Commission 2 – Gravity Field

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

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

Structure

Sub-commission 2.1:	Gravimetry and Gravity Networks
Sub-commission 2.2:	Spatial and Temporal Gravity Field and Geoid Modelling
Sub-commission 2.3:	Dedicated Satellite Gravity Mapping Missions
Sub-commission 2.4:	Regional Geoid Determination
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Study Group 2.1:	Comparisons of Absolute Gravimeters
Study Group 2.2:	High-Resolution Forward Gravity Modelling to Assist Satellite Gravity Missions Results
IC Working Gr. 2.1:	Absolute Gravimetry
IC Working Gr. 2.2:	Evaluation of Global Earth Gravity Models

Overview

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

1. Meetings

1-1. GGEO2008

One of the most important events of Commission 2 for the period was the International Symposium on Gravity, Geoid and Earth Observation 2008 (GGEO2008), which took place in Chania, Greece, 23-27 June, 2008. It was expertly organized by the members of the Laboratory of Geodesy and Geomatics Engineering, Department of Mineral Resources Engineering, the Technical University of Crete. The title of the symposium "Gravity, Geoid and Earth Observation" is currently very pertinent and points the direction to which the commission 2 as well as the IAG are pursuing. GGEO 2008 brought together 210 scientists

from 36 countries to discuss the state-of-the-art topics in 9 scientific sessions which cover the traditional research areas of Commission 2, as well as interdisciplinary topics relate to geoid, gravity modelling, geodynamics and the new challenges towards the Earth observation. All components of the Commission were well represented at the symposium not only in terms of participants but also by attracting 88 oral and more than 200 poster presentations. The Proceedings of the Symposium including 91 peer-reviewed papers has been published in the IAG Symposia series (Vol. 135, 538p, 2010) by Springer Verlag.

1-2. IAG2009 Buenos Aires

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

1-3. Other Meetings

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

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

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

2. Gravimetry and Gravity Networks

There are a great number of progresses in all the fields of activities of SC 2.1, i.e., absolute gravimetry, relative gravimetry, superconducting gravimetry, airborne gravimetry, and regional gravity networks aiming at hydrological, tectonic, seismological, and other applications. Among them, International Comparison of Absolute Gravimeters (ICAG) is one of the most relevant issues. It is reported that the evaluation of the results of the 7th ICAG-2005 was completed and the 8th ICAG-2009 in September-October 2009 at the Bureau International des Poids et Mesures (BIPM) in Sèvres, France was organized under umbrella of IAG and BIPM. The ICAG-2009 included a CIPM (Comité International des Poids et Mesures) -Key Comparison and a CIPM-Pilot Study. This shows that the growing demand for confident and

reliable absolute gravity measurements for the Consultative Committee on Mass and Related Quantities (CCM) as well. Since the BIPM terminated the local support for organizing ICAGs after ICAG-2009 mainly due to economical aspects, SG 2.1 (Comparisons of Absolute Gravimeters), ICWG 2.1 (Absolute Gravimetry) and CCM WG on Gravimetry are jointly working to prepare the recommendations for the future ICAGs.

3. Spatial and Temporal Gravity Field and Geoid Modelling

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

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

4. The gravity field satellite missions

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

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

5. Regional Geoid Determination and Commission Projects

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

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

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

6. Satellite Altimetry

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

7. Summary

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

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

Sub-Commission 2.1: Gravimetry and Gravity Networks

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

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

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

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

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

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

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

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

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

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

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

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

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

It was decided that the draft of the Recommendations for geodetic-geophysical community on the organization of future comparisons of absolute gravimeters will be prepared for the

discussion at the CCM WGG meeting on 10 May 2011 at BIPM. The Recommendations should be agreed with metrology community.

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

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

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

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

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

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

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

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

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

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

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

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

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

1st day: Monday 28 June

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

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

2nd day: Tuesday 29 June

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

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

Marine gravity - Prof. O. Andersen

3rd day : Wednesday 30 June

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

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

4th day : Thursday 1 July

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

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

5th day: Friday 2 July

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

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

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

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

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

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

Annex 1

17.01.11

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

Dear colleagues,

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Annex 2

Document CCM WGG/11-22

To:

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

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

10.03.11

Dear colleagues,

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

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

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

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

Best regards,

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

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

28 February – 1 March 2011
BKG, Germany

Preamble:

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

The meeting supported

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

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

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

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

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

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

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

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

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

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

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

The proposals was prepared by

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

Annex 3

East Asia and Western Pacific Gravity Networks

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

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

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

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

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

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

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

Reference

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

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

President: Martin Vermeer (Finland)

Terms of Reference

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

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

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

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

Activities

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

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

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

Sub-Commission 2.3: Dedicated Satellite Gravity Mapping Missions

President: Roland Pail (Germany)

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

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

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

1. Static and temporal global gravity field models

Activities and results

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

The GOCE High-Level Processing Facility (HPF) is responsible for the generation of GOCE final orbit and gravity field products ([14]). This task is performed by a consortium of 10 university and research facilities in Europe. In the frame of this project, innovative strategies for the solution of several specific problems of high-level gravity field modelling, precise orbit determination and the analysis and calibration of space-borne accelerometer, gradio-meter, and star-tracker observations have been investigated (e.g., [1], [2], [10], [20], [21], [30], [31]). An alternative algorithm for the angular rate reconstruction in the frame of the gravity gradient processing has been developed ([29]), which is currently being implemented

in the official ESA Level 1b processor and will further improve GOCE Level 1b products. Additionally, extensive validation activities of GOCE observations have been performed, e.g., [12], [23].

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

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2. Alternative methods for gravity field modelling

Activities and results

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

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

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

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

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3. Future gravity field missions

Activities and results

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

In parallel to the international programmatic meetings mentioned above and based on the success of the gravity mission CHAMP, GRACE and GOCE, which brought an enormous improvement in the knowledge of the Earth's gravity field and particularly in its temporal

evolution, a number of studies and proposals for future gravity field mission concepts have been performed. All these studies and proposals address science requirements to be met by such a mission, observations and orbit concepts needed in order to improve spatial and temporal resolution and in order to reduce temporal aliasing, and candidate satellite and instrument technology needed for the identified mission concepts.

On ESA level during the reporting period three studies on future gravity field missions were conducted. The first study was about "Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the Earth system by Means of Satellites" and run in the period from 2007 to 2008. Goals of this study were the development of a complete multi-year forward simulation of mass variations in the Earth system and the identification of potential mission scenarios and their performance. Results of this study are reported in [53]. In the period from 2009 to 2010 two studies on the "Assessment of a next Generation Mission for Monitoring the Variations of Earth Gravity" were conducted in parallel by joint industrial and scientific consortia. Goal of these studies were the definition of mission requirements resulting from science requirements, the definition of measurement objectives and the required performance, the identification of engineering requirements for key technology, a complete mission analysis and finally an end-to-end simulation by means of numerical methods. Both studies recently were finalized and final reports are under preparation ([43] and [51]).

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

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

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4. Interfacing with user communities

Activities and results

The workshops discussed above ([48], [54]) represent an important platform to involve all relevant user groups of gravity field products in the planning of satellite gravimetry missions and the definition of their requirements.

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

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

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

The International Center for Global Earth Models (ICGEM; [61]) has been furthermore well established as one of the six centres of the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). ICGEM is also maintained by GFZ and comprises a widely used archive of all existing global gravity field models and an increasingly used service for calculation and visualization of gravity field functionals.

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Sub-Commission 2.4: Regional Geoid Determination

President: Urs Marti (Switzerland)

Terms of Reference

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

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

Gravimetric geoid modeling techniques and methods, available software

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

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

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

Objectives

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

The Continental Gravity and Geoid Projects

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

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

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

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

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

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

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

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

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

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

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

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

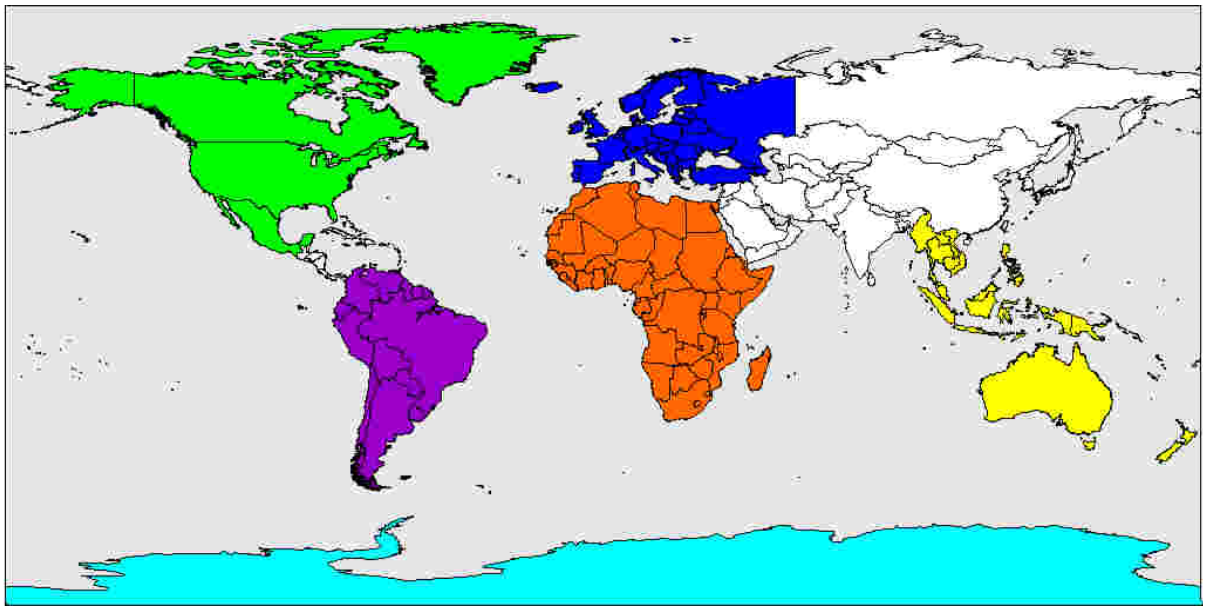

Figure 1: Overview of the coverage of the Commission 2 geoid projects

Activities of the Continental Gravity and Geoid Projects

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

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

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

The North-American Geoid project is on a good way and several meetings took place mainly between American and Canadian authorities. Mexico as well is now an active member of the project and offered to take the lead in an extension towards Central America. The USA

mainly focuses on the harmonization of their gravity data set by means of airborne gravity missions (GRAV-D project) as the basis for a national to continental height system. There are interests in extending these activities towards the Caribbean and even some northern parts of South America. Funding for such activities seems to be granted. The IAG project should continue beyond 2011.

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

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

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

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

Other regional geoid projects

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

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

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

Other activities

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

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

Sub-Commission 2.5: Satellite Altimetry

President: Cheinway Hwang (Taiwan)

1. Introduction

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

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

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

2. Workshops

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

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

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

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

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

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

3. Summary

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

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

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

Chair: Heiner Denker (Germany)

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

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

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

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

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

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

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

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

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Commission Project 2.2: North American Geoid

Chair: Dan Roman (USA)

Bottom Line Up Front

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

Meeting Activities

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

ready occurred. Refinements of the techniques employed in the development of the recent gravimetric geoid model were presented at the EGU 2011 meeting and further presentations were made during the F.I.G. 2011 meeting in Marrakech, Morocco to reinforce the reliability of using GNSS technology with a geoid height model to promulgate vertical heights consistent with a global vertical datum but meeting local needs.

Data Improvement

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

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

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

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

Planned Implementation

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

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

International Great Lakes Datum of 2015 (IGLD15)

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

of the gravimetric geoid height model for a new vertical reference system in 2018 (IGLD85 actually was released in 1988).

Collaboration with Other Groups/Projects/Commissions

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

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

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

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

Outlook

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

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

Commission Project 2.3: African Geoid

Chair: Hussein Abd-Elmotaal (Egypt)

Primary Objectives

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

The objectives of the project are summarized as follows:

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

Main activities (2007–2011)

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

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

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

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

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

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

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

Future Activities

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

Problems and Request

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

Membership Structure

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

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

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

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Commission Project 2.4: Antarctic Geoid

Chair: Mirko Scheinert (Germany)

Short Review

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

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

The coverage of gravity data in Antarctica has been continuously improved by new surveys. In this respect, the International Polar Year 2007/2008 (IPY, March 2007 – February 2009) played an important role. Within a number of IPY projects gravity observations have been carried out, mainly aerogravimetric surveys, but also terrestrial relative gravimetry or tidal gravimetry. Especially the following IPY projects should be mentioned: #67 "Origin, evolution and setting of the Gamburtsev subglacial highlands (AGAP)" – where a number of new results have been reported (e.g. Bell et al., 2011) –, #97 "Investigating the Cryospheric Evolution of the Central Antarctic Plate (ICECAP), and #185 "Polar Earth Observing Network (POLENET)".

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

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

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

Future plans and activities

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

absolute gravimetry at coastal stations). The main goal is to finally deliver a suitable grid of terrestrial gravity data and of the regional geoid. A presentation dedicated to this topic will be given at the IUGG General Assembly 2011 in Melbourne.

With regard to new gravity surveys in Antarctica, aerogravimetry provides the most powerful tool to survey larger areas. In this context, airborne gravimetry forms a core observation technique within an ensemble of aerogeophysical instrumentation. In continuation of the IPY several projects are in progress which include aerogravimetry over Antarctica, from the US (e.g. Icebridge), from Germany, Denmark, the UK and other nations. Still it has to be stated that a lot of work has to be done, especially to close the polar data gap of (terrestrial and airborne) gravity. In view of the global gravity field this problem gets a special focus since the latest gravity satellite mission GOCE (launched March 17, 2009) features a data gap of about 1,400 km diameter at the poles (due to its inclination of 96.5°). Future airborne missions may help to solve this problem when adopting long-range aircrafts capable to fly under Antarctic conditions (e.g. utilizing the German research aircraft HALO, cf. Scheinert et al., 2010).

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

- IUGG General Assembly, Melbourne (Australia), June 28 – July 07, 2011
- International Symposium on Antarctic Earth Sciences (ISAES XI), Edinburgh (UK), July 10 – 16, 2011.
- XXXII SCAR Meeting and Open Science Conference, Portland (USA), July 13 – 25, 2012 .

Selected conferences and workshops with participation of AntGP members

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

Membership

(active members)

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

(corresponding members)

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

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

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

Primary Objectives

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

Activities

Introduction

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

Geoid Model

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

Evaluation of Geopotential Models

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

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

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

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

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

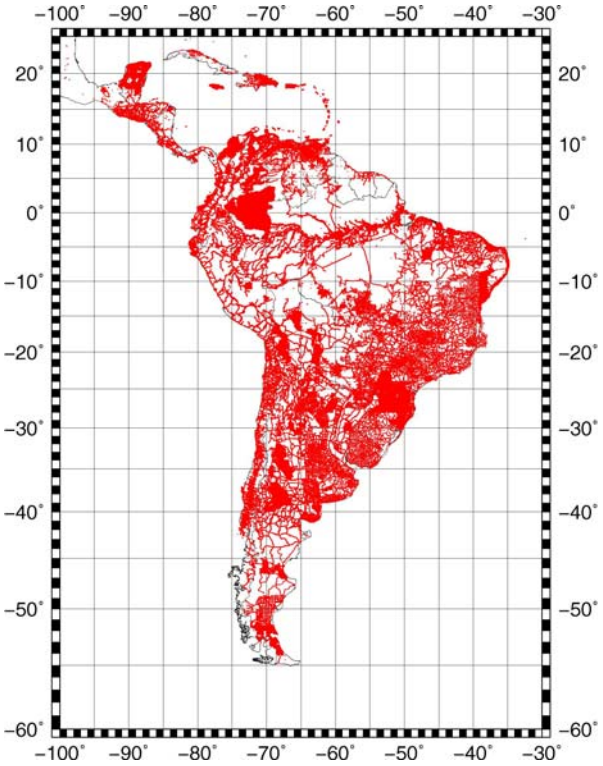

Figure l: South America gravity data

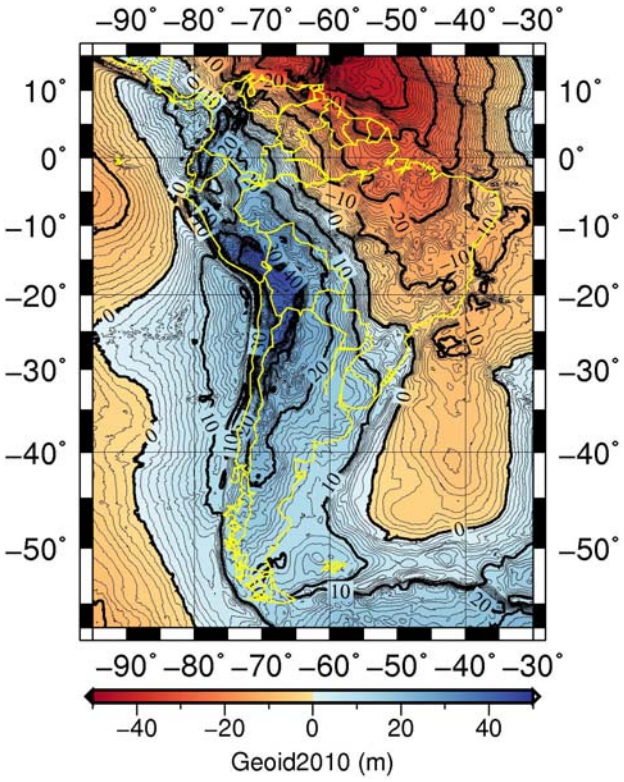

Figure 2: South America geoid model

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Commission Project 2.6: South Asian and Australian Geoid

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

1. Primary Objectives

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

Ideally, we should explore ways in which we may

(a) share available gravity data

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

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

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

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

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

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

(b) combining efforts in regional GPS campaigns

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

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

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

(b) technical sessions in scientific and professional conferences

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

Sadly, the above objectives have not been realised in any significant manner, due in part to the difficulty which exists between countries in the sharing of data of common interest. Indeed, any such outcome comes possibly indirectly through the GGM's, the most recent of

which is EGM08. Obviously, even there the quality of data derived from this model depends largely upon the quality of the data supplied to the computing authority. As a result, the work done over the last few years has mainly been based upon individual national geoid studies, and a brief summary of these now follows.

2. Main activities (2007–2011)

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

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

3. Future Activities

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

4. Problems and Request

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

5. Membership Structure

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

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

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Study Group 2.1: Comparisons of Absolute Gravimeters

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

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

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

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

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

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

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

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

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

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

Chair: Michael Kuhn (Australia)

1. Primary Objectives

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

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

2. Main activities (2007-11)

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

2.1 Meetings

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

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

2.2 Study Group Webpage

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

2.3 Study Group's special focus:

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

2.4 Individual Activities

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

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

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

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

Tsoulis et al (2009b) and Jamet et al. (2010) implemented and tested a numerically stable recursive algorithm which evaluates the potential harmonic coefficients of a constant density

polyhedron. By improving previous methods the present contribution demonstrates an efficient numerical computation of these coefficients up to degree 60 when applied from simple tetrahedral simplices to more complicated triangulated shape models. The presented linear algorithm opens possibilities to practical applications especially in the frame of gravity field modelling and interpretation, e.g. in satellite gradiometry or terrestrial gravimetry.

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

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

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

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

3. Membership Structure

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

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

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Inter-Commission Working Group 2.1: Absolute Gravimetry

Chair: Herbert Wilmes (Germany)

Overview

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

Motivation

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

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

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

The absolute gravity database AGrav

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

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

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

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

A database query distinguishes between two basic features:

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

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

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

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

to the database. The database works as the official database of the International Association of Geodesy.

Continuation of the International Comparison of Absolute Gravimeters

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

Realisation of a new International Gravity Reference System

The calibration and standardization of AG measurements and evaluation are important conditions to build up a precise and consistent gravity reference system. It is proposed that a new International Gravity Reference System be built up which can replace the International Standardization Net 1971 (Morelli 1974). IGSN71 is still the valid gravity reference system of the IAG. Its accuracy is estimated with ±1 μm/s² (±100 μGal!) and therefore cannot cover the needs of observations with modern absolute gravimeters. This value shows the strong discrepancy between the realization of the gravity reference system and the much improved absolute gravimeters. The gap between gravity reference system and present-day instrument reaches almost two orders of magnitude.

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

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

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

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

1. Terms of Reference

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

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

2. Evaluation of EGM08 model

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

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

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

3. Evaluation of GRACE and GOCE models

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

Appendix A

Contents of Newton's Bulletin N. 4

Foreword (J. Huang, C. Kotsakis)

Global

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

The Americas

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

Europe and Africa

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

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

Asia, Australia and Antarctica

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

Appendix B

Selected publication in other scientific journals and proceedings

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

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

Claessens, S.J. and W.E. Featherstone (2007) Is Australian data really validating PGM2007A, or is PGM2007A just in/validating Australian data?, Technical Report, Western Australian Centre for Geodesy, Curtin University of Technology, 32 pp.

Claessens, S.J., W.E. Featherstone and I.M. Anjasmara (2010) Is Australian data really validating EGM2008, or is EGM2008 just in/validating Australian data?, In: Mertikas, S. (Ed.) Gravity, Geoid and Earth Observation, Springer, International Association of Geodesy Symposia, Vol. 135, pp. 473-479

Claessens, S.J. (2011) Evaluation of gravity and altimetry data in Australian coastal regions, Proceedings of the IAG Scientific Assembly Geodesy for Planet Earth, Buenos Aires, Argentina, September 2009, in press

Gruber, T.; Visser, P.N.A.M., Ackermann, C., Hosse, M.; Validation of GOCE Gravity Field Models by Means of Orbit Residuals and Geoid Comparisons; submitted to Journal of Geodesy, 2011

Hirt, C., U. Marti, B. Bürki, and W.E. Featherstone (2010) Assessment of EGM2008 in Europe using accurate astrogeodetic vertical deflections and omission error estimates from SRTM/DTM2006.0 residual terrain model data. Journal Geophysical Research (JGR) - Solid Earth, Vol. 115, B10404, doi:10.1029/2009JB007057

Hirt, C. (2010) Prediction of vertical deflections from high-degree spherical harmonic synthesis and residual terrain model data. Journal of Geodesy, Vol. 84, No. 3, pp. 179-190, doi: 10.1007/s00190-009-0354-x

Hirt, C. (2011) Assessment of EGM2008 over Germany using accurate quasigeoid heights from vertical deflections, GCG05 and GPS levelling. Zeitschrift für Geodäsie, Geoinformation und Landmanagement (zfv), accepted Feb. 2011.

Hirt, C., T. Gruber and W.E. Featherstone (submitted) Evaluation of the first GOCE static gravity field models using terrestrial gravity, vertical deflections and EGM2008 quasigeoid heights. Journal of Geodesy

Ihde, J., Wilmes, H., Müller, J., Denker, H., Voigt, C., Hosse, M. (2010). Validation of satellite gravity field models by regional terrestrial data sets. In: F. Flechtner, et al. (eds.), System Earth via Geodetic-Geophysical Space Techniques (Series: Advanced Technologies in Earth Sciences), 277-296, Springer-Verlag, Berlin, Heidelberg

Kalvoda J., Klokočník J, Kostelecký J. (2010) Regional correlation of the Earth Gravitational Model 2008 with morphogenetic patterns of the Nepal Himalaya, Acta Universitatis Carolinae, Geographica, XLV, 2, 53 – 78, Prague. (SCOPUS)

Klokočník J, Wagner CA, Kostelecký J, Bezděk A, Novák P, McAdoo D (2008) Variations in the accuracy of gravity recovery due to ground track variability: GRACE, CHAMP and GOCE. Journal of Geodesy 82: 917-927.

Klokočník J, Kostelecký J, Novák P, Bezděk A, Gruber C, Sebera J (2009). Mapping the Earth's gravitational field using GOCE. Geodetický a kartografický obzor 55(97): 165-174.

Klokočník J., Kostelecký J., Pešek I., Novák P., Wagner C.A., Sebera J. (2010) Candidates for multiple impact craters?: Popigai and Chicxulub as seen by the global high resolution gravitational field model EGM08, Solid Earth EGU 2010, 1, 71-83, DOI: 10.5194/se-1-71-2010.

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Appendix C

Selected presentations and posters:

Avalos, David, Marcelo SANTOS and Petr Vaníček (2008). "Insights into the Mexican Gravimetric Geoid (GGM05)." Observing our Changing Earth, Proceedings of the 2007 IAG General Assembly, Perugia, Italy, 2 – 13 July, 2007, International Association of Geodesy Symposia Vol. 133 (M. Sideris, Ed.), pp. 421-425, Springer

Benahmed Daho S. A., C. L. Merry (2007) – New investigation on the choice of the tailored global geopotential model for Algeria, presented at the XXIV IUGG General Assembly, July 2-13, Perugia, Session GS002 Gravity field.

Benahmed Daho S. A., (2009) – Evaluation of EGM2008 Earth Gravitational Model in Algeria using gravity and GPS/levelling data – Geophysical Research Abstracts, EGU General Assembly, Vol. 11 – Vienna (Austria), 19-24 April 2009

Blitzkow, Denizar, Matos, Ana Cristina Oliveira Cancoro de, Grace and the geoid in South America, American Geophysical Union, Fall Meeting - 2009, San Francisco.,USA, Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract G54A-08, 2009

Blitzkow, Denizar, Matos, Ana Cristina Oliveira Cancoro de, Lobianco, Maria Cristina Barbosa, Campos, Ilce de Oliveira, The progress of the geoid model computation for South America under GRACE and EGM2008 models, SIRGAS Meeting - Geodesy for Planet Earth IAG2009, 2009, Buenos Aires, Argentina, Geodesy for Planet Earth: book of abstracts, p.1 - 222

Blitzkow, Denizar, Matos, Ana Cristina Oliveira Cancoro De, Guimaraes, G. N., Lobianco, Maria Cristina Barbosa, Costa,Sônia Maria Alves, A new version of the geoid model for South America, 2010, SECOND INTERNATIONAL SYMPOSIUM OF THE INTERNATIONAL GRAVITY FIELD SERVICE

Denker, H., Voigt, C., Müller, J., Ihde, J., Lux, N., Wilmes, H. (2007). Terrestrial data sets for the validation of GOCE products. Geotechnologien Science Report, No. 11, 85-92, Potsdam

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Gruber, T.; Ackermann, C.; Fecher, T.; Heinze, M.; Visser, P.: Validation of GOCE Gravity Field Models and Precise Science Orbits; ESA Living Planet Symposium, Bergen, Norway, 29.06.2010

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

Gruber, T.; Ackermann, C.; Hosse, M.; Visser, P. N.: Validation of GOCE gravity field models by means of geoid comparisons and orbit fits; AGU Fall Meeting 2010, San Francisco, 15.12.2010

Gruber, T; Ackermann, C.; Hosse, M.; Visser, P.N.A.M.; Validation of 2nd Release of GOCE gravity field models; 4th GOCE User Workshop, Munich, Germany, 31.3.2011

Gruber, T; Ackermann, C.; Hosse, M.; Visser, P.N.A.M.; Validation of newly released of GOCE gravity field models; European Geophysical Union, General Assembly, Vienna, 4.4.2011

Huang J, Véronneau M (2010) Methods of Using the Satellite-Based Global Gravity Models to Model the Geoid in Western Canada and Alaska, Second International Symposium of the International Gravity Field Service 20-22 September 2010, University of Alaska Fairbanks, USA

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