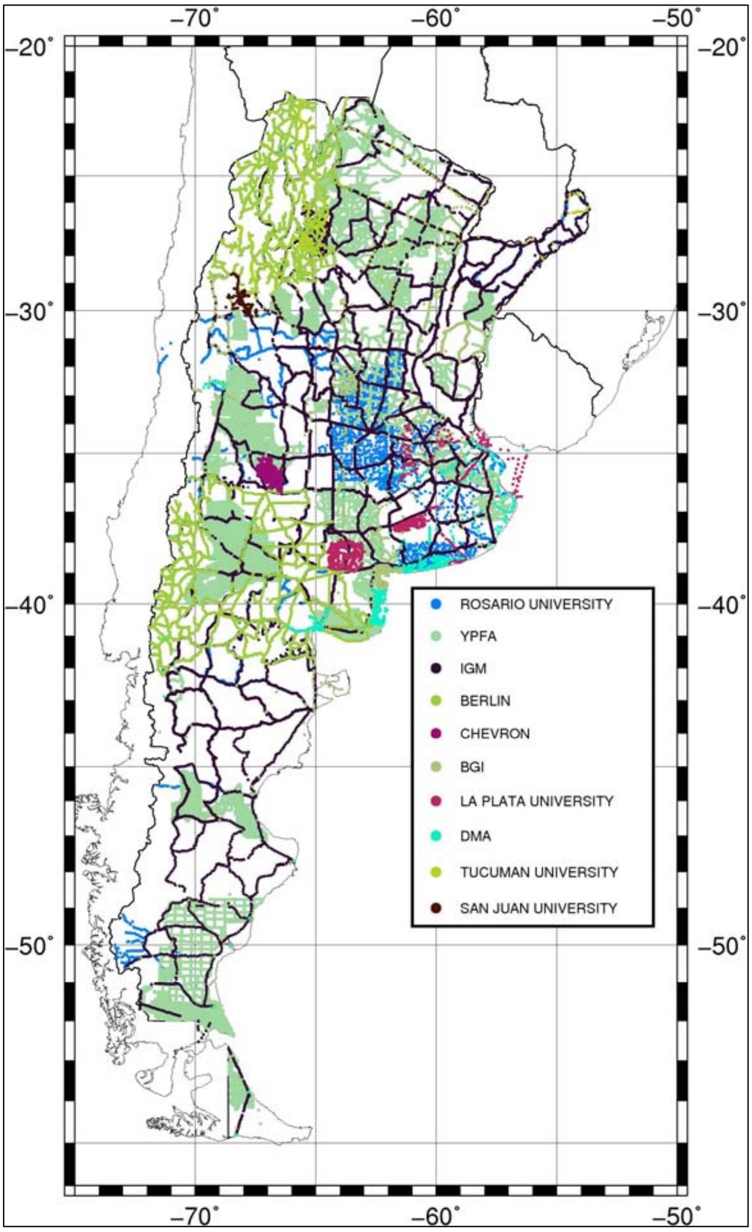


Figure 1 – South America gravity data

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

[2] University of Rosario (UNR)

1.1 Argentina



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

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

1.2 Brazil

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

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

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

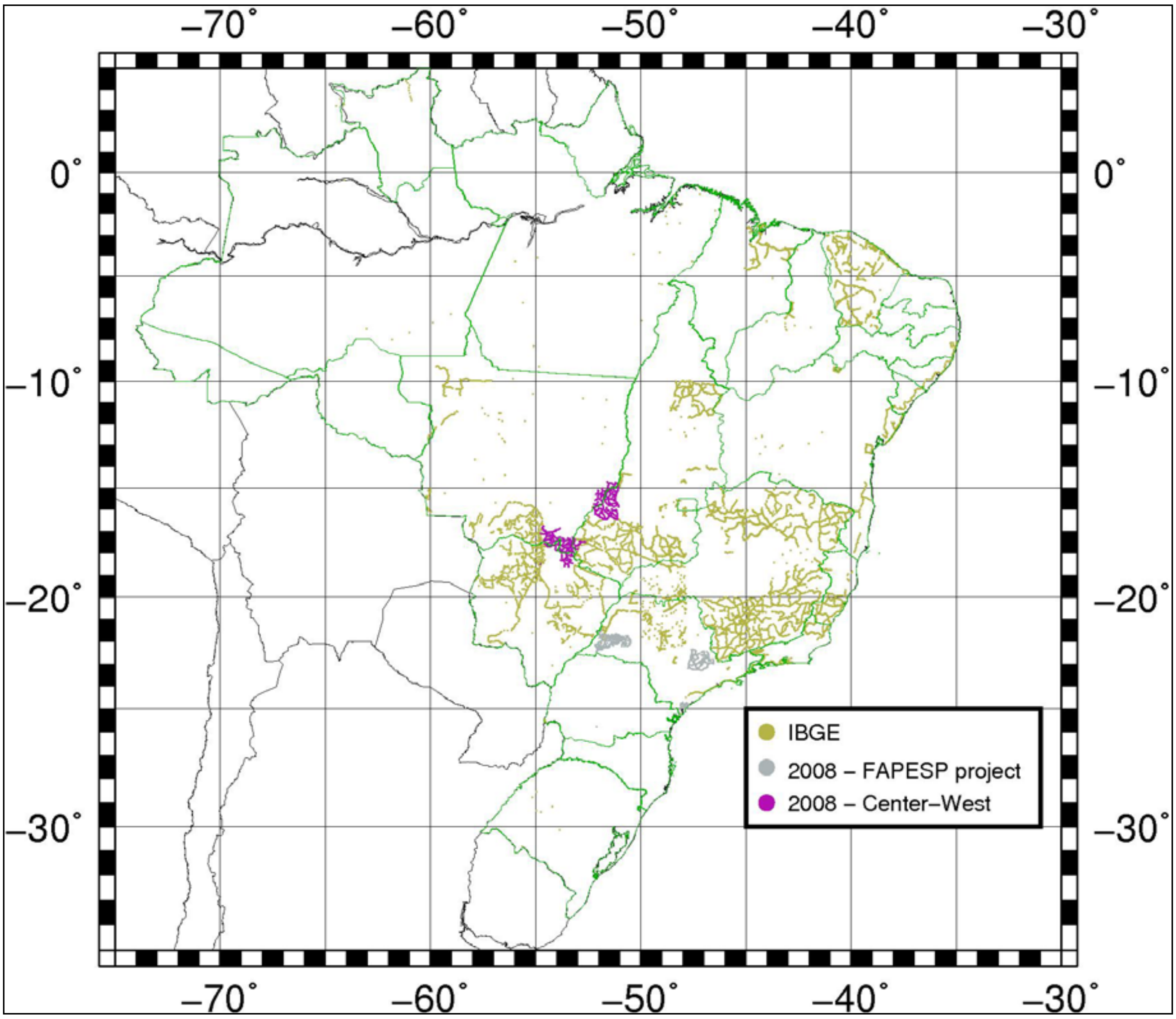


Figure 3 – Brazil new gravity data

1.3 Chile

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

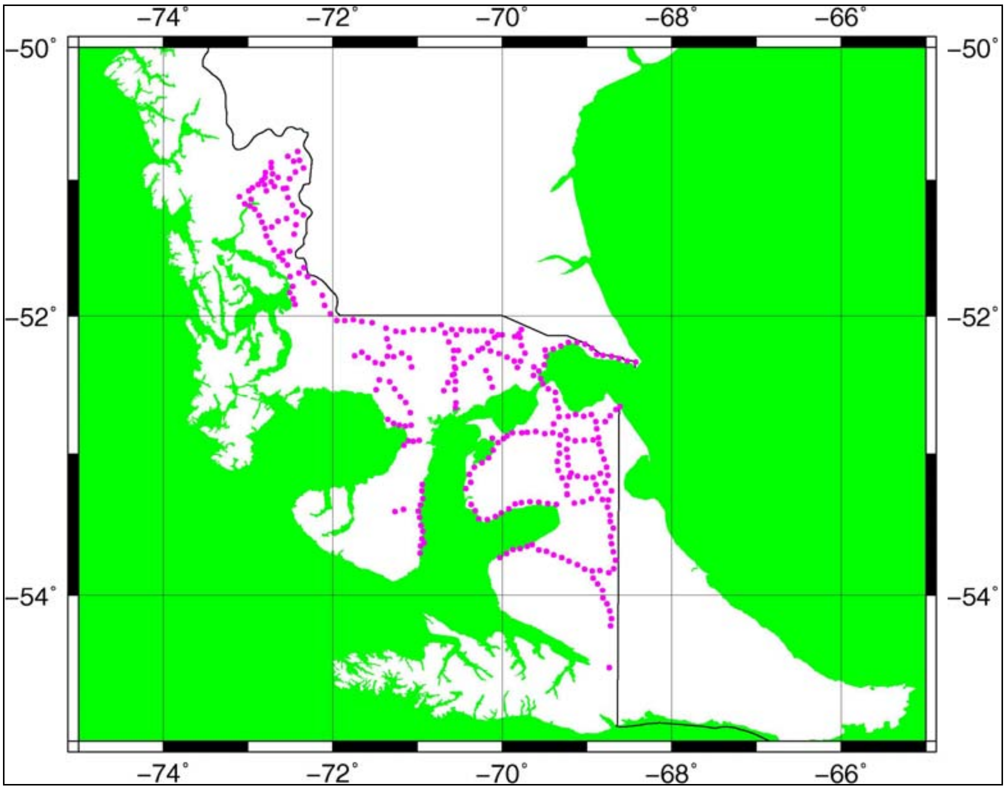


Figure 4 – Chile new gravity data

1.4 Colombia

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

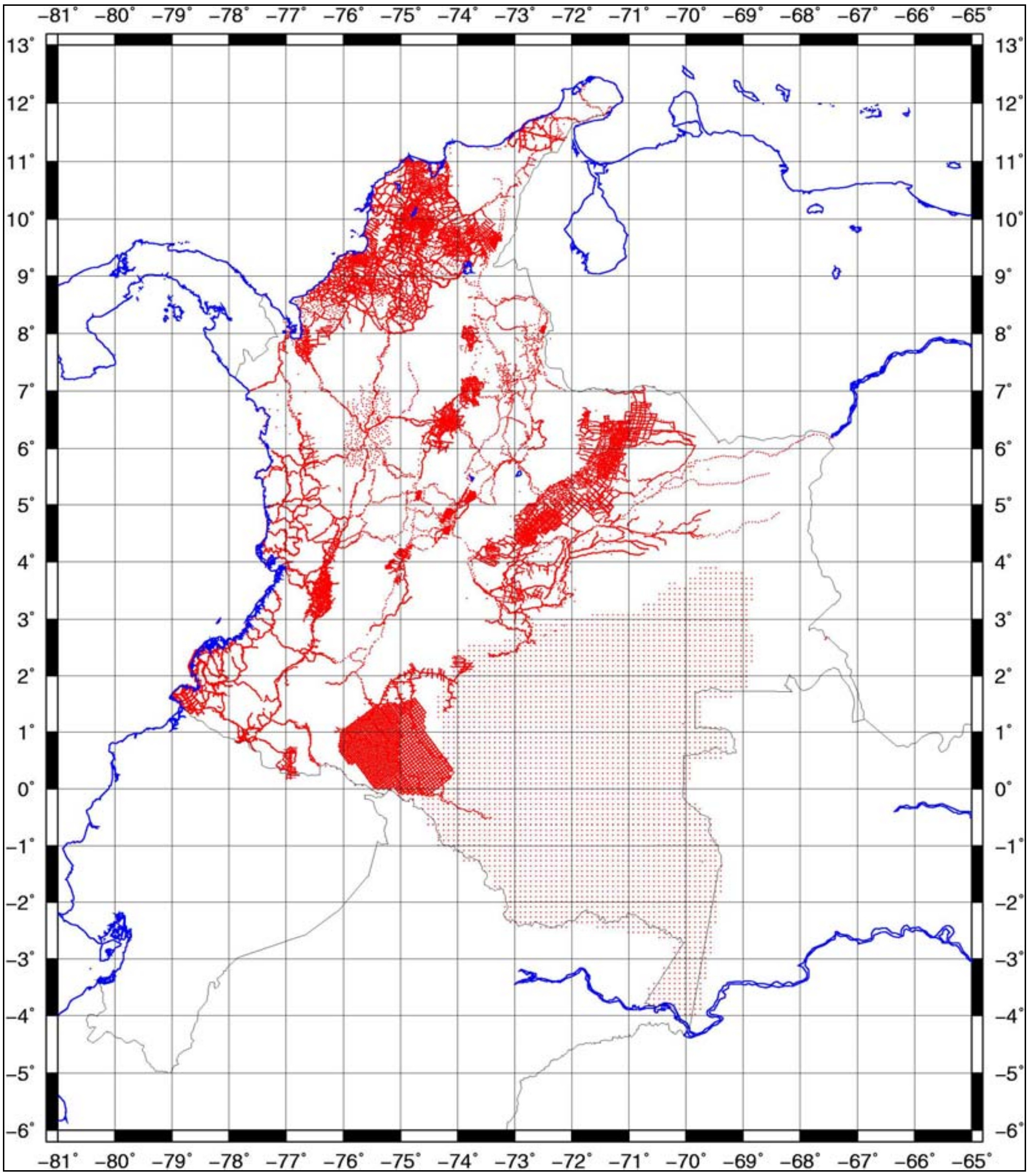


Figure 5 - Gravity data provided by IAG CP2.5 to SIRGAS-WGIII.

1.5 Paraguay

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

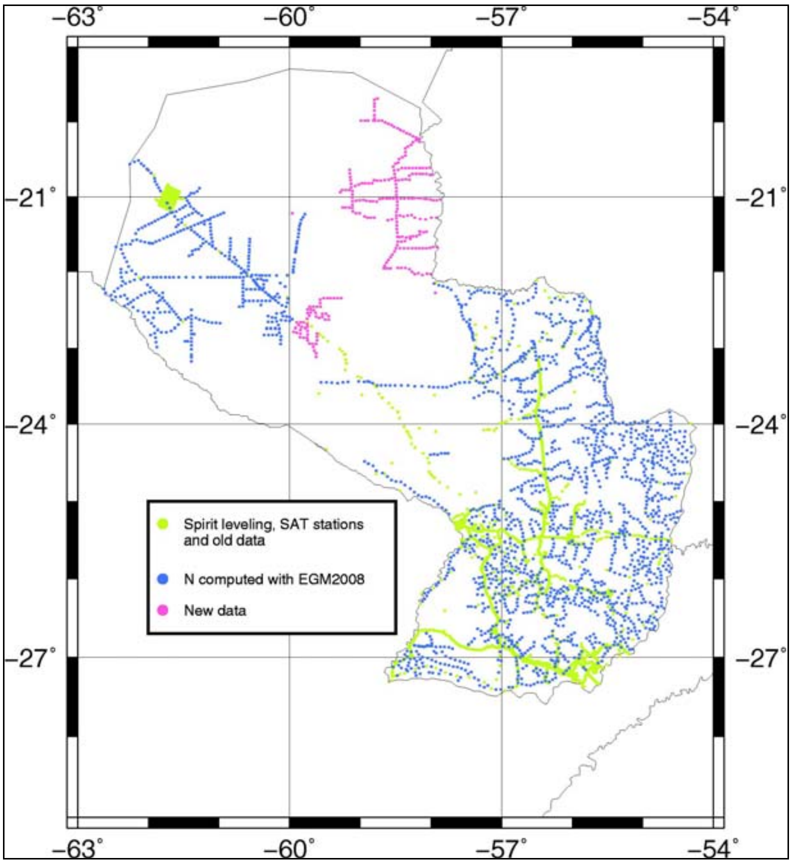


Figure 6 – Gravity data in Paraguay: new and old data.

2. Digital Terrain Model of 3" for South America

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

It has been derived the following two DTM:

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

Future efforts

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

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BLITZKOW, Denizar; MATOS, Ana Cristina Oliveira Cancoro de; CAMPOS, Ilce de Oliveira; FONSECA JR., Edvaldo Simões; ALMEIDA, Flavio Guilherme Vaz; BARBOSA, Augusto César Barros. Water level temporal variation analysis at Solimões and Amazonas rivers. Conference Proceedings, IAG International Symposium on Gravity, Geoid and Earth Observation GGEO 2008, 23-27 June, 2008, Chania, Crete, Greece.

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Commission Project 2.6: South Asian and Australian Geoid

Chair: Bill Kearsley (Australia)

1. Primary Objectives

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

Ideally, we should explore ways in which we may

(a) share available gravity data

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

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

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

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

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

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

(b) combining efforts in regional GPS campaigns

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

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

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

(b) technical sessions in scientific and professional conferences

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

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

2. Main activities (2007–2009)

No specific meetings have been held at the recent IAG events (e.g. IUGG 2007 at Perugia, Italy, 2007) or GGEO 2008 in Chania, Crete. However a number of papers and presentations have been given which reflect the geoid-related research over this period. These include investigations into the *Australian and New Zealand* Geoid and Height datums (Amos (2007), Claessens et al. (2007), Featherstone (2007), Filmer (2007), Kearsley et al(2007), *Malaysia* (Forsberg, 2006; Forsberg and Olesen, 2006), and *Indonesia* (Kasenda, 2009; Kasenda and Kearsley (2007).

3. Future Activities

During the upcoming two-year period 2009–2011, the SE Asian Geoid Commission needs to establish stronger links with the Geodesy Sub-Committee of PCGIAP, (as this group is comprised of the main authorities which deal with national geoids and height datums in the region and beyond) and with the FIG Commission 5 (who also have a strong interest in these matters from the stand-point of operational geodesy. The current economic decline is of course affecting much progress in areas of science, but the emerging issues of climate change and Sea Level Rise are giving some urgency to these studies.

4. Problems and Request

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

5. Membership Structure

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

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Study Group 2.1: Comparisons of Absolute Gravimeters

Chair: Leonid F. Vitushkin (BIPM)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Chair: Michael Kuhn (Australia)

1. Primary Objectives

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

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

2. Main activities (2007-09)

This document presents the status report of IAG Study Group 2.2 (SG 2.2) since its creation in 2007. During the period 2007-09 the SG established its terms of references, organized its membership structure, created an internet site, held one official meeting and is currently working on a special focus topic for the assessment of space domain forward gravity modelling techniques (see primary objectives above). It is acknowledged that this report can only cover the main activities of the SG as per information provided by its members and that there are likely more activities within as well as outside the SG.

2.1 Meeting at GGEO2008

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

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

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

2.2 SG's Special Focus

The SG agreed during its meeting at the GGEO2008 conference that the first focus of the SG is on the assessment of space-domain forward gravity modelling techniques/software with the particular view on both theory and practical determination (e.g. required computation time and accuracy). For this purpose the chair prepared a sample topography DEM data set (9-arc-sec by 9-arc-sec) over parts of Australia. The sample data as well as a description of the special focus can be downloaded from the SG's webpage (see link above).

2.3 Individual Activities

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

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

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

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

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

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

3. Future Activities

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

4. Membership Structure

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

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

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

5. Publications and Conference Presentations

5.1 Publications

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5.2 Conference Presentations

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

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Inter-Commission Working Group 2.1: Absoulte Gravimetry

Chair: Herbert Wilmes (Germany)

Overview

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

Motivation

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

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

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

[3] cf. IGFS – http://www.igfs.net/

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

[5] cf. GGOS – http://www.ggos.org/

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

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

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

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

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

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

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

The absolute gravity database AGrav

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

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

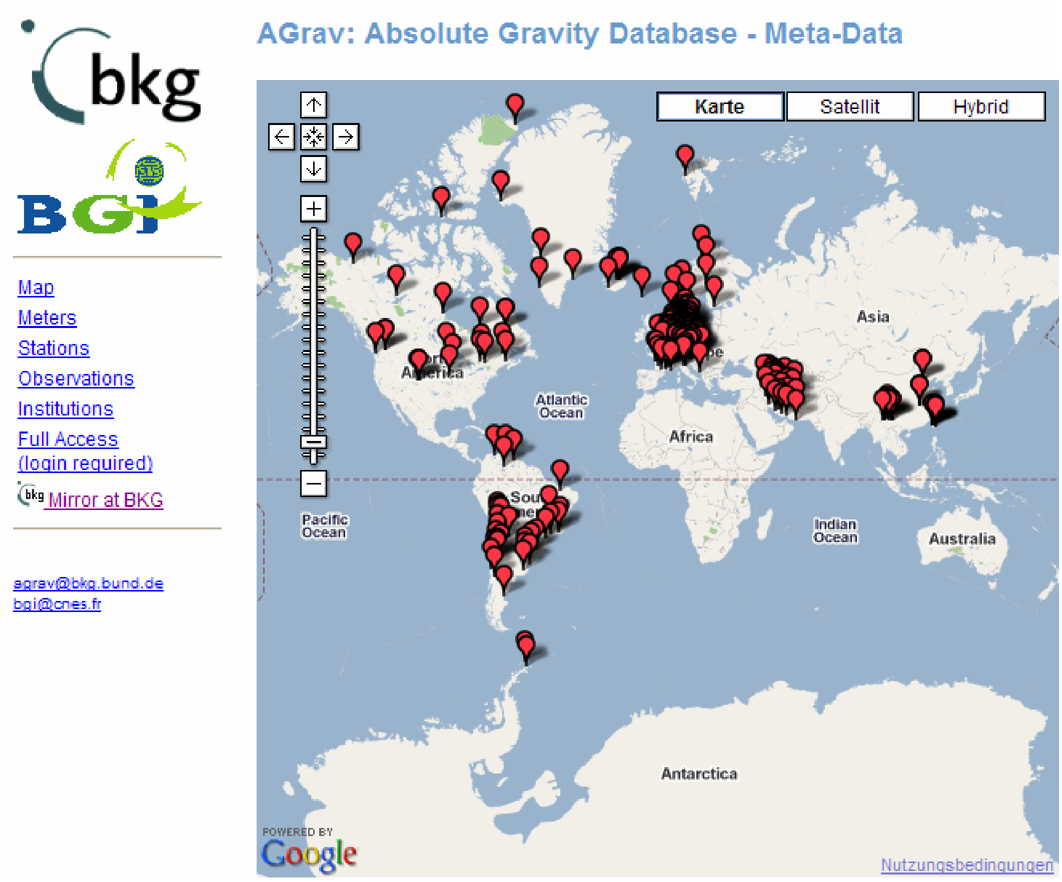

Figure 1: Layout of the AGrav database web interface (status 2009)

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

The AGrav database informs about station location, observation epoch, instrument type and serial number, instrument owner or user respectively and measurement results. Accordingly, the basic structure of the relational database is composed by four tables to store information about the stations, instruments, measurement epochs, and involved institutions, which are linked to each other. Other details can be stored in supplemental tables. In this way, storage of redundant information is avoided and a flexible adaption to future needs is possible. Concerning observation epochs for instance, it is possible just to store time and date of the observation up to complete processing results, including single drop observations.

The database concept distinguishes two basic features:

- It can inform with meta-data about measurements and, where the details are available, about results, but with limited accuracy. This service is freely available without access restrictions.
- It can store the measurement results including all corrections and processing details. Here, restrictions are applied, access is granted only to users, who have contributed own data.

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

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

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

Continuation of the work

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

The absolute gravity database and a standardisation of the data evaluation would make it much easier to create a new gravity reference system which could replace the IGSN71, the International Standardization Net 1971 after Morelli (1974). Its accuracy is estimated with ±1 $\mu m/s^2$ (±100 µGal!). This value shows the strong discrepancy between the realization of the gravity reference system and the much improved absolute gravimeters. The gap between gravity reference system and present-day instrument reaches almost two orders of magnitude.

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

Chair: Jianliang Huang (Canada)

Summary of Activities

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

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

This special issue of Newton's Bulletin consists of 25 peer-reviewed evaluation papers of EGM2008 (and partially of PGM2007A), which are grouped into four different sections according to the geographical region of the evaluation tests: Global, the Americas, Europe and Africa, and Asia, Australia and Antarctica. Their results provide a thorough external assessment of EGM2008, using a variety of geodetic data and testing methodologies.

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

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

Appendix

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Evaluation of the Earth gravity model EGM2008 in Algeria (S. A. Benahmed Daho)

Evaluation of the EGM2008 geopotential model for Egypt (Hussein A. Abd-Elmotaal)

EGM2008 evaluation for Africa (C. L. Merry)

Asia, Australia and Antarctica

Is Australian data really validating EGM2008, or is EGM2008 just in/validating Australian data? (S. J. Claessens, W. E. Featherstone, I. M. Anjasmara, M. S. Filmer)

Evaluation of the Earth Gravitational Model 2008 using GPS-leveling and gravity data in China (J. C. Li, J. S. Ning, D. B. Chao, W. P. Jiang)

Gravity and geoid estimate in South India and their comparison with EGM08 (D. Carrion, N. Kumar, R. Barzaghi, A. P. Singh, B. Singh)

Assessment of EGM2008 over Sri Lanka, an area where 'fill-in' data were used in EGM2008 (P. G. V Abeyratne, W. E. Featherstone, D. A. Tantrigoda)

Evaluating EGM2008 over East Antarctica (P.J. Morgan and W. E. Featherstone)