Commission 2 – Gravity Field

http://www.iag-commission2.ch

President: Urs Marti (Switzerland)
Vice President: Srinivas Bettadpur (USA)

Structure

Sub-Commission 2.1: Gravimetry and Gravity Networks
Sub-Commission 2.2: Spatial and Temporal Gravity Field and Geoid Modeling
Sub-Commission 2.3: Dedicated Satellite Gravity Missions
Sub-Commission 2.4: Regional Geoid Determination
Sub-Commission 2.4a: Gravity and Geoid in Europe
Sub-Commission 2.4b: Gravity and Geoid in South America
Sub-Commission 2.4c: Gravity and Geoid in North and Central America
Sub-Commission 2.4d: Gravity and Geoid in Africa
Sub-Commission 2.4e: Gravity and Geoid in the Asia-Pacific
Sub-Commission 2.4f: Gravity and Geoid in Antarctica
Sub-Commission 2.5: Satellite Altimetry
Sub-Commission 2.6: Gravity and Mass Displacements
Joint Project 2.1: Geodetic Planetology (JP-GP)
Joint Working Group 2.1: Techniques and Metrology in Absolute Gravimetry
Joint Working Group 2.2: Absolute Gravimetry and Absolute Gravity Reference System
Joint Working Group 2.3: Assessment of GOCE Geopotential Models
Joint Working Group 2.4: Multiple geodetic observations and interpretation over Tibet, Xinjiang and Siberia (TibXS)
Joint Working Group 2.5: Physics and dynamics of the Earth's interior from gravimetry
Joint Working Group 2.6: Ice melting & ocean circulation from gravimetry
Joint Working Group 2.7: Land hydrology from gravimetry
Joint Working Group 2.8: Modeling and Inversion of Gravity-Solid Earth Coupling

Overview

This report covers the period of activity of the entities in Commission 2 for the year 2011 to Middle of 2013. Commission 2 consists of six sub-commissions (plus 6 regional sub-commissions), one joint project and several joint working groups and study groups. It is clear that some entities of the Commission were significantly more active than others, but most of them made progress in their stated objectives. Each of the chairs of the entities was asked to summarize their activities. These can be found further down. Here is given only a short summary.

Conference GGHS2012

The symposium "Gravity, Geoid and Height Systems GGHS2012" was the most important meeting by IAG Commission 2. It was organized with the assistance of the International Gravity Field Service (IGFS) and GGOS Theme 1 “Unified Global Height System”. It was arranged by the OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste) which has presently the role of the Central Bureau of the IGFS. The symposium was success-
fully held on the island of San Servolo in the Venetian Lagoon from October 9 to 12 2012 with 140 participants. 30 of them were registered as students and had free access to the conference.

GGHS2012 was the 5th event of the traditional conferences organized by IAG Commission 2 every 4 years after "Gravity, Geoid and Marine Geodesy (Tokyo, Japan, 1996), "Gravity, Geoid and Geodynamics" (Banff, Canada, 2000), "Gravity, Geoid and Space Missions" (Porto, Portugal, 2004) and "Gravity, Geoid and Earth Observation" (Chania, Greece, 2008). The conference covered all activities of IAG Commission 2 except from satellite altimetry which was covered in a special symposium "20 years of progress in radar altimetry" just 2 weeks before the GGHS2012 - as well held in Venice.

A total of 89 oral presentations and 64 posters were presented in 8 sessions (Gravimetry and Gravity Networks, Global Gravity Field Modeling, Future Gravity Field Missions, Advances in Precise Local and Regional High-Resolution Geoid Modeling, Establishment and Unification of Vertical Reference Systems, Gravity Field and Mass Transport Modeling, Modeling and Inversion of Gravity-Solid Earth Coupling, Gravity Field of Planetary Bodies). Peer-reviewed proceedings of the conference will be published in the IAG Symposia series (volume 140) with Springer. The review process is almost finished.

An important part of the conference was the presentation of the results of the very successful space missions GRACE and GOCE and their application in oceanography, mass transport and solid earth modeling, hydrology and atmospheric sciences. Special attention was given to the loss of ice masses over Greenland and Antarctica and the resulting global sea level rise. Unfortunately, the GRACE and GOCE missions will end in the near future. Therefore, another important topic of the conference was the continuation of gravity space missions. It seems now that a GRACE follow-on mission is advancing well and probably can be launched in 2017 as a result of a collaboration of American and European agencies.

The groups working on the realization of a global height system met during the conference in a splinter meeting of the Joint Working Group "Vertical Datum Standardization" and presented their results of their estimation of the global vertical reference level $W_0$. The individual results are now in good agreement in the order of a few centimetres. This implies, that the groups are very close to an agreement on a conventional value for $W_0$ and the definition of a global height system which can be presented to other interested institutions and be adopted by the scientific communities.

Another open issue of the gravity community is the replacement of the outdated International Gravity Standardization Network IGSN-71 by considering modern absolute measurements and the time series of super-conducting gravimeters. These activities in the corresponding working groups are on a good way and the future of the international comparison campaigns of absolute gravimeters could be assured for the next years.

Activities of the Sub-Commissions

SC 2.1 Gravimetry and Gravity Networks

One activity is the future organization of the International and regional campaigns of absolute gravimeters. They seem to be assured until 2017. The future of these campaigns will be regulated by a strategic paper between the metrological (CCM-GGM of the BIPM) and the geodetic side (IAG commission 2, especially SC 2.1).
One other important issue is the replacement of the out-dated global gravity network IGSN71 and the transfer of the former Global Geodynamics Project (GGP) into a permanent service under the umbrella of the IGFS. These tasks are handled mainly in the JWG 2.2.

A special workshop TGSSM2013 for the practical issues of measuring gravity will be held in St. Petersburg (Russia) in September 2013.

**SC 2.2 Spatial and Temporal Gravity Field and Geoid Modeling**

This SC deals with the theoretical practical problems in gravity field determination. Many results were presented at various conferences using the latest GRACE, GOCE and combined models in combination with terrestrial and airborne data. The validation of global models in comparison to local solutions and/or GPS/levelling is an activity of many groups and in special of JWG 2.3.

**SC 2.3 Dedicated Satellite Gravity Missions**

This SC is deeply involved in the derivation of new releases of global gravity field models based on GRACE and GOCE mission data, applying updated background models, processing standards and improved processing strategies. The SC actively contributed to the development and investigation of alternative methods of global gravity field modelling and related problems. It is as well deeply involved in national and international studies in the planning and design of future gravity field missions - especially of a GRACE follow-on mission, which is on a good way.

**SC 2.4 Regional Geoid Determination**

SC 2.4 coordinates the activities of the 6 regional sub-commissions on gravity and geoid determination and helps in the organization of conferences, workshops and schools. The activities in these regional SCs vary from 'almost no activity' to 'very active'. See descriptions below. In some regions, there are activities on the national level, but absolutely none in international cooperation or data exchange.

**SC 2.5 Satellite Altimetry**

One main part of this SC over the past two years was the development of new retrackers and experiments with several retrackers to improve altimeter range measurement accuracies globally and over shallow waters around Taiwan, Australia and the Arctic Ocean. Another result is the publication of an improved Global Marine Gravity Field from Altimetric Geodetic Missions. Future activities include the SCs help in establishing a permanent altimetry service and give to it a better visibility to the public.

**SC 2.6 Gravity and Mass Displacements**

This new (since 2011) SC profits especially from the long time series and excellent quality of GRACE data. There is an enormous potential for the interpretation of these data in several topics, for which special study groups and working groups have been established. Many interesting and promising results have been presented at several conferences in the fields of sea level rise, ocean circulation, ice melting, land hydrology and gravity/solid earth coupling.
Activities of the Joint Project 2.1, Geodetic Planetology

This is a joint project of commissions 1, 2 and 3 and the ICCT. One of its main goal is the establishment of geodetic planetology as a permanent IAG entity such as an Intercommission Committee on Planetology (ICCP). This task seems to very difficult to reach. The main problem is to motivate scientists to work in this field. There are only very few active groups. Nevertheless, there were some presentations in a special session at the GGHS2012 conference and during the International Symposium on Planetary Sciences (IAPS) (2013, Shanghai, China) with theoretical studies interesting results for the moon and mars.

Activities of Study Groups

There are nine Joint Study Groups where commission 2 is involved as a partner, but none of them reports directly to commission 2. Their reports can be found in the ICCT section (8 groups) or under Commission 3 (1 JSG).

Activities of Working Groups

There are 8 Working Groups reporting to Commission 2. All of them are established as Joint Working groups with Commission 3 and/or the IGFS. Their reports can be found in the corresponding chapters and as a summary in the reports of the leading sub-commissions.

Another JWG "Vertical Datum Standardization" in which Commission 2 is involved, reports to GGOS. Its activities can be found there.

Unfortunately, in one WG (2.5) there was not enough activity and the chair does not see a possibility to be more active in this topic in the near future. It is better to dissolve for now, although there is certainly much potential for activities.
Sub-Commission 2.1: Gravimetry and Gravity Networks

Chair: Leonid F. Vitushkin (Russia)
Vice-chair: Hideo Hanada (Japan)

Sub-Commission 2.1 with its Joint Working Groups (JWG) with IGFS JWG 2.1 "Techniques and Metrology in absolute gravimetry" (chaired by Vojtech Palinkas) and JWG 2.2 "Absolute gravimetry and absolute gravity reference system" (chaired by Herbert Wilmes) was active in the most fields of activity in the frame of its Terms of Reference (ToR). It promoted scientific studies of the methods and instruments for terrestrial, airborne, shipboard measurements, establishment of gravity networks and improvement of strategy in the measurement of gravity networks. The Sub-commission provides the geodesy-geophysics community with the means to access the confidence in gravity measurements at the well-defined level of accuracy through organizing, in cooperation with metrology community, Consultative Committee on Mass and Related Quantities and its Working Group on Gravimetry (CCM WGG), Regional Metrology Organizations (RMO) the international comparisons of absolute gravimeters on continental scale.

The Report of SC2.1 prepared by the members of its Steering Committee and by JWG 2.1 and JWG 2.2 promotes the exchange of information on national activities in various fields of gravimetry.

The comparisons of absolute gravimeters

The first comparison of gravimeters at the International Bureau of Weights and Measures (BIPM, Sèvres, France) took place in 1981 (8 gravimeters took part) and the latest comparison will be organized by CCM and SC2.1 in November 2013 in Walferdange (Luxembourg) with 27 absolute gravimeters.

In 2011 the comparison of European Regional Metrological Organization (RMO) EURAMET was also organized in Walferdange (see Report of JWG 2.1)

The scientific Second North-American Comparison of Absolute Gravimeters (NACAG-2013) is under organization in the Table Mountain Geophysical Observatory (Longmont, Colorado).

The growing request from geodesy community for the determination of metrological characteristics of absolute gravimeters and corresponding growing request for the participation in comparison had put the question about gradual transition to establishing a metrological service for absolute gravimeters on the basis of the primary standards in gravimetry maintained at in NMIs and DIs and about calibrations of absolute gravimeters at the level of National Metrology Institutes (NMI) and Designated Institutes (DI). The creation of such metrological system will require a lot of efforts of both the metrology and the geodetic-geophysical communities because so far the evaluation and presentation of the results of comparison organized by CCM or RMO were different for the absolute gravimeters belonging to NMIs and DIs and for the absolute gravimeters from other institutes and services.

Further investigations of the sources of the uncertainties of the absolute gravimeters based on different principles of operation (laser interferometric absolute ballistic gravimeters of different constructions with macroscopic test body, cold atom gravimeters, etc.), of the reproducibility of their measurements, of the linking between the results of different comparisons and other essential issues still necessary.
The agreement between the CCM and IAG should be reached concerning the ways for implementation of metrological assurance in absolute gravity measurements.

Currently the cooperation between SC2.1, its JWGs and CCM WGG is realized through the mutual membership of their members and joined meetings. The establishment of the connections between the CCM and IAG on the basis of the official documents will ensure the metrological support of gravity measurements in the frame of important geodesy projects like the Global Geodetic Observation System (GGOS), the former Global Geodynamic Project (GGP) and others.

Support to development of the project of the global International System of Fundamental Absolute Gravity Stations

SC2.1 supports the development of a new international gravity reference system (currently with a preliminary name International System of Fundamental Absolute Gravity Stations - ISFAGS) which can be realized through organization in cooperation with relevant metrological bodies of comparisons of absolute gravimeters at the sites of future ISFAGS situated on all the continents and superposed with the system of the sites of GGP.

Support of the R&D of gravity measurement techniques

SC 2.1 supports the projects of the research and development of absolute gravimeters and gravity gradiometers. It encourages and promotes special absolute/relative gravity campaigns, techniques and procedures for the adjustment of the results of gravity surveys on a regional scale (see, for example, the reports of Vice-President of SC2.1 Hideo Hanada and of the member of SC2.1 Steering Committee Yoichi Fukuda).

The NMI "D.I. Mendeleyev Research Institute for Metrology" (Russian acronym VNIIM) reported to SC2.1 on the development of a new absolute ballistic gravimeter VNIIM-ABG-1.

Workshops, conferences, symposiums

The SC2.1 and its JWGs organize and participate in the meetings, workshops, symposiums and conferences.

In February 2012 JWG 2.1 and JWG 2.2 in cooperation with CCM WGG organized in Vienna the Discussion Meeting on Absolute Gravimetry dedicated to the analysis of some systematic effects in absolute gravimeters and results of international comparisons of absolute gravimeters (see details the report of JWG 2.1).

SC2.1 organized the Third IAG Commission 2 Symposium "Terrestrial Gravimetry. Static and Mobile Measurements - TGSMM-2013" in St Petersburg, Russian Federation (http://www.elektropribor.spb.ru/tgsmm2013/eindex). This symposium is organized for the third time with three-years interval and dedicated mainly to the techniques and methods of terrestrial gravity measurements. The TGSMM symposium helps to diminish the load on IAG Assemblies with the details of the measurement techniques in gravimetry and represents a forum for reporting and discussion in this field.
References:


Reports of members of the Steering Committee

**Gravimetry in Japan** *(Reported by Hideo Hanada)*

*Absolute gravimetry*

Tsubokawa et al developed a prototype of small sized absolute gravimeter using silent drop method which can reduce the rotation of a falling body and vibration induced from dropping mechanism. The accuracy is estimated to be about $8 \times 10^{-9} \text{m/s}^2$ (0.8 µGal) as a standard error from 601 drops. Kazama et al. compared the frequency of atomic clocks used in absolute gravimeters, and found that the frequency of the Rubidium clock in the A10 gravimeter (No. 1) shifts by about $+0.15$ Hz from 10 MHz. They pointed out the importance of correction of frequency difference. Sakai and Araya of the Earthquake Research Institute, University of Tokyo (ERI) are trying to miniaturize the absolute gravimeter of rise and fall method in order to apply it to observation in volcanic area. At present, combination of one absolute gravity station as a reference and many gravity stations surveyed by relative gravimeters are usually used in volcanic area and it takes longer time and is troublesome. The new absolute gravimeter which lifts a corner cube about 10 cm up and has the target accuracy of in the order of $1 \times 10^{-7} \text{m/s}^2$ (10 µGal), will overcome these difficulties.

*Relative gravimetry*

Murata of the National Institute of Advanced Industrial Science and Technology (AIST) checked the drift rate of a Scintrex CD Gravimeter (#270) in the period not used for gravity surveys, and found annual variation of the drift rate. Tokue et al. of Tokyo Institute of Technology (TITEC) proposed a 2D and 3D numerical model of a two-axes gimbal system for supporting of relative gravimeters, and made a prototype of the gimbal. The gimbal system can maintain the gravity meter horizontally and can attenuate a vibration caused by the body.

*Other kinds of gravimetry*

Fujimoto et al. of Tohoku University began to build a brand-new hybrid gravimetry system in 2010, which consists of a gravimeter and a gradiometer both for underwater gravimetry. The former aims at quantitative mapping of density anomalies below the seafloor, and the latter can be more sensitive in detection of density variations. The hybrid system can estimate the subterranean structure more accurately than a gravimeter alone. The gradiometer consists of a pair of high precision accelerometers that have been developed for an absolute gravimeter. Both of the sensors will be kept vertical with each gyro. The new underwater gravimeter of the hybrid system, on the other hand, was designed considering the results of the examination of the old one in the previous year. While the concept of design remains unchanged, a gravity sensor is kept vertical with forced gimbals by use of a gyro, the gravimeter has adopted a
newly developed dynamic gravity sensor, a high precision gyro, and a highly rigid mechanism for the gimbals in order to improve the precision.

**Gravity networks**

Geographic Survey Institute (GSI) is constructing new gravity standardization net, "Japan Gravity Standardization Net 2010 (JGSN2010)", to improve former one and contribute to research for the earth’s internal structure. Constructing it requires to conform JGSN2010 to a gravity reference system. In this presentation, we will report the proposal of Japan Gravity Reference System and the plan of future construction of JGSN2010. It consists of 29 stations measured by absolute gravimeters and 172 stations measured by relative gravimeters. Standard error of absolute stations will be less than 1x10^{-8} m/s^2 (1 µGal) and that of relative stations will be less than 1x10^{-7} m/s^2 (10 µGal). The website of JGSN2011 (in Japanese) is [http://www.gsi.go.jp/common/000071404.pdf#search='JGSN2011'](). Doi et al. of National Institute of Polar Research (NIPR) have started a project to implement absolute gravity measurements with GPS measurements at two areas, i.e. Syowa Station and Langhovde in East Antarctica in the framework of the 53rd Japanese Antarctic Research Expedition (JARE53). The objectives of the measurements are precise determination of gravity field of Antarctic region and estimation of crustal movements associated with Glacial Isostatic Adjustment (GIA). The absolute gravity measurements have already been made by A10 tentatively with standard deviation of 2.4 µGal.

**Gravity gradiometer**

Araya et al. of Earthquake Research Institute of University of Tokyo (ERI) are developing a gravity gradiometer for hybrid gravimetry system including a gravimeter and a gravity gradiometer. The gravity gradiometer comprises two vertically-separated accelerometers with astatic reference pendulums, and the gravity gradient can be obtained from the differential signal between them. Rotation of the instrument would be a major noise source and is controlled to keep it vertical installed on a gimbal. We operated the developed gradiometer at a quiet site on land and estimated its self-noise to be 6 E (6x10^{-9} s^{-2}) in the range from 2 to 50 mHz where gravity gradient signal is expected to be dominant when an autonomous underwater vehicle passes above a typical ore deposit. Shiomi et al. of Aso Volcanological Laboratory, Kyoto University are developing another kind of gravity gradiometer employing the free-fall interferometer similar to that developed for tests of the Weak Equivalence Principle. [1] Two test bodies are put in free fall and their differential displacements during the free fall are monitored by a laser interferometer. Unlike the tests of the Equivalence Principle, the centres of mass of the test bodies are separated along the vertical direction before free falls. This separation allows us to obtain the vertical difference in the gravitational fields. Because of the differential measurements, the obtained gravity gradients are, in principle, insensitive to the motion of the vehicles on which the measurements are carried out. The target sensitivity is a few microgals which is about two orders of magnitude better than the sensitivity of mechanical gravimeters which are typically used on aircraft and ships. This gravity gradiometer would allow us to carry out on-board measurements in inaccessible areas, with an unprecedented high sensitivity.

**References**

East Asia and Western Pacific Gravity Networks (Reported by Yoichi Fukuda)

Geospatial Information Authority of Japan (GSI) has organized local comparisons of absolute gravimeters in Japan annually since 2002. The comparisons have been taken place at a quiet site near Mt. Tsukuba. Each time about 4-5 FG5s from GSI, universities and other institutions including National Metrology Institute of Japan (NMIJ), which has regularly joined ICAGs, participated in the comparisons. The comparison results generally show good agreements and they ensure the reliability of the gravity values measured by the FG5s which participated in the comparisons.

The Japan Gravity Standardization Net 1975 (JGSN75) which was established in 1976 has been used as the reference of the Japanese gravity network until now. GSI has conducted a huge number of gravity measurements so far, and the accuracies of the data have been improved drastically. Using the newly obtained data including absolute gravity data, GSI is working to revise JGSN75 whose accuracy is 0.1mgal and establish a new gravity network with the accuracy of 0.01mgal. GSI has already finished to calculate the new gravity values at the reference gravity points (34 points) and the 1st order gravity points (80 points), however still needs time to complete the net adjustments of the 2nd order gravity points (about 14,000 points).

GSI has conducted the gravity measurements at the reference and the 1st order gravity points repeatedly and detected the gravity changes before and after the 2011 Tohoku-Oki earthquake. The obtained gravity changes were several tens micro gals and showed the tendency of gravity increases along the coastal areas and decreases at inland areas.

GSI and Earthquake Research Institute of the University of Tokyo have cooperatively conducted repeated absolute gravity measurements at Omaezaki FGS since 2000. The station is located in the area of the anticipated great Tokai earthquake, where the clear subsidence due to the plate motion is observed. Using the obtained gravity data so far, the estimated rate of the gravity increase is 0.0011mGal/yr.

Gravimetry in North America (Reported by Mark Eckl)

North American Comparison of Absolute Gravimetry (NACAG 2013)
See: http://www.ngs.noaa.gov/GRAV-D/Comparison/index.shtml

- The results of the first North-American Comparison of Absolute Gravimeters are published [1].
- Scheduled for the 1st and 2nd weeks of October 2013 at the NOAA Table Mountain Geophysical Observatory (TMGO), Longmont, Colorado.
- As with NACAG 2010 we expect representatives from NGA/NIST/NOAA/USGS (U.S.), GSD/NRCAN (Canada), NSF (operated by Micro-g), and gravimeters from Brazil and Germany- - A one day forum is scheduled to be held Monday, Oct. 14 during a break in the comparison.

AGRAV Database
See: (http://agrav.bkg.bund.de/agrav-meta/)

- AG operators have been tasked with loading any new U.S. absolute gravity observations into the AGRAV database of BKG-BGI.
- Past observations will be loaded as time allows.
Superconducting Gravity
- SG CT 024 has been returned to its observing pier at TMGO after a thorough inspection, repair, and upgrades by GWR Instruments
- SG 024 is installed and operating at TMGO on a backup compressor (the main compressor is in for repair).
- Sometime during the summer of 2013 SG CT 024 will be once again contributing to the Global Geodynamics Project (GGP) database (www.eas.slu.edu/GGP/ggphome).

Terrestrial Gravity Standards and Specifications
- As the lead for the geodetic theme for the FGDC NGS is working towards standards and specifications for gravity data submitted to the NGS Integrated Database (NGSIDB)
- NACAG 2013 will be an opportunity for the U.S. Federal agencies and Canadian representative to discuss common terrestrial gravity data needs

New Vertical Datum
- An expected adoption year of the new U.S. vertical datum is 2023
- The reference surface of this new datum will be a geopotential surface (geoid)
- The U.S. and Canada have agreed on a W₀ for the reference surface

Gravity for the Redefinition of the American Vertical Datum (GRAV-D)
See: http://www.ngs.noaa.gov/GRAV-D/
- We are currently in the possession of three of Micro-g LaCoste airborne gravity meters.
- Government/Contracted flights have covered nearly 25% of the U.S.
- Alaska, Great Lakes, and large sections of CONUS coast line has been surveyed.
- Currently working on the North-East coast line to support recovery efforts from Hurricane Sandy

Geoid Slope Validation Surveys (GSVS12 & GSVS14)
See: http://www.ngs.noaa.gov/GEOID/GSVS11/
- The GSVS surveys are designed to validate the short wave lengths of various geoid models.
- The surveys consist of airborne gravity, LIDAR, differential leveling, static GPS, deflection of the vertical (w/DIADEM¹), gravity gradients, relative gravity (L&R meters), and absolute gravity (FG-5 & A10).
- 200+ kilometres with marks set at one mile intervals (GSVS11 = Texas, GSVS14 = Iowa).
- The primary study was to look at the differences comparing geoid slopes determined by 1) various geoid models, 2) GPS/Leveling segment differences and, 3) the DIADEM DOV.
- GSVS11 was little to no separation between the ground surface and geoid while the GSVS14 will study the same issues with a large separation between surfaces.
- Papers and presentations have been given at various gatherings and published regarding GSVS11.
- GSVS14 mark setting is now in progress.

¹ DIADEM = The Digital Astronomical Deflection Measuring System http://www.ggl.baug.ethz.ch/people/buerki)
Abbreviations

CONUS = Continental U.S. (Lower 48 states)
GSD = Geodetic Survey Division of Canada
NGA = formally NIMA formally DMA = National Geospatial Intelligence Agency
NGS = National Geodetic Survey
NIST = National Institute of Standards and Technology
NRCan = National Resources Canada
NSF = National Science Foundation
USGS = U.S. Geological Survey

References


Shipboard Gravimetry
(Reported by Dag Solheim)

Golden opportunity (not to be missed)

The last years several dedicated national marine mapping projects have been initiated. Ideally marine gravity measurements should be an integrated part of these projects, whenever applicable, in order to maximise the return of the considerable investments involved in these projects. An example of such an activity is the Norwegian MAREANO-project (http://www.mareano.no/en). Gravity is unfortunately not an integrated part of this project, but gravimeters may be installed on the ships for free. Another example are Danish measurements along the coast of Greenland.

Considering the importance of such measurements in determining a high precision geoid both on land and sea, these projects represent an opportunity not to be missed if geodesy is to provide information on the ocean circulation on smaller scales than typically 100km provided by the ESA Satellite GOCE. Satellite altimetry in combination with an accurate and detailed geoid will eventually become an important and valuable new source of information for oceanography and climate research. To achieve this, improved knowledge about the geoid is necessary, something that can be accomplished by having access to detailed high quality marine gravity data sets.

Marine gravity data sets are also of huge value to geologists, geophysicists, oil companies in search of new oil and gas fields as well as for connecting height systems on a global scale. IAG should encourage gravity measurements to be a part such projects and if necessary provide guidelines and recommendations.

Processing of data.

There seems to be two slightly different schools on how to process marine gravity data. A fast and efficient method processing the data as a continuous stream of data and afterwards selecting the "good part" of the data based on criteria like the Eötvös correction, velocity and heading. Another approach is to divide the stream of data into straight line segments and process each segment separately.
The first method is generally very efficient but is highly dependent on the algorithm used to determine reliable data. The second method is normally much more laborious but the processing of each line segment may be fine-tuned in a way not possible by the first method. This can be very advantageous when alternating between sailing with and against the waves/wind in which case the need for filtering may vary a lot. The second method is also often accompanied by graphical visualization aids making it easier to identify erroneous data. Both methods may be further developed, increased quality for the first method and improved efficiency for the second.

**Marine gravity survey example**

The second method was used when processing the data from a joint Icelandic Norwegian survey between Iceland and the island Jan Mayen in the North Atlantic. As can be seen from the cross over statistics in table 1, excellent results were obtained. With $\sigma_T$, the standard deviation of each track and assuming that all tracks have the same standard deviation, then $\sigma_T$ is related to the standard deviation of the cross overs, $\sigma_X$, by $\sigma_T = \sigma_X / \sqrt{2}$.

**Table 1. Cross over statistics of the free air anomalies (units mGal)**

<table>
<thead>
<tr>
<th>#</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>RMS</th>
<th>$\sigma_X$</th>
<th>$\sigma_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before adjustment</td>
<td>186</td>
<td>0.21</td>
<td>-1.49</td>
<td>1.29</td>
<td>0.55</td>
<td>0.51</td>
</tr>
<tr>
<td>After adjustment</td>
<td>186</td>
<td>0.00</td>
<td>-0.58</td>
<td>0.78</td>
<td>0.20</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The post cross over statistics may be slightly misleading and too optimistic. A more realistic measure of the accuracy may be obtained by comparing the 2D filtered version of the data set with unfiltered one. The statistics of these comparisons are shown in table 2.

**Table 2. Inter comparison of filtered and unfiltered data set (units mGal)**

<table>
<thead>
<tr>
<th>#</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>RMS</th>
<th>$\sigma_X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18390</td>
<td>0.00</td>
<td>-5.30</td>
<td>2.07</td>
<td>0.33</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Even though cross over computations are very easy to perform, they are, for some strange reason, not always done when using the first method. Small cross over differences is a required condition for a high accuracy data set. Large cross overs are an indication of significant errors in the data set. Small cross overs do however not necessarily imply high quality data. Further investigations are needed to decide upon that.

**Importance for the geoid on land**

As mentioned above marine gravity data are of great importance for the geoid on land. This has been clearly demonstrated in the Sognefjorden area in Norway. Figure 1 shows the difference between the gravity field with and without the marine gravity data in the fjord. The effect on the geoid is presented in Figure 2.
Without marine gravity data and when not correcting for the bathymetry, the computed gravity value on the fjord, based on data on land only, is too high, as expected since the density of sea water is less than that of rocks. When the gravity field decreases the geoid also decreases in accordance with what is shown in figures 1 and 2.

If a detailed high precision geoid is to be determined in areas with deep fjords, either access to marine gravity data is needed or a proper handling of the bathymetry (missing mass) is necessary. Ideally access to both a detailed bathymetric model and marine gravity data would be preferable.
Sub-Commission 2.2:
Spatial and Temporal Gravity Field and Geoid Modelling

Chair: Yan Ming Wang (USA)

Introduction

This document presents a status report of the work undertaken by the sub-commission (SC) 2.2 since 2011 after the IUGG General Assembly in Melbourne, Australia.

Primary Objectives of Sub-Commission 2.2

The primary objective of this SC is to promote and support scientific research on the determination of the Earth’s gravity field which is essential for many scientific and operational applications. Some research topics are endorsed by this SC are as the following:

- Studies of the effect of topographic density variations on the Earth’s gravity field, including the geoid.
- Rigorous yet efficient calculation of the topographic effects, and refinement of the topographic and gravity reductions.
- Studies on harmonic upward and downward continuations.
- Non-linear effects of the geodetic boundary value problems on geoid determination.
- Optimal combination of global gravity models with local gravity data.
- Exploration of numerical methods in solving the geodetic boundary value problem (domain decomposition, finite elements, and others).
- Studies on data requirements, data quality, distribution and sampling rate, for a cm-accurate geoid.
- Studies on the interdisciplinary approach for marine geoid determination, e.g., research on realization of a global geoid consistent with the global mean sea surface observed by satellite altimetry.
- Studies on airborne, ship-borne gravimetry and the Antarctica gravity field.
- Studies on $W_0$ determination, and on global and regional vertical datum realization.
- Studies on ocean, solid-Earth and polar tides.
- Studies on time variation of the gravity field due to postglacial rebound and land subsidence.
- Studies on geocentre movement and time variation of $J_2$ and its impact on the geoid.
- Studies on sea level change and the vertical datum realization

Activities of the SC

The SC continues the long journey of gravity field determination. From the current satellite gravity missions GRACE and GOCE, the static and time varying gravity field have been determined to a very high accuracy and high spatial resolution. A few airborne gravity projects have been collecting gravity data near Earth’s surface which can be viewed as supplementary to satellite gravity missions. Research on geoid determination, national and global vertical datum establishment and improvement has drawn considerable devotion. The SC has proposed and participated in scientific meetings, summer schools, and seminars. Research results have been presented at various meetings and conferences such as the AOGS.
2012, Singapore; at the International Symposium on Gravity, Geoid and Height Systems 2012, Venice; and the AGU, CGU and EGU, as well as in scientific journals and proceedings.

**Future Activities**

The SC will work closely with the officers of commission 2 to promote the gravity filed determination through organizing meetings, conferences, seminars and summer schools. It encourages the establishment of special study groups on important contemporary research areas, e.g., the contribution of airborne gravimetry to the gravity field determination, and studies in theory and computation methods in data combination.

**Publications**


Hirt C (2012) Efficient and accurate high-degree spherical harmonic synthesis of gravity field functionals at the Earth’s surface using the gradient approach, J Geod 86:729–744


Hosse M, R Pail, T Romanyuk, M Horwath, N Köther(2012) Validation of ground gravity data in the Andes region with GOCE for the purpose of combined regional gravity field modeling, presented at GGHS 2012, Venice.


Saleh J, X Li, YM Wang, DR Roman and DA Smith (2013) Error analysis of the NGS’ surface gravity database, J Geod 87:203–221.


Sub-Commission 2.3: Dedicated Satellite Gravity Missions

Chair: Roland Pail (Germany)


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

- 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, satellite altimetry, etc.).
- investigation of alternative methods and new approaches for global gravity field modelling, with special emphasis on functional and stochastic models and optimum data combination.
- identification, investigation and definition of enabling technologies for future gravity field missions: observation types, technology, formation flights, etc.
- communication/interfacing with gravity field model user communities (climatology, oceanography/altimetry, glaciology, solid Earth physics, geodesy, ...).
- communication/interfacing with other IAG organizations, especially the GGOS Working Group for Satellite Missions and the GGOS Bureau for Standards and Conventions.

Static and temporal global gravity field models

Activities and results

Sub-commission members are deeply involved in the derivation of new releases of global gravity field models based on GRACE and GOCE mission data, applying updated background models, processing standards and improved processing strategies, e.g.: EIGEN-6S ([3]), AIUB-GRACE03S [7]. In addition to improved static gravity field models, also monthly, 10-days, weekly and even daily GRACE solutions (GFZ, CSR, JPL, CNES-GRGS, Univ. Bonn) have been derived. The GRACE Science Data System has reprocessed the complete GRACE mission data with improved instrument data, background models and processing standards, resulting in the release 05 of monthly and weekly models (e.g. GFZ Release 5; [2]). Compared to RL04, the current RL05 time-series shows improvements of about a factor of 2 in terms of noise reduction (i.e. less pronounced typical GRACE striping artefacts) and spatial resolution (cf. Fig. 1). 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., [2], [14]).

Several members of the SC 2.3 are also active participants in the ESA project GOCE High-Level Processing Facility (HPF), which is responsible for the generation of GOCE final orbit and gravity field products. 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, gradiometer, and star-tracker observations have been investigated. An alternative algorithm for the angular rate reconstruction in the frame of the gravity gradient processing has been developed ([12]) implemented in the official ESA Level 1b processor ([13]), and the complete mission data has been reprocessed, leading to a substantial improvement of the gravity field solutions ([9]). In the report period the Releases 3 and 4 of GOCE Gravity field models have been computed and...
released. Three different strategies are applied for gravity field processing ([8]): the direct approach (DIR), the time-wise approach (TIM), and the space-wise approach (SPW). While the DIR models ([1]) are satellite-only combination models, the TIM models ([10]) are based solely on GOCE data. The SPW approach has been redefined to provide gravity gradient grids mainly for geophysical users ([11]). These gravity field models have been externally validated applying different validation strategies ([5]). As an example, Fig. 2 shows the rms of geoid height differences between release 3 and 4 gravity field models and 675 GPS/levelling observations in Germany.

In addition to these GOCE models, also combinations with complementary satellite data from GRACE, CHAMP and SLR such as GOCO03S ([6]), and additionally terrestrial and satellite altimetry data such as EIGEN-6C2 ([4]) have been released with intense participation of members of the SC 2.3.

Selected References


Alternative methods and new approaches for global gravity field modelling

Activities and results

Sub-commission members have actively contributed to the development and investigation of alternative methods of global gravity field modelling and related problems, such as the optimum combination of different gravity data types, and stochastic modelling issues. As an example, an alternative approach for the combination of high-resolution and satellite-only global gravity models has been proposed ([15]). A complete overview compilation will be presented and discussed in the final report.

Selected references

Future gravity field missions

Activities and results

Members of SC 2.3 were deeply involved in national and international studies in the planning and design of future gravity field missions. On ESA level, during the reporting period 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 and meanwhile have been finalized ([16] and [19]). 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.

Further studies and mission proposals on national and international level have been worked out during the reporting period. Within the framework of the German Geotechnologien Programme further studies on future gravity field missions with a medium to long perspective have been carried out.

Members of this SC play a central role in the implementation of the next gravity field mission, i.e. the US-German project GRACE Follow-on (GRACE-FO), to be launched in 2017 ([17]). The primary objective of GRACE-FO is to continue the current GRACE gravity data series with a gap as short as possible. Therefore it is essentially a re-build of GRACE using the same microwave inter-satellite ranging system. In addition, as a secondary objective, it will carry an experimental Laser Ranging Interferometer (LRI) intended as technology demonstrator for future missions ([20]). The LRI will measure with about 20 times less measurement noise and provide in addition precise data about the orientation of each spacecraft with respect to the line of sight to the other spacecraft. That additional data will allow mutual comparisons and diagnostics between the microwave and laser systems. Preparations for the required new data analysis algorithms are already under way. The LRI is a joint development between NASA/JPL and a German team under the technical leadership of the AEI Hannover and general management by GFZ.

The 12 COSMIC-2 satellites will be equipped with a SLR retro-reflector for precise orbit determination and time-varying gravity study. The Phase I and II of COSMIC-2 satellites will be launched in 2016 and 2018, respectively. A joint Taiwan-UCAR team will work on the COSMIC-2 SLR data processing and applications.

Several scientific studies on specific challenges of future gravity field missions have been investigated, such as improved methods of de-aliasing by including covariance information of the background models ([20]) or the optimum orbit choice for aliasing reduction ([17]).

On an organizational and programmatic level, in a joint initiative of SC 2.3 and the GGOS Satellite Mission Working Group a letter by the IUGG President Harsh Gupta to ESA and NASA has been triggered, which expresses the strong need of the science community for a future gravity field mission, in accordance with the IUGG 2011 Resolution 2: „Gravity and magnetic field missions““. Additionally, as a joint initiative of IAG SC 2.3 and SC 2.6, GGOS SMWG and the IUGG, and supported by the space agencies, a workshop on the “Consolidation of Science Requirements” for a future double-pair mission is in preparation, which shall take place in the second half of 2014.
Several German members of the SC 2.3 are involved in a German preparatory study “NGGM-Germany” funded by the German Aerospace Center (DLR) in preparation of the upcoming call for ESA Earth Explorer 9.

Selected References


[21] Zenner L (2013) Atmospheric and oceanic mass variations and their role for gravity field determination; Dissertation, Faculty of Civil, Geo and Environmental Engineering, TU München

Communication / interfacing with user communities

Activities and results

The workshop discussed above, joint organized with the IUGG and its associations, will 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.

Online service access points for geoscientific data products, such as the Information System and Data Center (ISDC) portal maintained by the GFZ ([23]) show a steadily growing number of users from various user communities (climatology, oceanography, glaciology, geodesy, solid Earth physics, etc.).

The International Center for Global Earth Models (ICGEM; [22]) 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.

Selected References


Communication / interfacing with other IAG organizations

Activities and results

Close cooperation between the SC 2.3 and SC 2.6 exists with the joint preparation of a future gravity workshop on “Science Requirement Consolidation”. With this and other joint initiatives, close interactions exist also with the GGOS SMWG. Another strong interface has been built with GGOS Bureau for Standards and Conventions, where members of the SC2.3 play an active role, especially concerning the definition of consistent gravity standards ([24]).

Selected References

Sub-Commission 2.4: Regional Geoid Determination

Chair: Hussein Abd-Elmotaal (Egypt)

Webpage: http://www.minia.edu.eg/Geodesy/Comm2.4/

The main purpose of Sub-Commission 2.4 is to initiate and coordinate the activities of the regional gravity and geoid sub-commissions. These have been re-structured from the former regional geoid projects into SCs in 2011 in order to give them a more long-term character. Currently there are 6 of them:

- SC 2.4a: Gravity and Geoid in Europe (chair H. Denker)
- SC 2.4b: Gravity and Geoid in South America (chair M.C. Pacino)
- SC 2.4c: Gravity and Geoid in North and Central America (chair D. Avalos)
- SC 2.4d: Gravity and Geoid in Africa (chair H. Abd-Elmotaal)
- SC 2.4e: Gravity and Geoid in the Asia-Pacific (chair W. Featherstone)
- SC 2.4f: Gravity and Geoid in Antarctica (chair M. Scheinert)

The chair persons of these regional SCs form the steering committee of SC2.4.

These regional SC nominally cover the whole world with the exception of a larger region in the middle east (see figure 1). But it is clear that not all countries which are listed as a member of a regional SC, are actively participating in international projects or data exchange agreements. This is especially true for some countries in Central America, the Caribbean, Africa and Asia.

In comparison to the former regional geoid projects the covered areas have been extended in 2 cases:

a) Central America and the Caribbean are associated with the North American SC. But there is a very close collaboration as well with the South American SC in some countries.

b) The former regional geoid project of South Asia and Australia has been extended to all 48 member countries of PCGIAP (Permanent Committee for GIS Infrastructure for Asia and the Pacific). In the case of gravity field determination, the collaboration of these countries is not very strong.

Figure 1: Coverage of the regional sub-commissions
Short summary of the activities of the regional SCs

SC 2.4a (Europe) is planning to release a new computation of the European geoid/quasigeoid in 2015. Due to the already very good quality of the gravity data set, improvements by including GOCE data, are expected only in some limited areas. New terrestrial gravity data will be available for some countries (Germany, Bulgaria).

SC 2.4b (South America) is improving the gravity data coverage and the corresponding database in several countries by activities of many groups.

SC 2.4c (North and Central America) extended their activities into several countries of Central America and the Caribbean and good contacts have been established. Good contacts exist as well with the South American SC and several North American universities. The main goal is in definition of a common North American height datum and in some countries the education for setting up national gravity networks and the calculation of national/regional geoid models.

SC 2.4d (Africa) is trying to improve the collaboration between the countries and to collect the available terrestrial gravity data from different sources. Many tests are made with the newly available satellite data and with global and national DHMs. An IUGG project "Detailed Geoid Model for Africa" was initiated and accepted and is still going on.

SC 2.4e (Asia Pacific) was not very active until now. There were some contacts through the PCGIAP, which still have to be improved. It is very difficult to make contacts and, moreover, get data in this region. In this region, most activities still remain on the national level, where good results were presented in several countries.

SC 2.4f (Antarctica) is active in trying to densify the gravity data coverage mainly by airborne but also terrestrial campaigns. Other activities include getting access to already existing data. The publication of a gridded gravity data set and a geoid model is planned for the near future.

SC 2.4 was and will be very active in organising courses and related sessions at international conferences such as the GGHS2012 conference in Venice (2012) and the IAG Scientific Assembly in Potsdam 2013.

A Meeting of the steering committee of SC 2.4 will take place at the commission 2 meeting during IAG2013 in Potsdam.
Sub-Commission 2.4a: Gravity and Geoid in Europe

Chair: Heiner Denker (Germany)

Activities and future plans

The topic of regional geoid determination was handled from 2003 – 2011 within Commission 2 Projects, and since 2011 the responsibility for this task is with Sub-Commission 2.4, which is further sub-divided according to different regions of the world, such as Sub-Commission SC 2.4a “Gravity and Geoid in Europe”. The primary objective of SC 2.4a is the development of improved regional gravity field models (especially geoid/quasigeoid) for Europe which can be used for applications in geodesy, oceanography, geophysics and engineering, e.g., height determination with GNSS techniques, vertical datum definition and unification, dynamic ocean topography estimation, geophysical modelling, and navigation. SC 2.4a cooperates with national delegates from nearly all European countries, whereby existing contacts have been continued and extended.

The last complete re-computation of the European geoid/quasigeoid is EGG2008 (European Gravimetric Geoid 2008); the used theory and possible refinements as well as the detailed computation procedure are described in a monograph published by Denker (2013). Besides this, the work concentrated on the use of the GOCE global geopotential models, which were first evaluated by the existing terrestrial gravity field data sets, showing that the GOCE models improved from release to release with the inclusion of longer observation time series. The agreement between the release 3 GOCE models and terrestrial data up to degree and order 200 is about 5.5 cm for height anomalies, 1.7 mGal for gravity anomalies, and 0.55” for vertical deflections, respectively, being fully compatible with the relevant error estimates. So far, the combination solutions based on GOCE and terrestrial data mostly perform similar to corresponding calculations relying on EGM2008, which is due to the high quality of the European data sets utilized in the EGM2008 development; however, in selected areas with known weaknesses in the terrestrial gravity data (e.g., Bulgaria, Romania), the inclusion of the GOCE models instead of EGM2008 leads to some improvements in terms of GPS/leveling fits. Most of the GOCE investigations were carried out in the framework of the REAL GOCE project funded by the German Ministry of Education and Research (BMBF) and the German Research Foundation (DFG); for further details see Ihde et al. (2010) as well as Voigt and Denker (2011 and 2013).

Besides the global models, also selected terrestrial gravity data sets were upgraded and extended, e.g., in Germany and Bulgaria. For Bulgaria, work is not yet completed, but it appears that the existing mean gravity values can be replaced by much better point gravity values. A few other countries have also been approached regarding an update of the relevant gravity data.

Furthermore, the Leibniz Universität Hannover is involved in another interesting project, which is related to the new optical clocks with a projected performance at the level of 10-18; according to the laws of general relativity, such clocks are sensitive to the gravity potential equivalent to 1 cm in height. Hence, the optical clocks may offer in the near future completely new options to independently observe and verify geopotential differences over large distances; for further details on the entire project (International Timescales with Optical Clocks, ITOC) see Margolis et al. (2013a,b).
A SC 2.4a meeting is planned for the IAG Scientific Assembly 2013 in Potsdam, and a complete re-computation of the European geoid is foreseen until 2015, which should then utilize the latest terrestrial data sets as well as a corresponding global geopotential model based on GOCE and other satellite gravity field mission data.

References


Sub-Commission 2.4b: Gravity and Geoid in South America

Chairs: Maria Cristina Pacino (Argentina), Denizar Blitzkow (Brazil)

Introduction

This report intends to cover most of the activities in South America related to gravity field determination. It is not complete certainly due to the many activities going on by different organizations, universities and research institutes.

A big effort was carried out by many different organizations in the last few years to improve the gravity data coverage all over South America. As a result approximately 953,316 stations gravity data is available for geoid determination. Figure 1 shows the new and old gravity data. The new gravity observations have been carried out with LaCoste&Romberg and/or CG5 gravity meters. GPS double frequency receivers have been used to derive the geodetic coordinates of the stations. The orthometric height for the recent surveys was derived from geodetic height using EGM2008 restricted to degree and order 150.

Figure 1 – South America gravity data
Argentina

The last two years, 504 new gravity stations have been measured in Argentina (Figure 2).
Brazil

In the last two years, IBGE (CGED), Polytechnic School of the University of São Paulo, Laboratory of Surveying and Geodesy (EPUSP-LTG), SAGS project (GETECH/NGA) and the Thematic Project (FAPESP, Brazilian research foundation) a total of 11,941 new gravity stations have been measured (Figure 3).

Just Thematic Project surveyed a total of 8,521 points in recent surveys (details in Figure 4).
Ecuador

From 2009 up to 2012, gravimetric surveys in Ecuador obtained 235 new points (SAGS2011-2012) and another 308 points by IGM. SAGS gravity data were surveyed by IGM, IBGE and EPUSP in NAPO and AGUARICO rivers and in some trials.

A sophisticated logistics were established to support the surveys along the wild rivers. The gravity values of the densification surveys were connected to the existing FGN (Fundamental Gravity Network) in the country.
Paraguay

New gravity data in Paraguay surveyed 771 points located in the Chaco region (northwest part of the country), Concepcion and San Pedro provinces. Chaco is a remote region with difficult logistics.

Figure 6 – Gravity data in Paraguay
Earth tide model

A new project in Brazil under the coordination of the LTG is designed to establish an Earth tide model. This Project will be supported by GEORADAR Levantamentos Geofísicos S.A. and IGC (Instituto Geográfico e Cartográfico).

Two MicroG LaCoste (gPhone) and one A-10 (absolute) gravimeters are available. The first phase of the project is intended to determine a preliminary model for the Earth tide in São Paulo state. The project aims to establish 5 stations well distributed in Brazil, one of long term in Manaus, Amazon, and 4 others in a sequence of one year operation in different places (Figure 7).

![Figure 7 – g-Phone survey.](image)

A fundamental gravity network will be established in Brazil with A-10 absolute gravimeter as a reference for densification measurements. It will be used also for controlling de drift of the gPhone when necessary. In a first phase, stations will be established in São Paulo state (Figure 8) and in the second in Amazon region across the main rivers in cooperation with CPRM (Figure 9).

An agreement is under arrangement in order to undertake measurements in Argentina as cooperation between EPUSP and the University of Rosario.
Figure 8 – A-10 Absolute Network in São Paulo state.

Figure 9 – A-10 Absolute Gravity meter in Amazonia region.
Sub-Commission 2.4c: Gravity and Geoid in North and Central America

Chair: David Avalos (Mexico)

Steering Committee
David Avalos (Chair, INEGI, Mexico)
Rene Forsberg (DTU, Denmark)
Marc Véronneau (NRCan, Canada)
Dan Roman (NOAA, U.S.A.)
Laramie Potts (NJIT, U.S.A.)
Vinicio Robles (IGN, Guatemala)
Carlos E. Figueroa (IGN-CNR, El Salvador)
Anthony Watts (L&SD, Cayman Islands)
Oscar Meza (IP, Honduras)
Alvaro Alvarez (IGN, Costa Rica)

Activities

Collaboration continues expanding from the achievements reported on 2011 by the commission 2 project 2.2 on the North American geoid. Within the period 2011-2013, governmental geodetic sections and some universities expressed in different forums an interest in gravity field and geoid determination with two fundamental coincidences: further promote an open access to databases on terrestrial gravity, and the unification of vertical reference frames over the realization of a standard geopotential surface.

Regarding the impulse to inter-institutional relations, Canada and the U.S.A. were most actively represented by the NRCAN/GSD, the University of Calgary, University of Toronto and the NOAA/NGS. A coordinated work among them delivered a study on the geopotential value representative of the North American mean sea level as well as a formal agreement between GSD and NGS to make national geoid modeling correspond to the value Wo=62,636,856.0 m² s⁻², which was recommended as a standard by the study. PSMSL and ESA participated in this effort as partners from abroad.

From Central America and Caribbean countries, Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama and the Dominican Republic consolidated a communication network with the aim to exchange expertise on gravity field and geoid determination. The corresponding partner institutions in this group are: Instituto Nacional de Estadística y Geografía (Mexico), Instituto Geográfico Nacional (Guatemala), Centro Nacional de Registros (El Salvador), Instituto de la Propiedad (Honduras), Instituto Nacional de Estudios del Territorio (Nicaragua), Instituto Geográfico Nacional (Costa Rica), Instituto Geográfico Nacional Tommy Guardia (Panama) and Instituto Cartográfico Militar (Dominican Republic). The Pan-American Institute of Geography and History, together with Mexico’s representation, had the role of initial supporters on 2011. The results from this collaboration can be summarized in: a) sharing information about existing national geodetic control to integrate a document of public domain, b) exchange of capabilities in handling terrestrial gravity data, c) exchange of theoretical concepts for modern geoid modeling, d) establishment of a minimum structure for national gravity databases. The NGS and the Canadian University of New Brunswick have participated in this effort as consultants from abroad.

Regarding the current national geoid models in the region and their discrepancy, Canada and the U.S.A. achieved a mean difference of 0 cm with standard deviation of 4 cm, while
Mexico’s model differs by 18 cm in the mean and 18 in standard deviation. So far, none of the published models comply with the $W_0$ value mentioned above; however, Canada plans to deliver the first geoid model on such a geopotential value as an official vertical datum before the end of year 2013. Since May 2012, representatives from national geodetic agencies of Canada, USA and Mexico concurred in the convenience to adopt a scheme of producing geoid models with an explicit reference epoch and an associated model of geoidal height velocity. This in order to guarantee that the nearly 1 cm accuracy achieved can be preserved in time.

Meetings

International scientific forums have served as meeting points for the people interested in gravity field and geoid within North and Central America. These opportunities derived on impulse to plans for future collaboration in topics like a) the determination of gravity field from permafrost over Greenland and Canada, b) the unification of gravity databases in North and Central America, c) the promotion of open access to all national gravity holdings in the region, d) the promotion of a standard $W_0$ value for regional reference, and e) the analysis of pros and cons about merging the Sub-Commissions for North, Central and South America. This is a list of conferences where the main discussion has taken place:

- IUGG in Melbourne, Australia (2011),
- INEGI’s workshop in Aguascalientes, Mexico (2011),
- AGU in San Francisco, USA (2011),
- INEGI’s teleconference, Mexico (April 2012),
- CGU in Banff, Canada (2012),
- IAG Commission 2 (GGHS2012) in Venice, Italy (2012),
- INEGI’s teleconference, Mexico (November 2012),
- AGU in San Francisco, USA (2012),
- AGU Meeting of the Americas in Cancun, Mexico (2013),
- CGU in Saskatoon, Canada (2013).

The CGU meetings in 2012 and 2013 included the annual Canadian geoid workshop. In 2012, the participation came from Canada, USA, Mexico and European countries which attended the meeting to focus on results from GOCE for the Unification of the Height Systems. In 2013, the workshop focussed on the collection, processing and analysis of the GRAV-D data. The participants included only USA and Canada.

Following events during the next two years will likely continue to serve as the main opportunity to progress towards a better modeling of the entire region.

Main advances in gravity data collection.

Presently two major programs of field gravity data collection exist in the region: the NOAA/NGS’ GRAV-D project and the INEGI’s gravity network. The former continues delivering final results of gravity values from airborne gravimetry over areas with little coverage within the conterminous USA. With this effort, the gravity field determination improved significantly over large extensions in Alaska, Eastern and Southern US. Next, areas like Mexico-US border are targeted. In Mexico, the survey of terrestial gravimetry expands by about 5000 new observations, making a uniform coverage over 9 degree cells every year. The
NOA/NGS managed to set an open access to a large collection of marine gravimetry from different epochs.

Regarding the determination of a reference gravity field to link the work of target areas on a consistent surface, most parties in the region make a strong use of the GOCE models. These gravity field representations in spherical harmonics up to degree and order 180 are seen as basic tools to implement a regional datum unification.

**Contributions from research.**

Several universities continue to deliver useful results to understand the dynamic behaviour of the gravity field in North and Central America. Researchers from the University of Texas at Dallas, University of Calgary, York University, University of New Brunswick, and from national geodetic agencies like the NRCAN/GSD and NOAA/NGS released most of the methodological improvement to model the gravity field, the geoid and their time variations.

The GEOIDE network of centres of excellence’s project named “A geoid-based vertical reference frame for height modernization in North America”, produced a large series of results like new parameters and models linked to inter-institutional agreements. Within the numerous conclusions obtained, this is a representative sample: a) a $W_0$ value expressed as a recommendation to fit the mean sea level in North America, followed by a formal agreement between NGS and GSD to use it for national geoid modeling; b) threshold values to use the GOCE and GRACE models as reference to specific spectral resolution; c) magnitudes of the bias among official vertical datums; d) estimates of the effect in the geoid from long term variations in post glacial rebound, hydrology and ice load.

**Collaboration with other Sub-Commissions**

In communication, mainly by e-mail, this Sub-Commission has promoted the understanding with the chair and co-chair of Sub-Commission 2.4b Geoid and Gravity in South America. For now, the topics for discussion are focused in two points: a) the impulse to increase contacts and partners to increase the capability of Central American countries to start their own gravity surveys, and b) the terms to obtain permission from individual institutions to give open access to gravity databases in benefit of both regions. An activity to promote the contact between particular Central American agencies and North American institutions of known experience in collaborative surveying (i.e. NGS and NGA) is currently on its way to help assembling project proposals for target zones. During the following year it is expected to facilitate the direct communication between those Central Americans or Caribbeans that express a concrete interest (including Mexico) and those institutions with a possibility to act as partners.
Sub-Commission 2.4d: Gravity and Geoid in Africa

Chair: Hussein Abd-Elmotaal (Egypt)

Webpage: http://www.minia.edu.eg/Geodesy/AFRgeo/

Activities and future plans

A 2-year project "Detailed Geoid Model for Africa" in collaboration between IAG and IASPEI was accepted by IUGG. In this project, IUGG helps in the acquisition of gravity data for Africa needed for computing the geoid as well as in attending the geodetic international conferences to disseminate the project results. This will allow the determination of a precise geoid for Africa as well as it will foster cooperation between African geodesists and will help in providing high-level training in geoid computation to African geodesists. A separate detailed report of this project will go directly to IUGG.

There were several attempts to collect gravimetric point data for the African continent. Contacts were established with the BGI, NGA and GETECH. Until now, this was not very successful.

Abdalla et al. (2012) have tested the most recent GRACE/GOCE global geopotential models using GPS/levelling data (in Khartoum State) and gravity data of Sudan.

Abd-Elmotaal (2012) performed gravity interpolation within large gaps, which is the case of the gravity network in Africa, in order to obtain the best suited interpolation process for such cases.

Abd-Elmotaal and Ashry (2013) have established a 3" x 3" DHM for Egypt using SRTM 3" and other local and regional resources.

Abd-Elmotaal et al. (2013) have established a very detailed 1" x 1" DHM for Egypt using ASTER-GDEM 1", SRTM 3" and other local and regional resources.

Abd-Elmotaal and Kuehtreiber (2013) have investigated the effect of DHM resolution in computing the topographic-isostatic harmonic coefficients within the window technique in order to get the optimum resolution of computing the window topographic-isostatic coefficients.

Abd-Elmotaal and Makhloof (2013) have made a study regarding the gross-errors detection in the ship-borne data set for oceans surrounding Africa, which will be presented at the Geodetic Week & INTERGEO 2013, Essen, Germany, October 8-10, 2013.

Comparison of recent geopotential models for the recovery of the gravity field in Africa has been performed by Abd-Elmotaal and Makhloof (2013) and will be presented at the Geodetic Week & INTERGEO 2013, Essen, Germany, October 8-10, 2013.

Land gravity data has been collected, and a gross-error detection algorithm is being under process.

An African 3" x 3" DHM using SRTM 3" and SRTM30+ is under process.
A Tailored Reference Geopotential Model for Africa is being computed with the cooperation of Heck and his co-workers and will be presented at IAG2013 in Potsdam.

Establishment of the Gravity Database for the African Geoid, which is the core of the regional sub-commission for Africa and the most important and time consuming task, is taken place with the cooperation of Heck and his co-workers and Kuehtreiber and his co-workers. It is planned to present the output of this research at the EGU2014 in Vienna 2014.

The geoid computation for the African geoid model will then take place and will be presented at the IUGG XXVI General Assembly 2015.

A splinter meeting for the steering committee of the 2.4d regional sub-commission will take place during IAG2013 in Potsdam

Ben Ahmed Daho works on the investigation the possibility of improving the accuracy of the latest geoid model for Algeria using the new and revolutionary Global Gravitational Model EGM2008 and the satellite altimetry-derived marine gravity anomalies. For this purpose, a new gravimetric geoid model for Algeria has been computed using the land gravity data supplied by the BGI, EGM2008 to degree 2190 as the reference field, Digital Elevation Model derived from SRTM for topographic correction, and DNSC2008GRA altimetry-derived gravity anomalies offshore. According to our numerical results, the new geoid shows an improvement in precision and reliability, fitting the geoidal heights of these GPS/levelling points with more accuracy than the previous geoids. Its standard deviations fit with GPS/levelling data are 12.7cm and 2.5cm before and after fitting using the seven-parameter similarity transformation model.

Moreover, the analysis of the results shows that the signals in benchmarks are dominated by errors in the geoid due to the bad gravimetry, while the noise level indicates of the presence of errors in our vertical datum. The available and accuracy of the land gravity data remains insufficient to agree with GPS/Levelling at the sub-centimetre level. This new geoid model will be used to support Levelling by GPS at least for the low order levelling network densification.

Improvement the accuracy of the latest geoid model (Benahmed et al., 2009), especially in mountainous areas by considering the effect of lateral density variations. Numerical results show that the differences in the geoid height due to actual density model can reach up to 13 cm, which is not negligible in a precise geoid determination with centimetre accuracy. Our results suggest that the effect of topographical density lateral variations is significant enough and ought to be taken into account especially in mountainous regions in the determination of a precise geoid model for Algeria. However, basically because of the lack of GPS/levelling data in mountainous areas and the most of our GPS/levelling points used in this investigation are located in moderate heights areas, we could not see much improvement by evaluation of the corrected gravimetric geoid model versus GPS/levelling.

References


Sub-Commission 2.4e: Gravity and Geoid in the Asia-Pacific

Chair: Will Featherstone (Australia)

Summary of Problems

This group has not been as active as it should have. As was the case for its predecessor SCs, it is difficult to make contacts and, moreover, to get data exchange. Depending on one’s definition of Asia-Pacific, this SC could cover as many as 48 counties. These are diverse in terms of languages, politics, governments and wealth, which presents a significant challenge for the exchange of gravity and geoid data and expertise.

Future Activities (2013-2015)

• Determine list of countries and establish contacts.
• Audit data sources and determine their availability.
• Establish protocols for data sharing and/or exchange.
• Follow up on potential contacts through the Geodesy Working Group of the Permanent Committee for GIS Infrastructure in Asia and the Pacific (PCGIAP). This group comprises the main authorities that deal with geoids and height datums in the region and beyond.
• The chair is also member of a group recently convened by J. Kwon (South Korea) on height systems and vertical datums in the Asia-Pacific region (APRHSU: Asia-Pacific Regional Height System Unification), so that may generate more contacts.
• Establish other contacts in the Asia-Pacific region through FIG Commission 5, which has a strong interest in these matters from the viewpoint of operational geodesy.

Explore ways in which we may
(a) share available gravity data (e.g. via International Gravity Bureau)
(b) share available DEMs along common borders (National Geodetic Authorities)
(c) combine resources for terrestrial gravity surveys along common borders
(d) combine resources for airborne gravity surveys in the region.

Explore ways in which countries of the region may cooperate by
(a) sharing geometric (GNSS/levelling and vertical deflections) geoid control data
(b) combining efforts in global GNSS campaigns
(c) undertaking joint campaign for the connection of regional vertical datums.

Encourage and sponsor, for the region,
(a) meetings and workshops, e.g., with the International Geoid Service, to foster understanding of gravimetric quasi/geoids, and in their application to efficient height determination with GNSS.
(b) technical sessions in scientific and professional conferences
(c) research into matters of common concern/interest.
References (Australia and New Zealand only)


Featherstone WE, Filmer MS (2012) The north-south tilt in the Australian Height Datum is explained by the ocean’s mean dynamic topography, J Geophys. Res. – Oceans 117(C8), C08035, doi: 10.1029/2012JC007974.


Sub-Commission 2.4f: Gravity and Geoid in Antarctica

Chair: Mirko Scheinert (Germany)

Short Review

This group was adopted at the IAG General Assembly in Sapporo 2003. In 2011 it was transferred from a Commission Project to the Sub-Commission 2.4f. The Sub-Commission is dedicated to the determination of the gravity field in Antarctica. In terms of observations mainly airborne, but also terrestrial campaigns have been and are being carried out to complement and to densify satellite data. Because of the region and its special conditions the collaboration extends beyond the field of geodesy – the cooperation is truly interdisciplinary, especially incorporating experts from the fields of geophysics and glaciology. This is also reflected in the group membership (cf. below).

During the last period of (2011-2013) further progress has been made to include new data and to open access to already existing data. It is anticipated to finally deliver a suitable grid of terrestrial gravity data and of regional geoid solution(s). A respective publication is in progress. Presentations dedicated to this topic have been given at the IUGG General Assembly in Melbourne, 2011, at the XI International Symposium on Antarctic Earth Sciences (ISAES) in Edinburgh, 2011, or at the XXXII SCAR Meeting and Open Science Conference, Portland, 2012.

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. Of these IPY projects, for instance, gravity data from the project 67 “Origin, evolution and setting of the Gamburtsev sub-glacial highlands (AGAP)” could be incorporated.

Further data were released by the NASA project ICEBRIDGE (which mainly aims to close gaps between ICESAT and ICESAT-2 satellite missions), and by further national or multinational projects.

A close linkage is maintained to the Scientific Committee on Antarctic Research (SCAR), where the geodesy group (SCAR Standing Scientific Group on Geosciences (SSG-GS), Expert Group on Geospatial Information and Geodesy (GIANT Geodetic Infrastructure in Antarctica)) adopted a new program at the SCAR Meeting in Portland, Oregon, 2012. M. Scheinert co-chairs GIANT as well as chairs the GIANT project “Gravity Field”.

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 surveys, coordination is organized well in advance and on a broad international basis. Within AntGG, 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 finally to deliver a suitable grid of terrestrial gravity data.

With regard to new gravity surveys in Antarctica, aero-gravimetry provides the most powerful tool to survey larger areas. In this context, airborne gravimetry forms a core observation technique within an ensemble of aero-geophysical instrumentation. In continuation of the IPY several projects are in progress which include aero-gravimetry 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. In this respect, the chair of AntGG is acting as PI of a German project to utilize the German research aircraft HALO for an Antarctic airborne geodetic-geophysical survey (ANTHALO). In 2012 HALO could be successfully utilized for such a survey over Italy and adjacent seas demonstrating the feasibility of aero-gravimetry aboard HALO.

Selected conferences and workshops with participation of AntGG members

- 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;
- Workshop “Geodesy and Geophysics on flying platforms (with special attention to HALO)”, Potsdam (Germany), 08-09 November 2012;

Membership

(active members)

<table>
<thead>
<tr>
<th>Member</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirko Scheinert (chair)</td>
<td>TU Dresden, Germany</td>
</tr>
<tr>
<td>Don Blankenship</td>
<td>UTIG, USA</td>
</tr>
<tr>
<td>Alessandro Capra</td>
<td>Universita di Modena a Reggio Emilia, Italy</td>
</tr>
<tr>
<td>Detlef Damaske</td>
<td>BGR Hannover, Germany</td>
</tr>
<tr>
<td>Fausto Ferraccioli</td>
<td>British Antarctic Survey, UK</td>
</tr>
<tr>
<td>Christoph Förste</td>
<td>GFZ Potsdam, Germany</td>
</tr>
<tr>
<td>René Forsberg</td>
<td>DTU Space, Denmark</td>
</tr>
<tr>
<td>Larry Hothen</td>
<td>USGS, USA</td>
</tr>
<tr>
<td>Wilfried Jokat</td>
<td>AWI Bremerhaven, Germany</td>
</tr>
<tr>
<td>Gary Johnston</td>
<td>Geoscience Australia</td>
</tr>
<tr>
<td>Steve Kenyon</td>
<td>National Geospatial-Intelligence Agency, USA</td>
</tr>
<tr>
<td>German L. Leitchenkov</td>
<td>VNIIOkeangeologia, Russia</td>
</tr>
<tr>
<td>Jaakko Mäkinen</td>
<td>Finnish Geodetic Institute, Finland</td>
</tr>
<tr>
<td>Yves Rogister</td>
<td>Université Strasbourg, France</td>
</tr>
<tr>
<td>Kazuo Shibuya</td>
<td>NIPR, Japan</td>
</tr>
<tr>
<td>Michael Studinger</td>
<td>NASA Goddard SFC, USA</td>
</tr>
</tbody>
</table>
(corresponding members)

Matt Amos  LINZ, New Zealand

Selected publications and presentations with relevance to AntGG (2011 – 2013)


Muto, A., Anandakrishnan, S., and Alley, R. B. (2013), Subglacial bathymetry and sediment layer distribution beneath the Pine Island Glacier ice shelf, West Antarctica, modeled using aerogravity and autonomous underwater vehicle data, Annals of Glaciology, 54(64), 27-32, doi: 10.3189/2013AoG64A110


Sub-Commission 2.5: Satellite Altimetry

Chair: Xiaoli Deng (Australia)

Satellite Altimetry: Towards 1 mGal Global Marine Gravity Field and Extreme Sea Level Studies

Report by: Xiaoli Deng, Ole B Andersen, Cheinway Hwang, David Sandwell, Walter H.F. Smith and CK Shum

Over the past two years, we have developed new retrackers and experimented with several retrackers to improve altimeter range measurement accuracies globally and over shallow waters around Taiwan, Australia and the Arctic Ocean, as part of our contribution to IAG sub-commission 2.5. With newly available non-repeat altimeter data and recent progress in improvement of altimeter range precision, we have also made significant contributions towards the high-accuracy and high-resolution marine gravity field.

Improvement in Waveform Retracking and Studies of Extreme Sea Level

Waveform retracking is an important means that improves the retrieval of sea surface height (SSH) from altimetric range measurements. Idris and Deng (2012a and 2012b) focus on the coastal area where the existing MLE4 retracker usually fails. A sub-waveform retracker has been developed, which fits the Brown (1977) model to the truncated waveform samples that correspond to the returns reflected from the water surface. It has been used to improve altimeter-derived SSHs from Jason-1 and Jason-2 in the Great Barrier Reef, Australia. The study finds that the sub-waveform retracker when combining with other retrackers (i.e., MLE4) can retrieve SSHs closer to the coastline (Figure 1).

To measure marine gravity anomalies at accuracy under 1 mGal, the error in the along-track slopes from the altimeter profiles must be about 1 μrad, or there tracks to achieve the 1 Jason-1 geodetic mission (GM) waveforms towards this goal. A simple, but approximate,
analytic model has been derived for the shape of the CryoSat-2 SAR waveform that can be used in an iterative least-squares algorithm for estimating range. For the conventional waveforms, the two-pass retracking procedure has resulted in a factor of ~1.5 improvement in range precision (Table 1). This method was originally developed specifically for ERS-1 data with three and two parameters at the first and second retracking steps, respectively (Sandwell and Smith, 2005). The improved range precision and dense coverage from CryoSat-2, Envisat and Jason-1 GM should lead to a significant increase in the accuracy of the marine gravity field.

Table 1: 20 Hz altimeter noise (in mm) with significant wave heights of 2 m and 6 m*

<table>
<thead>
<tr>
<th>Altimeter</th>
<th>3-PAR @ 2 m</th>
<th>2-PAR @ 2 m</th>
<th>3-PAR/2-PAR</th>
<th>2 PAR @ 6 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geosat</td>
<td>88.0</td>
<td>57.0</td>
<td>1.54</td>
<td>105.4</td>
</tr>
<tr>
<td>ERS-1</td>
<td>93.6</td>
<td>61.8</td>
<td>1.51</td>
<td>111.8</td>
</tr>
<tr>
<td>Envisat</td>
<td>78.9</td>
<td>51.8</td>
<td>1.52</td>
<td>88.6</td>
</tr>
<tr>
<td>Jason-1</td>
<td>75.9</td>
<td>46.4</td>
<td>1.63</td>
<td>64.2</td>
</tr>
<tr>
<td>CryoSat-2 LRM</td>
<td>64.7</td>
<td>42.7</td>
<td>1.51</td>
<td>71.7</td>
</tr>
<tr>
<td>CryoSat-2 SAR</td>
<td>49.5</td>
<td>49.7</td>
<td>.996</td>
<td>110.9</td>
</tr>
<tr>
<td>CryoSat-2 SARIN</td>
<td>138.5</td>
<td>138.7</td>
<td>.998</td>
<td>148.6</td>
</tr>
</tbody>
</table>

*Standard deviation of retracked 20 Hz height estimates with respect to EGM2008 (mean removed). The data are from a region of the North Atlantic with relatively high sea state. The values represent the median of thousands of estimates over a 0.4 m range of SWH. The 10 Hz Geosat estimates were scaled by 1.41 to approximate the errors at the 20 Hz sampling rate. Note in all cases except for the CryoSat-2 SAR and SARIN modes, the 3-PAR to 2-PAR noise ratio is close to the 1.57 value derived from a least-squares simulation (Garcia et al., 2013)

Tide gauge and satellite altimetry has vastly different spatial and temporal sampling. However the data can be integrated to take advantage of the high temporal sampling of the tide gauges with the high spatial sampling of the satellite. Our investigation demonstrates the importance of optimal tide modeling using the response method as well as careful use of the dynamic atmosphere correction delivered by the MOG2D model (Cheng and Andersen, 2012; Andersen and Scharroo, 2011). Data from TOPEX/Poseidon and Jason1/2 altimetry missions and tide gauges recorders over the past 20 years around both European and Australia coasts general exhibit temporal correlation of more than 90% for nearly all tide gauge stations. These data are combined using a multivariate regression method, which have been used to investigate both high frequency signals (e.g., surges) and annual to decadal sea level signal (Deng et al., 2011, Andersen and Cheng, 2013). The results suggest the existence of ability to capture surge (and cyclones) and sea level along the Northwest European and Australian coastlines (Cheng and Andersen, 2012; Deng et al., 2012a and 2012b). The results of this study open the way for further research into monitoring of extreme sea level events.

Our retracking techniques are also applied to altimeter data over areas with potential land subsidence for hazard mitigation (e.g., Lee et al., 2013; Gommenginger et al., 2011). Height changes over ice-covered areas, particularly in Tibet, high mountains of Central Asia and permafrost areas of Siberia, are improved by retracking.
Improvement in Global Marine Gravity Field from Altimetric Geodetic Missions

Gravity field accuracy depends on four factors: spatial track density; altimeter range precision; diverse track orientation; and the accuracy of the coastal tide models (Sandwell et al., 2013). Efforts to exploit the altimetric-derived marine gravity field started soon after the advent of the modern altimeter era in the 1990s, with data from early Geosat and ERS-1 GMs. Recently three new non-repeat altimeter data sets have become available that have a significant impact on marine gravity recovery. These are (1) the CryoSat-2 that provides three measurement modes from a 369-day repeat orbit and has an average ground track spacing of 3.5 km at the equator; (2) the Envisat that was placed in a new partially drifting-phase repeat orbit (~30 days) and collected 1.5 years of data with dense coverage in high latitudes by April 2012; and (3) the Jason-1 GM of a 406-day orbit that results in an average ground spacing of 3.9 km at the equator. These new altimeter data sets have been exploited for high-resolution and high-accuracy mapping of marine gravity field globally, as well as in the Arctic Ocean (e.g., Stenseng and Andersen, 2011; Andersen, 2011; Andersen and Sandwell, 2012; Sandwell et al., 2013).

Stenseng and Andersen (2012) investigate three months, September to November 2010, of CryoSat-2 data from SAR L1b, LRM L1b and LRM L2 over the Baffin Bay (Figure 2). The L1b data has been retracked with three different retrackers and compared with an independent marine gravity dataset. From their first investigation it has found very promising results in the comparison with the mean sea surface for both LRM and SAR data, indicating that significant improvements in high-latitude marine gravity field can be achieved. The inclusion of three months of CryoSat-2 data also improves the local gravity field compared with the ERS-1 derived benchmark gravity field.

Figure 2: CryoSat-2 SAR (red), LRM (blue), and marine gravity (green) tracks in the Baffin Bay (Stenseng and Andersen, 2012).
Stenseng and Andersen (2012) also find that sea-ice and sea-ice debris are presented in the November SAR data, which increases the error on the residual geoid used for the gravity field calculation. A future editing scheme is planned to reject sea-ice contaminated data using SSMIS or equivalent data to avoid degradation of the derived sea surface and thereby the derived gravity field.

The National Chiao Tung University team, Taiwan, leaded by Hwang retracked waveforms from Geosat GM, ERS-1 GM, repeat Geosat/ERM, ERS-1/35d, ERS-2/35d and TOPEX/Poseidon. The results (Table 2) show that the sub-waveform threshold retracker (Yang et al. 2011) with a 20% of threshold value is the optimal retracker around the waters off Taiwan. Then, the inverse Vening Meinesz formula was used to compute gravity anomalies from along-track residual SSH slopes in a remove-compute-restore procedure with EGM2008 to degree 2190 as the reference field. Table 3 compares altimeter-derived gravity grids from Hwang’s group (NCTU), Sandwell V18.1 and DTU10GRAV with ship-borne gravity around Taiwan (presented in EGU 2012). All models perform quite similarly, but The NCTU gravity performs slightly better than other models.

<table>
<thead>
<tr>
<th>Data</th>
<th>Beta-5</th>
<th>Thresholda</th>
<th>sub-waveform threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Geosat/GM</td>
<td>0.0812</td>
<td>0.0742</td>
<td>0.0647</td>
</tr>
<tr>
<td>ERS-1/GM</td>
<td>0.0805</td>
<td>0.0975</td>
<td>0.0523</td>
</tr>
</tbody>
</table>

a full waveform and the threshold value equal to 0.5 are used

Sandwell et al. (2013) present a new global marine gravity field V21 based on all the available altimeter data. This includes the older Geosat GM and ERS-1 GM data that were used to construct the V18 global marine gravity widely used in the industry today (Sandwell and Smith, 2009), as well as newer Envisat, CryoSat-2 (until December 2012) and Jason-1 GM (until January 2013) data. The accuracy of the V21 gravity model is assessed through comparisons with industry-quality gravity data as well as lower quality data from the research cruises available at the National Geophysical Data Centre (NGDC). Through these comparisons it has demonstrated that the current accuracy is better than 1.6 mGal for latitudes less than 72 degrees and somewhat lower accuracy (2–3 mGal) at higher latitudes depending on ice cover. Finally based on this current analysis, the accuracy of altimeter-derived marine gravity in the year 2015, assuming Jason-1 and CryoSat-2 remain in operation, can be expected better than 1.4 mGal accuracy that is attainable in areas such as the Gulf of Mexico (Figure 3).
Figure 3: Jackknife estimate of the accuracy of the east (blue) and north (green) components of the marine gravity derived from satellite altimetry. Red boxes show the Gulf of Mexico and Canadian Arctic validations. Green box shows the precision of the EDCON gravity data. Marine gravity profiles collected by the academic fleet typically have gravity precision of 2.75 mGal. Our accuracy objective is 1 mGal. At latitudes less than 60° the north component of gravity is better determined than the east component because altimeter track-lines are preferentially oriented in the N-S direction. The availability of Jason-1 with its more E-W track orientation will continue to improve the accuracy of the gravity field, especially the east component. The steps in gravity accuracy at latitudes of 66°, 72°, and 81.5° reflect the sharp changes in track density associated with the maximum latitudes of the Jason-1, Geosat, and ERS-1/Envisat satellites, respectively (Sandwell et al., 2013).

Table 3: Statistics of differences (in mGal) between altimeter-derived and ship-borne gravity around Taiwan

<table>
<thead>
<tr>
<th>Alt gravity</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCTU12^a</td>
<td>83.771</td>
<td>-96.251</td>
<td>0.094</td>
<td>7.603</td>
</tr>
<tr>
<td>Sandwell V18.1</td>
<td>88.308</td>
<td>-110.160</td>
<td>0.263</td>
<td>7.745</td>
</tr>
<tr>
<td>DTU10</td>
<td>88.369</td>
<td>-100.649</td>
<td>0.385</td>
<td>7.624</td>
</tr>
</tbody>
</table>

^a Altimeter-derived gravity from the National Chiao Tung University team

Future Contributions

Before the next IUGG meeting (2015), we will continue to improve the retracking technique. Based on expected future data acquisitions, such as those from the Jason-1/GM and CryoSat-2 missions, and improved processing in the global geo-potential gravity field, we expect the accuracy of the marine gravity field to be better than 1.4 mGal.

Some Publications


Sub-Commission 2.6: Gravity and Mass Displacements

Chair: Shuanggen Jin (China)

Website: http://202.127.29.4/geodesy/IAG_SC2.6/

Steering Committee

Chair: Shuanggen Jin (China)
Co-Chair: Jürgen Kusche (Germany)
Carla Braitenberg (Italy)
Annette Eicker (Germany)
Isabelle Panet (France)
Bert Wouters (UK/USA) (since 2013)
Séverine Rosat (France)

Activities

The Sub-commission established Work Groups and Study Groups on relevant topics. It models and inverses gravity-Earth System coupling, structure and dynamics of the Earth’s interior and their interactions. A Steering Committee works closely with members and other IAG Commissions/Sub-Commissions to obtain the mutual goals. Also it promotes and jointly sponsors special sessions at IAG Symposia and other workshops/conferences.

Established Working Groups by SC 2.6

JWG 2.5: Physics and dynamics of the Earth's interior from gravimetry (joint with Comm. 3); Chair: Isabelle Panet (France)
JWG 2.6: Ice melting & ocean circulation from gravimetry (joint with Comm. 3); Chair until 2013: Jens Schröter (Germany); Chair since 2013: Bert Wouters (UK/USA)
JWG 2.7: Land hydrology from gravimetry (joint with Comm. 3) Chair: Annette Eicker (Germany)
JWG 2.8: Modeling and Inversion of Gravity-Solid Earth Coupling (joint with Comm. 3); Chair: Carla Braitenberg (Italy)

Established Study Groups by SC 2.6

JSG 0.8: Earth System Interaction from Space Geodesy (joint with the ICCT, description see ICCT); Chair: Shuanggen Jin (China)
JSG 3.1: Gravity and height change intercomparison (joint with IGFS, Comm. 1, Comm. 3, description see Commission 3); Chair: S. Rosat (France)

Special Issue of Journal of Geodynamics

SC 2.6 organized a Special Issue of the Journal of Geodynamics on “Earth System Observing and Modelling from Space Geodesy”. This special issue focuses on assessing current technological capabilities and presenting recent results of space geodetic observations and understanding the physical processes and coupling in the Earth system, and future impacts on climate. Topics include data retrieval of space geodetic techniques, reference frame, atmospheric-ionospheric sounding and disturbance, gravity field, crustal deformation and earth-
quake geodesy, GIA, Earth rotation, hydrological cycle, ocean circulation, sea level change, and ice sheet mass balance as well as their coupling in the Earth system. This special issue consists not only of papers given at the International Symposium on Space Geodesy and Earth System (2012, Shanghai) but also includes other contributions on this topic that were submitted in response to an open call for contributions. All related papers are welcome to submit to Special issue of Journal of Geodynamics on “Earth System Observing and Modelling from Space Geodesy” via http://ees.elsevier.com/geod. To ensure that all manuscripts are correctly identified for inclusion into the special issue, authors must select "SI: Geodetic Earth System" when they reach the "Article Type" step in the submission process. Guest editors: Prof. Shuanggen Jin, Shanghai Astronomical Observatory, CAS, Shanghai, China; A/Prof. Tonie van Dam, University of Luxembourg, Luxembourg; Dr. Shimon Wdowinski, University of Miami, Miami, USA.

Academic Activities

1-4 July 2013, Shuanggen Jin organized the International Symposium on Planetary Sciences (IAPS2013) as Co-Chair of the Symposium, Shanghai, China.

5-7 July 2013, Shuanggen Jin organized International Summer School on Planetary Geodesy and Remote Sensing and gave a half-day lecture on Planetary Geodesy and Science, Shanghai, China.

12 December 2012, Shuanggen Jin, Per Knudsen and Ole Andersen co-organized SHAO-DTU Workshop on Space Geodesy and discussed future possible collaboration, Shanghai, China.

18-21 August 2012, Shuanggen Jin organized International Symposium on Space Geodesy and Earth System (SGES2012) as Chair of Symposium, Shanghai, China.

21-25 August 2012, Shuanggen Jin organized International Summer School on Space Geodesy and Earth System and gave a half-day lecture on GNSS and Gravity Geodesy, Shanghai, China.

13-17 August 2012, Shuanggen Jin attended the AOGS-AGU (WPGM) Joint Assembly with convening two sessions and giving one talk, Singapore.

08-16 August 2011, Shuanggen Jin Convene one Session at Asia Oceania Geosciences Society (AOGS 2011) with one talk, Taiwan.

10-18 November 2011, Shuanggen Jin was invited to visit and give several talks at Taiwan National Chiao Tung University, National Cheng Kung University, National Central University and Institute of Earth Sciences, Academia Sinica, Taiwan.

Publications


**Conference Presentations**

Jin, S.G., and F. Zou, Recent melting of Greenland's glaciers observed by InSAR and satellite gravimetry, Proceeding of Progress In Electromagnetics Research Symposium (PIERS), 12-15 August, 2013, Stockholm, Sweden.

Feng, G., S.G. Jin, and F. Zou, Melting of ice-sheet in the Tien-Shan Mountains observed by satellite gravity measurements, International Conference on Geoinformatics, June 20-22, 2013, Kaifeng, China.

Jin, S.G., Y. Barkin, and W. Shen, Observation evidences on the northward drift of the Earth’s core from space geodesy, Japan Geoscience Union Meeting, May 19-24, 2013, Makuhari Messe, Japan.


Jin, S.G., and G.P. Feng, Glacier melting in Tibet observed from satellite gravity measurement, International Conference on Cryosphere: Changes, Impacts and Adaptation, November 10-12, 2012, Sanya, China.

Jin, S.G., Observing and understanding the Earth system from space, Redbud Forum on Global Change Science, Tsinghua University, November 1, 2012, Beijing, China.


Jin, S.G., What can Space Geodesy do? Recent Results and Challenges, Forum on Geomatics Science and technology, 12-14 October 2012, Lanzhou, China.


Jin, S.G., The Art of Space Geodesy: Recent Results and Challenge, Seminar at the Deutsches Geodätisches Forschungsinstitut (DGFI), 27 July 2012, Munich, Germany.


Joint Project 2.1: Geodetic Planetology

*Chairs: Oliver Baur (Austria), Shin-Chan Han (USA)*

Activities and results until now

Meetings

Conference sessions on geodetic planetology (co-)organized by the joint project are summarized in Table 1. In preparation for GGHS, we (the project chairs) put considerable effort to motivate both the project members and other scientists for session contributions. The GGHS session 'reanimated' geodetic planetology within IAG conferences. The IAPS is mainly organized by Shuanggen Jin.

Table 1: Conference sessions dedicated to geodetic planetology and (co-)organized by the project chairs

<table>
<thead>
<tr>
<th>Conference</th>
<th>Session</th>
<th># presentations oral/poster</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Symposium on Gravity, Geoid and Height Systems (GGHS), Venice, Italy</td>
<td>Gravity Field of Planetary Bodies</td>
<td>4 / 1</td>
</tr>
<tr>
<td>International Symposium on Planetary Sciences (IAPS), Shanghai, China</td>
<td>Science and Exploration of the Moon</td>
<td>12 / 1</td>
</tr>
</tbody>
</table>

Publications

Peer-reviewed proceedings papers by project members include

Visser P.N.A.M. (2013) Observing the gravity field of different planets and moons by space-borne techniques: predictions by fast error propagation tools, IAG Symp. 141, accepted

Maier A., Baur O. (2013) Sensitivity of simulated LRO tracking data to the lunar gravity field, IAG Symp. 141, accepted

Peer-reviewed journal papers by project members include


Results

The GRAIL (Gravity Recovery And Interior Laboratory) mission can be considered as the present 'highlight' in geodetic planetology. The science data allows estimating the lunar gravity field (Fig. 1) with highly improved accuracy and resolution compared to previous missions. Knowledge about the gravity field will upgrade our understanding of the interior structure and thermal evolution of the Moon. The global gravity field model from the primary mission yielded nearly unity correlation with topography to degree and order 300 and indicated considerably smaller density of the crust such as 2550 kg/m$^3$ with lateral variation of 250 kg/m$^3$. Since June 12, 2013, the primary and extended mission L1B data are publicly available.

Figure 1: Lunar free-air anomalies from GRAIL (up to spherical harmonic degree and order 200) based on data collected during the primary mission phase; figure taken from Klinger B., Baur O., Mayer-Gürr T., Yan J. (2013) Lunar gravity field recovery: GRAIL simulations and real data analysis, EGU General Assembly, Vienna, Austria, 7.-12.04.2013

Activities in the next two years

During the first two years of the joint project it turned out that enormous effort is required to motivate scientists to actively support and contribute to the project. Although several attempts have been undertaken to cooperate with scientists from GSFC/JPL (for instance, invitation to conference talks), the enquiries were not fruitful. As such, unfortunately, we made similar experience as made during the establishment of the project (list of members).

For the time being it remains unclear how the joint project should be continued. According to the ToR, we initially planned to organize a workshop with interdisciplinary emphasis. Against the background of the experience made during the last two years, we decided to abandon this intent. Moreover, the objective to "establish an Inter-Commission Committee on Geodetic Planetology for the period 2015-2019" (ToR) is likely to be revised.
Joint Working Group 2.1:
Techniques and Metrology in Absolute Gravimetry

Chair: Vojtech Palinkas (Czech Republic)

Primary Objectives

The IAG Joint Working Group 2.1 (JWG 2.1) focuses on the technical and metrological aspects in absolute gravimetry and the realization an appropriate system of comparisons of absolute gravimeters to fulfil requirements especially in geodesy. JWG 2.1 works in cooperation with the “Joint Working Group 2.2: Absolute Gravimetry and Absolute Gravity Reference System” (JWG 2.2) and the “Working Group on Gravimetry of Consultative Committee for Mass and Related Quantities of International Committee of Weights and Measures” (CCM-WGG).

Main Activities (2011-2013)

This section presents the intermediate report of the JWG 2.1 activities since its creation in 2011. During the period 2011-2013 the JWG 2.1 established its terms of reference, held one official meeting and contributed on realization of comparisons of absolute gravimeters.

Meeting in Vienna 2012

The discussion Meeting on Absolute Gravimetry, organized as a joint meeting of JWG 2.1 and JWG 2.2, was held in Vienna in February 2012. The meeting covered the following major topics related to the work of JWG 2.1:

- Treatment of systematic effects in absolute gravity determination: The scientific results of three systematic effects (self-attraction, diffraction, and finite speed of light) were presented by several authors related to papers of Biolcatti et al. (2012), Palinkas et. al. (2012), Rothleitner and Svitlov (2012), Rothleitner and Francis (2011), Nagornyi et al. (2011). Important results of this meeting are recommendations concerning implementations of corrections to absolute measurements, which were consequently followed by processing of comparisons in 2009 (Jiang et al. 2012) and 2011 (Francis et al. 2013).

- Determination of reference instrumental height. Unclearness connected with the position where the gravity is determined as invariant of the vertical gravity gradient, causes several troubles with practical determination and application of measured gravity acceleration. The concept of the effective position of the free-fall was reintroduced at the meeting. Two publications (Rothleitner and Svitlov 2012, Palinkas et. al. 2012) are related to this topic.

- International and Regional Comparisons of absolute gravimeters (ICAG and RCAG). (a) The final results of ICAG-2009 were presented and discussed. The paper Jiang et al. (2012) were consequently prepared and published. (b) Preliminary results of European comparison held in Walferdange (ECAG-2011) were presented. The final results were recently published in Francis et al. (2013). (c) The Technical Protocol goes through continuous developments with each new regional and international comparison. (d) The function of the “comparison site requirements” document was discussed. The text was distributed to the members of JWG 2.1 and CCM-WGG. The final document was consequently prepared, named “Guide to evaluation of the sites for comparison of absolute gravimeters”, and approved by CCM-WGG. (e) The working groups JWG 2.1 and JWG 2.2 agreed with the present periodicity of comparisons, four-yearly ICAGs with intermediate RCAGs two years after the ICAG.
• **Reference gravity stations.** The capability of the reference stations with a superconducting gravimeter for an AG offset check was demonstrated. The reference stations should play a key role for validation of absolute gravimeters used in geodesy.

**Comparisons of absolute gravimeters**

In November 2011, the third European Comparison of Absolute Gravimeters (ECAG) was held in Walferdange. It was organized by the University of Luxembourg (O. Francis) and METAS (H. Baumann) as metrological Key Comparison EURAMET.M.G-K1. Twenty-two absolute gravimeters participated of which results were processed in two groups: 1) comparison of six teams coming from National Metrology Institutes (NMIs) and Designated Institutes (DIs), 2) common adjustment of all the gravimeters. Excellent results (as in previous comparisons in Walferdange and Sevres) were obtained for the second group with reference gravity values at standard uncertainty of $1.5\,\mu\text{Gal}$ (Francis et al. 2013). For the first time the influence of the geophysical gravity changes during the comparison has been implemented to the results of comparison.

**Cooperation with CCM-WGG**

Nine members of JWG 2.1 are also members of CCM-WGG of the BIPM. Both groups have several common goals, especially those connected with comparisons of absolute gravimeters. Activities as organization of comparisons, discussion concerning methodology of data processing etc. have been arranged in the period 2011-2013 within CCM-WGG meetings (Istanbul 2012, Paris 2013), because the comparisons have official metrological status at present.

**Future Activities (2013-2015)**

The future activities significantly depend on the final version of the strategic document “CCM-IAG strategy for gravimetry” of which draft was prepared by CCM President and commented by CCM-WGG members. It was proposed by chairmen of JWG 2.2 to include members of JWG 2.1 and 2.2 into the discussion. The draft of strategy, supported by CCM-President and the minority of CCM-WGG members, is aiming to establish a typical traceability path in gravimetry. This effort is needed for practical applications in gravimetry but it might have significant consequences to the geodetic community. The strategy is aiming to organize comparison only for NMIs and DIs. It is expected that the majority of gravimeters from geodesy community will calibrate their instruments against the national standards. This idea is generally not wrong and works in many fields of our life. However, NMIs and DIs currently do not have more accurate gravimeters or more sophisticated operators as it can be seen from results of comparisons in the past. Thus the future organization of metrological support of absolute gravimetry should be carefully discussed by both metrology and geodesy communities and the agreement should be reached on the ways on how to reach the confidence in gravity measurements.

In the near future, JWG 2.1 has to discuss the data processing of comparisons: 1) the construction of constraint condition within the least-square adjustment, 2) the construction of non-diagonal covariance matrix of the observation equations for solving the correlations between results of a particular gravimeter and type of gravimeters. JWG 2.1 in cooperation with JWG 2.2 have to prepare and present the existing reference stations (equipped with superconducting gravimeters and connected to the system of comparison by means of repeated absolute gravity measurements) to the wide geodetic community as a solution for practical purposes in geodesy – verification or determination of biases of absolute gravi-
meters. This effort might be done in cooperation with the former Global Geodynamic Project (GGP) which willing to be transformed into an IAG service.

Publications


Joint Working Group 2.2:
Absolute Gravimetry and Absolute Gravity Reference Systems

Chair: Herbert Wilmes (Germany)

Overview
JWG 2.2 “Absolute Gravimetry and Absolute Gravity Reference System” is a part of IAG Sub-Commission 2.1 “Gravimetry and Gravity Networks” and joint with the International Gravity Field Service, one of the permanent services of IAG. A close link is drawn also to the metrological community, especially to the “International Committee of Weights and Measures” and to the “Working Group on Gravimetry of the Consultative Committee on Mass and Related Quantities”. This reflects the strong requirement to ensure the consistency of the absolute gravity measurements with the international metrological standards and with the SI quantities (International System of Units).

Motivation
Geodesy requires long-term available geodetic reference systems for the establishment and control of its gravity reference networks and for deduced data products like improved Geoid models for precise height system realisation. Further questions related to environmental changes need to be answered which are related to the expected sea level and ground water changes, the melting of ice covers in form of glaciers and larger ice sheets, or to reaching a better understanding of the physical processes behind tectonic plates deformation. This requires improving the accuracy and robustness of the global geodetic reference frame.

Workshop 2012
In 2012 a workshop has been organised cooperatively by JWG 2.1 and JWG 2.2 “Techniques and Metrology in Absolute Gravimetry” getting together experts from absolute gravimetry within the IAG community and also members of institutions responsible for metrological and calibration practices in gravimetry on national and international level. The workshop focussed on the continuation and further development of absolute gravity comparisons and on the benefit which the comparison stations can provide for the advancement of a future gravity reference system. An important aspect was the development of the technical protocol of future comparisons which shall fulfil the requirements and strategies of both, the metrological and the geodetic communities.

Absolute gravity database AGrav
An important contribution of the working group to the activities of the international community of absolute gravimeter users is the development, improvement and operation of the AGrav database which is now jointly operated by the Federal Agency for Cartography and Geodesy (BKG), Germany and the International Gravimetric Bureau (BGI). The database runs on two mirrored servers with web-based frontend located at BGI: http://bgi.dtp.obs-mip.fr/agrav-meta/ and at BKG: http://agrav.bkg.bund.de/agrav-meta/. This database now acts as the official BGI AG database. The continuously increasing number of participating institutions, instruments and observations reflect the growing acceptance and use of the database on international level. By June 2013 the number of participating institutions has reached 41.
global stations 760 and stored absolute measurements 2560. This includes metadata and full results (cf. Fig. 1).

![AGrav database use](image)

**Figure 1:** Increasing acceptance of the AGrav database

Further effort was invested in the development of improved or new functions of the database, like an optimized user interface, the replacement of earlier commercial map products by OSM graphical data (OpenStreetMap) and the handling of time series into the database. In future it will be possible to display time series of repeated absolute gravity measurements which is helpful for judging the stability of a reference station or for checking the reliability of instruments and for comparing gravimeters and measurement results.

A new data type has been included in the database for time series of superconducting gravimeters operating at gravity reference stations.

![New design of the AGrav web interface 2013](image)

**Figure 2:** New design of the AGrav web interface 2013
**Steps to a consistent global reference system**

Recent comparisons of absolute gravimeters included continuous superconducting gravity measurements at the comparison sites. These additional observations allow determining and reducing gravity variations during the comparison period by providing a comparison reference function. Such successful experiments have been carried out in the regional comparisons 2010 and 2013 in Wettzell (Germany) and during the European comparison 2011 in Walferdange (Luxembourg). Another AG comparison should be mentioned here which has been conducted at Table Mountain Gravity Observatory in Boulder (USA) which focussed upon the AG instruments in North America in 2010. A participation of additional AG instruments from other continents and from other regional comparisons supports the transfer of comparison results and contributes to the realisation a global gravity standard. In 2013, a repetition of the comparisons in Boulder and Walferdange are in preparation.

The connection between the comparisons at distributed sites and the set of reliably operating gravity reference stations are the condition for the realisation of a consistent global reference system. Gravity variations can be bridged with high resolution Superconducting gravimeter time series and repeated AG observations between the comparison events and by this complete the system in the time domain.

**Cooperation with the new GGP-ICET Service of IAG**

Several groups operating AG instruments carry out repeated measurements at the sites of the network of superconducting gravimeters. The chair persons of the new GGP-ICET Service project have asked the community of AG owners to contribute with repeated AG measurements for the determination of SG instrumental drift parameters and calibration factors. It is planned to support this request using the AGrav database.

**Cooperation with the metrological community**

This working group supports the cooperation of the institutions which are responsible for geodetic and metrological reference measurements and calibrations. In this context we look back to a very successful period of four-yearly AG comparisons hosted by the BIPM. Also in the future, comparisons are necessary and shall be continued. Only in a cooperation where the best instrumental standards from metrology and geodesy can participate in the comparisons, we shall be able to maintain the global metrological and geodetic gravity standard with highest accuracy, which is a precondition for the realisation of a consistent and precise global gravity reference frame.

**Continuation of the work**

As mentioned above, the standardisation of AG observations and its evaluation are an important condition for providing consistent and robust results.

In the following period the working group will need to focus upon the agreement of the necessary standards and the establishment of the new International Gravity Reference System based upon distributed AG comparison sites and with the aim to replace IGSN71.

Another challenge will be to fulfil the requirement of GGOS to combine absolute gravity data with geometric observations.
Joint Working Group 2.3: Assessment of GOCE Geopotential Models

Chairs: Jianliang Huang (Canada), Christopher Kotsakis (Greece)

Presentations and discussions at GGHS2012

There were about 19 presentations/posters from members on assessment of GRACE and GOCE models in various sessions, most of them in Session II (13). These assessments indicated that the third releases of GOCE and GOCE&GRACE-based satellite models showed improvement over previous releases. They suggested that recent GOCE models had an accuracy of 3-5 cm for the baseline of about 100 km.

Some discussions were held between a few members and chairs on publication of the special issue of Newton's Bulletin. Based on these discussions, it was proposed that the JWG published all assessment reports in the special issue of NB after the Release 4 models were made available so that all reports could reflect the best and final quality of GOCE models. A tentative deadline for submitting a manuscript was set as the end of 2013 after the IAG2013. The JWG targeted to publish the special issue of NB by the end of March, 2014. Members may choose to publish their assessment results in other scientific journals and proceedings. These reports may not be suitable for the special issue of NB if no significant new results are added.

Another initiative is synthesizing assessments from publications (not limited to those in the special NB) into one or a few papers, and publishes them as either an ESA report or journal papers. To achieve this objective, the JWG needs to form a few topic groups. Further discussions on this issue will resume in the upcoming IAG 2013 in Potsdam, Germany.

Highlights from members

Christopher Jekeli et al (2013) have determined for the Bolivian Andes that the new global gravity models derived from GOCE may be used directly to study lithospheric structure. A numerical comparison of the spherical harmonic models to conventional three-dimensional modelling based on topographic data and newly acquired surface gravity data in Bolivia confirmed their suitability for lithospheric interpretation. Specifically, the relatively high and uniform resolution of the satellite gravitational model (better than 83 km) produces detailed maps of the isostatic anomaly that clearly delineate the flexure of the Brazilian shield that is thrust under the Sub-Andes. Inferred values of the thickness of Airy-type roots and the flexural rigidity of the elastic lithosphere agree reasonably with published results based on seismic and surface gravity data. In addition, the GOCE model generates high resolution isostatic anomaly maps that offer additional structural detail not seen as clearly from previous seismic and gravity investigations in this region.

Heiner Denker et al. concentrated on the use of the GOCE global geopotential models, which were first evaluated by the existing terrestrial gravity field data sets, showing that the GOCE models improved from release to release with the inclusion of longer observation time series. The agreement between the release 3 GOCE models and terrestrial data up to degree and order 200 is about 5.5 cm for height anomalies, 1.7 mGal for gravity anomalies, and 0.55° for vertical deflections, respectively, being fully compatible with the relevant error estimates. So far, the combination solutions based on GOCE and terrestrial data mostly perform similar to corresponding calculations relying on EGM2008, which is due to the high quality of the European data sets utilized in the EGM2008 development; however, in selected areas with known weaknesses in the terrestrial gravity data (e.g., Bulgaria, Romania), the inclusion of
the GOCE models instead of EGM2008 leads to some improvements in terms of GPS/leveling fits. Most of the GOCE investigations were carried out in the framework of the REAL GOCE project funded by the German Ministry of Education and Research (BMBF) and the German Research Foundation (DFG); for further details see Ihde et al. (2010) as well as Voigt and Denker (2011 and 2013).

Pavel Novák et al. compared gravitational gradients observed by the GOCE gradiometer to gradients forward modelled from mass components/layers of the CRUST2.0 model and to gradients computed from ground and satellite altimetry-derived gravity data. Within the ESA's STSE project GOCE-GDC, main results of these studies will be reported to ESA by the end of August 2013.

For the geoid as well as for geopotential models the most common way to analyse their quality and consistency is to compare with GPS observations on Bench Marks of the spirit leveling network (GPS/BM). Due to a PhD thesis developed at the University of São Paulo, Laboratory of Surveying and Geodesy (LTG), an effort for many different comparisons was undertaken. Looking to the RMS difference the conclusion is that we are below half meter in the state of São Paulo and surrounding areas.

Hussein Abd-Elmotaal et al. have examined GOCE models for both Egypt and Africa in the framework of the African Geoid Project (http://www.minia.edu.eg/Geodesy/AFRgeo).

During the period 20011-2013, BENAHMED DAHO Sid Ahmed focused on the evaluation of the performances of the latest GOCE-based GGMs models. The terrestrial gravity data over Algeria supplied by BGI and new set of GPS/leveling-derived geoid heights were used as ground-truth data sets for the new GOCE-based GGMs evaluation. Analysis of the root mean square (RMS) residuals between the terrestrial data sets and spectrally enhanced GGM functionals showed that the GOCE-based models improved knowledge in the spectral bands around 160 to 180 for with respect to GRACE. Furthermore, when analyzing the results obtained with the high-quality GPS/levelling data, it can be concluded that the global geoid accuracy is at the level of 9 cm at degree and order 180. It is about to 5 to 6 cm if we take into account the error level of the GPS/levelling data. This indicates that the objectives of mission have not been reached yet.

As a member of the European GOCE Gravity Consortium EGG-C and ESA's GOCE High Level Processing Facility GOCE-HPF, Christoph Forste routinely assesses and evaluates all global GOCE gravity field models including GOCE models which were jointly generated by GFZ Potsdam and CNES/GRGS Toulouse.

Jaroslav Klokocnik et al. focused on the inversion from kinematic orbits of GRACE and GOCE to the parameters of the gravity field of the Earth and their time variations and on experimental application of EGM 2008 in geomorphology, using the gravity disturbances, Marussi tensor, the gravity invariants and their various combinations as well as newly defined virtual deformations in selected areas of the Earth.

Nikolaos N Pavlis has been doing various comparisons with the GOCE models, as those become available. He plans to continue performing these tests and comparisons in the future, and will show the results at some meeting, or for possible publication.

C Hwang and HJ Hsu use gravity data and GPS-levelling data in Taiwan (Figure 1; the GPS-levelling data are on the first-order benchmarks with distinct line patterns in Figure 1) to
assess the GOCE-Tim3 and –Tim4 models, which are independent of all terrestrial data. The omission error is reduced by using the EGM2008 high degree terms and we remove the residual terrain effect. Figure 2 shows that GOCE-TIM4 has a reliable degree to 220, compared with degree 180 for GOCE-TIM3. GOCE-TIM4 uses ~26.5 months of mission data, whereas GOCE-TIM3 uses only ~12 months of data. In conclusion, the best harmonic expansion degree for the GOCE-TIM4 model is 220.

Figure 1: Marine and land data used to assess GOCE model (V4)
Figure 2: RMS difference between GOCE-TIM3 (red circles) and GOCE-TIM4 (green triangles) augmented by EGM2008 where \( n \) indicates the degree to which the GOCE models replace the low-degrees of EGM2008 and (a) 186 GPS-levelling points, and (b) 4,373 land free-air anomalies (Dataset C in Table 2) and including residual terrain modelling from the 9”x9” DEM.

Additional assessments can be found under the Publications section.

**Publications by members**

*Referred papers*


Ince, ES, Sideris, MG, Huang, J, Véronneau, M (2012), Assessment of the GOCE-based global gravity models in Canada, Geomatica 66 (2) , pp. 125-140


Conference proceedings papers

Ågren J, Sjöberg L E (2013) Investigation of gravity data requirements for a 5 mm-quasigeoid model over Sweden. (accepted for publication in Springer, IAGS of GGHS12)


Bilker-Koivula, Mirjam (2013) Assessment of high-resolution global gravity field models and their application in quasigeoid modelling in Finland (accepted for the IAGS of GGHS12)


Tocho C., G. S. Vergos, M. C. Pacino (2013) Evaluation of GOCE/GRACE derived Global Geopotential Models over Argentina with collocated GPS/Levelling observations (Accepted for the IAGS of GGHS2012)

Conference presentations/posters

Benahmed Daho S. A. – Evaluation of GRACE/GOCE geopotential models in Algeria. Communication accepted for presentation in upcoming IAG General Assembly – Potsdam - Germany


Blitzkow, D.; Matos, A. C. O. C.; Guimarães, G. N.; Lobianco, M. C. B.; Pacino, M. C.; Present and Future of the gravity surveys and geoid model in South America. SIRGAS, 2012, Universidad Concepción; Ciudad: Concepción – Chile;


Matos, A. C. O. C.; Blitzkow, D.; Guimarães, G. N.; Lobianco, M. C. B.; GOCE and the geoid in South America. The XXV IUGG General Assembly, 2011. Melbourne Convention & Exhibition Centre; Melbourne, Australia;


Joint Working Group 2.4:  
Multiple Geodetic Observations and Interpretations  
over Tibet, Xinjiang and Siberia

Chair: Cheinway Hwang (Taiwan)  
Vice-Chair: Wenbin Shen (China)

Introduction

This joint working group is dedicated to studies of geodynamic process and climate change over the Tibet, Xinjiang and Siberia (TibXS), using geodetic tools ranging from satellite altimetry to satellite gravimetry. Additional techniques, such as GPS, terrestrial gravimetry, and interferometry SAR are also used. The members, as listed in the geodesy handbook 2012, are all very active in this JWG, with activities ranging from personnel exchange, to attending the annual meetings, and to publishing papers in special issues of this JWG (see below).

Activities

Starting from 2011, we hold annual meetings to exchange research results and ideas, and propose new directions of study over TibXS, as the major activity of JWG2.4. We have published special issues in the journal of Terrestrial, Atmospheric and Oceanic Sciences (TAO), with papers from the meetings (with enhancements) and from outside. Highlights of the meetings and special issues are:

TibXS2011 meeting (22-26 July, 2011)  

This meeting was held in Xining, Qinghai Province of China, with more than 60 participants. Several landmark papers on GRACE determination of mass change over TibXS were presented. The TAO special issue, “Geodynamic process and Climate Change in TibXS” was launched to publish 13 papers on research results mainly from GRACE, satellite altimetry and terrestrial gravimetry (TAO, Vol. 22, No.2, April 2011).

TibXS 2012 meeting (26-30, August, 2012)  

Held in Chengdu, Sichuan Province of China, the meeting is another important activity of JWG2.4. Another TAO special issue was published (TAO, Vol. 24, No. 4, August 2013). The highlights of the activities reported in the papers are:

1) An updated Moho depth model and a new geoid model over Tibet from recent GRACE/GOCE gravity models and CRUST2.0 crust model.

2) Improved methods of retracking altimeter waveforms and improved method of lake level determination and prediction; TibXS hydrology variability and climate variability from height and backscatter observations of TOPEX.

3) Crustal movements in China and tsunami simulations related to the Tohoku-Oki earthquake of March 11, 2011, Japan.

4) Changes in ice mass and in seasonal ocean tide over arctic islands and subarctic oceans (near Siberia) from GRACE and satellite altimetry.

5) A distinct crustal structure of Tibet compared to PREM, using GOCE and GPS data.
(6) A new SG is installed at Lhasa, Tibet. The preliminary result reported in this special issue both contrasts or confirms the model predictions, depending on the subjects. A long-term SG record here is needed to enhance the current determinations of tidal amplitude factors and the SG calibration function.

We will hold the 2013 annual meeting on July 28 to Aug 1, 2013 in Yining, Xianjiang, China (http://space.cv.nctu.edu.tw/altimetryworkshop/TibXS2013/TibXS2013.htm).

All these meetings are kindly supported by Wuhan University (financially) and IAG (spiritually). In the meetings, we have some international participants outside of China, but more are encouraged.

Due to the vast area and the remoteness of TibXS, in situ data here are quite limited in spatial coverage and temporal coverage. We believe the discussions in the annual meetings and the papers in the special issues will provide important references for strategic plans of in situ observations over TibXS. In turn, such observations are critical to substantiating and validating current and future geodetic results. We will continue the effort to promote geodetic and geophysical studies in such a climate-sensitive and geodynamic-active region as TiBXS.
Joint Working Group 2.5: Physics and Dynamics of the Earth’s Interior from Gravimetry

Chair: Isabelle Panet (France)

This WG will be closed. The chair does not see any possibility for activities for it.
Joint Working Group 2.6:
Ice Melting and Ocean Circulation from Gravimetry

Chair: Bert Wouters (UK/USA) (as of April 9, 2013)

Active members: Jennifer Bonin, Carmen Boening, Don Chambers, Annette Eicker, Martin Horwarth, Felix Landerer, Scott Luthcke, Jürgen Kusche, Roelof Rietbroek, Riccardo Riva, Ingo Sasgen, Jens Schroeter, Clark Wilson, Bert Wouters.

Goals and priorities of JWG 2.6

The mission statement in the IAG JWG 2.6 document is rather general. The goals of the JWG 2.6 have been discussed at the past two meetings and the following was concluded: Since the process of land ice melting includes signals in many geodetic observations and solid earth processes as well as oceanography is important as well, it was found that all aspects of the process should be addressed. Although this group combines a lot of knowledge and expertise in various fields, time and funding to initiate such a project is lacking. Therefore, a large-scale, communal science project is ruled out. Considering the topics of other working groups and of large funded projects concerned with land ice and sea level we agreed that our strength lies in combining different experts and aspects i.e. in networking and in providing advice, setting up guidelines and best practices and communication/outreach of results to scientists in other fields (i.e., non-geodesists).

Past meetings of JWG 2.6

- European Geosciences Union General Assembly 2013. Vienna (Austria) April 7 – 12, 2013

Current projects of JWG 2.6

- The members of the WG recognize that working towards a grand inversion including all processes and measurements represents an ambitious and challenging goal that the WG should support. On this background several specific (sub)tasks were discussed at the meetings. One of them was to identify where to locate future measurements and what to measure in order to address a well-defined issue. E.g. when measuring total ocean mass where to place on ocean bottom pressure recorder such that land ice processes have the least influence on the data
- In early GRACE years, there was a wide spread in published values of mass loss of the ice sheets. Despite the recent convergence (e.g., IMBIE, see Shepherd et al, Science, 2012), there are still outliers (e.g., Wu et al. 2009, Bergmann et al. 2012). Geodesist are generally aware of reasons for differences. Non-geodesists do not always understand why there is no agreement, since this requires knowledge of methods and GRACE processing. JWG 2.6 will work on an overview paper that reviews published estimates and explains the differences. The format of the article has been discussed at the past EGU 2013 meeting and the following was concluded:
  - article should focus on non-geodesists, so a short introduction to GRACE should be included. Possible journal: The Cryosphere
  - focus should be on GRACE
give an overview of published estimates (no new methods) and a short description of the methods used. Authors will be invited to provide this short description or comment.

- article should not give a judgement of which estimates are 'correct' and which not, but explain reason for differences and explain outliers.

- Compare different estimates over same period. Proposed period is March 2003 – February 2013.

- should stress that there will always be differences in the estimates because of natural variability (→ different time spans will give different results, even with same method), differences in GIA models, improvement in GRACE data (e.g., RL04 vs. RL05) etc.

- possibly also include analysis of residuals (scatter, autocorrelation)

- Although GRACE observations are becoming increasingly popular to estimate the mass balance of glaciers and ice caps (GICS) the group members agrees that it is too early to do an IMBIE-like intercomparison project for GICS (only two GRACE studies addressing all major GICS published so far: Jacob et al, 2012; Gardner et al., 2013 (in press)). This may be picked up in the future.

- GRACE mission may be coming to an end, JWG 2.6 encourages researchers to think about methods to fill up gap with follow-on mission, e.g. using SLR. Within the framework of the e.motion project a model of time variable gravity has been developed which may act as a test bed for such methods. Felix Landerer is PI of the new NASA MEaSUREs project 'Earth Surface Mass Changes' (essentially the Tellus website and all its data products), which is looking into this issue and is supposed to provide data products (like EOF-based reconstruction using lower order SLR etc.)

- Guidelines and best practices: M. Horwath proposes to look at sensitivity kernels of methods used to estimates mass loss. This could also be included in overview paper, or in a separate work if too technical.

- At a later stage (after completion of overview paper), a web site could be set up where researchers can upload their Antarctica and Greenland time series and users can compare different estimates. Not much experience with setting up web sites in group, so R. Rietbroek proposes to use an existing wiki-like interface.

Collaboration with JWG 2.7 on hydrology

- Hydrological correction is important when estimating mass balance of continental ice caps and glaciers. Likewise, GRACE needs to be corrected for glacier signal when studying hydrology (For example, in High Mountain Asia region, see presentation). Hydrological models show very different trends in some regions and are one of the main causes of uncertainty in glacier mass balance estimates. A collaboration between JWG 2.7 and JWG 2.6 is therefore logical.

- A. Eicker (Chair of JWG 2.7) informed us that currently the hydrology group is still determining its goals and priorities. Will contact group members and provide overview of reasons for large discrepancies in trends of models.

Points of action

- overview paper:
  - contact the editors of "The Cryosphere" about interest for overview paper (summer 2013)
– compile list of published GRACE estimates mass loss Greenland and Antarctica and send out to group (summer 2013)
– prepare draft outline of paper and send out to group for comments (summer/fall 2013)

• hydrology: A. Eicker will contact JWG 2.7 group members and provide overview of reasons for large discrepancies in trends of models in High Mountain Asia region.

**Future meetings**

• Next meeting will be at AGU 2013 or EGU 2014
Joint Working Group 2.7: Land Hydrology from Gravimetry

Chair: Annette Eicker (Germany)

Members:
Jean-Paul Boy (University of Strasbourg), jeanpaul.boy@unistra.fr
Petra Döll (University of Frankfurt), P.Doell@em.uni-frankfurt.de
Andreas Güntner (GFZ Potsdam), guentner@gfz-potsdam.de
Laurent Longuevergne (University of Rennes), laurent.longuevergne@univ-rennes1.fr
Matt Rodell (Goddard Space Flight Center, NASA), matthew.rodell@nasa.gov
Himanshu Save (University of Texas), save@csr.utexas.edu
Bridget Scanlon (University of Texas), bridget.scanlon@beg.utexas.edu
Ben Zaitchik (Johns Hopkins University Baltimore), zaitchik@jhu.edu

Webpage:

A website was set up to coordinate and document the group activities:
http://www.igg.uni-bonn.de/apmg/index.php?id=535

It includes the terms of references, contact information of the working group members and a complete list of publications originating from the years 2011-2013. It will be complemented by reports and joint results.

Activities

General activities

During the previous two years, working group members have been involved in various research areas associated with “Land hydrology from gravimetry”. Activities comprised tailored GRACE data analysis and signal interpretation, hydrological model development, model validation and calibration, as well as assimilation of GRACE data into hydrological and land surface models. Further research interests include water resource analysis and ground water monitoring, and the use of local, superconducting gravity observations to monitor local water storage variations. Additionally, assistance has been provided by working group members to the hydrological community via preparation of easy-to-use GRACE products and pedagogy on the use of GRACE data.

An email list has been set up and a discussion was started regarding individual research goals and unresolved topics associated with the above research activities.

Future Gravity Workshop

In 2014 a workshop will be held on future gravity missions with the goal “Consolidation of science requirements”, which was initiated, among others, by Sub-Commission 2.3 (Dedicated satellite gravity mapping missions). Preparations have already started 2013 and will be continued during the course of the next year by thematic sub-groups. The hydrology sub-group will be covered by JWG 2.7.
Collaboration with IAG JWG 2.6 (Ice melting and ocean circulation from gravimetry)

A cooperation was established during a joint splinter meeting at EGU 2013 between working groups 2.6 and 2.7 to work together on a better understanding of hydrological and glaciological effects in the Himalayan region. Different hydrological models show very different output in this region. As these models are applied to disaggregate the gravity signal and to isolate the ice melting effects, they represent a large source of uncertainty to the glaciological community. The reasons for the different hydrological modeling results are currently under discussion.

Future plans

An important task for the upcoming year will be the preparation and realization of the future gravity mission workshop, as mentioned above. This implies, as a first step, the inventory and review of various previous studies on future mission scenarios from a hydrological perspective. The next step will be the formulation of hydrological research goals that could be achieved with the different mission designs. Furthermore, the cooperation with JWG 2.6 and the joint discussion e.g. on the Himalayan glaciers will be continued. The discussion within the hydrology working group (e.g. regarding signal interpretation, preparation of dedicated GRACE products to hydrologists and data assimilation techniques) shall be intensified. Splinter meetings are planned at the IAG Meeting in Potsdam 2013 and at AGU 2013 in San Francisco.

Bibliography

A list of publications with contributions from working group members in 2011-2013 can be found on the WGs webpage.
Joint Working Group 2.8:
Modelling and Inversion of Gravity-Solid Earth Coupling

Chair: Carla Braitenberg (Italy)

Here follows the complete report of the activities and main results.

The activities were decided in the three regular meetings of the Working Group and reported in the circulars. The circulars are deposited in the homepage of the WG described below.

Definition of activities for Working Group

The planned activities of the working group (WG) were published in the first and second circular:

1. Create a platform in which density models can be tested through geodynamic models. This needs the interaction of the geodynamic modeller with the geophysical modeller, and allows a consistency check of the density models from the point of view of observations of the potential field and of geodynamics. Vice versa the geodynamic models producing density variations are checked against consistency with density models constrained by further geophysical observations.

2. Create a reference database covering the subject of gravity-sol,o earth coupling (mass loading, under-plating, isostatic Moho, crustal thickness, lithospheric thickness, dynamic topography versus mass loading).

3. Create a database on methodology of gravity forward and inversion calculations, spherical calculations

4. Create a kit of software tools that have been tested and verified by the WG and that will be shared among the members of the working group. It shall cover the different aspects of the goals of the WG. If several software-programs are made available they can be benchmarked against each other.

5. Set up a social networking page for the members of the WG.

6. Organize dedicated yearly meeting of the WG.

7. Organize a practical-theoretical school on Modeling and Inversion of Gravity-Solid Earth Coupling

8. Apply for funding of activity of WG through international agency.

Final goal for 2011-2015

At the end of the WG period (2011-2015) the WG shall have set up a variety of tools that allow to tackle and improve understanding of solid earth-gravity coupling processes. In particular the efforts will be summarized in a home-page that shall contain an exhaustive overview of the most important and relevant papers on a few key topics necessary for fulfilling the scientific task. Secondly the page will house a useful collection of software tools that will have been validated by the WG, and that are recommended as useful tools for gravity forward and inverse modelling. Ideally the WG will give the opportunity to give a platform on which to exchange news and information regarding gravity modeling.

These actions have started and are in a good stage of development. Three meetings have been held, detailed in Table 1, and the homepage has been set up, as described in the next section.
Table 1: The meetings of the Workgroup were held at various conferences relevant to potential fields.

<table>
<thead>
<tr>
<th>Convention</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splinter meeting at EGU2012, SPM1.30.</td>
<td>First Meeting of the Joint Working Group JWG2.8 (IAG) Modeling and Inversion of Gravity-Solid Earth</td>
<td>26 Apr, 2012, 19:00–20:00</td>
</tr>
<tr>
<td>Splinter meeting at the Symposium Gravity, Geoid and Height Systems GGHS2012, 09-12 October 2012, San Servolo Island, Venice, Italy</td>
<td>Second Meeting of the Joint Working Group JWG2.8 (IAG) Modeling and Inversion of Gravity-Solid Earth</td>
<td>10 October 2012</td>
</tr>
</tbody>
</table>

Working Group Discussion page

We have set up a discussion page for the Work group, located here: [http://www.lithoflex.org/IAGc2](http://www.lithoflex.org/IAGc2)

The scope of the homepage and the responsibility from side of the members for the different topics were defined in the GGHS2012 meeting in Venice.

In Venice it was decided that the page shall contain an exhaustive overview of the most important and relevant papers on a few key topics necessary for fulfilling the scientific task. Secondly the page will house a useful collection of software tools that will have been validated by the WG, and which are recommended as useful tools for gravity forward and inverse modeling. Ideally the WG will give the opportunity to give a platform on which to exchange news and information regarding gravity modelling.

Throughout the period of the WG the page will be in development and updated. The accredited members of the WG are able to edit the pages after registering and can post messages. News include an interesting paper, or a recent publication, or a topic of discussion.

The homepage should allow the WG-members to discuss the topics of the WG at ease.

The pages dedicated to relevant publications have been divided among the WG-members as follows:

- **Properties of rocks:** Density, velocity, correlation between density and seismic velocity, mineral composition, dependence on pressure and temperature. Jörg Ebbing (Norway), Javier Fullea (Spain), Richard Lane (Australia)
- **Gravity forward modeling:** Spatial-domain techniques (flat vs. spherical. prisms, tesseroids), and spectral-domain techniques (spherical harmonic expansion), Resp. Leonardo Uieda (Brazil), Rezene Mahatsente (Germany), Thomas Grombein (Germany), Christian Hirt (Australia)
- **GOCE and other satellites:** Application of GOCE satellite gravimetry in solid Earth investigations, GOCE mission overviews, GOCE gradients and gravity recovery, and GOCE model quality, Christian Hirt (Australia), Carla Braitenberg (Italy).
- **Gravity Associations:** Gravity associations, gravity discussion groups (all members)
- **Inverse gravity modeling:** Flat, spherical, spectral approach, Surface harmonics (Valeria Barbosa (Brazil), Riccardo Barzaghi (Italy)
• **Isostatic modeling**: Different techniques on isostatic modeling. John Kirby (Australia)

• **Topographic Corrections**: Methods for calculation of mass effect of topography; cartesian and spherical coordinates, Orlando Alvarez (Argentina), Nils Köther (Germany)

The Opening page is shown in Figure 1.

![Welcome page of the IAG JWG 2.8 homepage](image)

Figure 1: Welcome page of the IAG JWG 2.8 homepage, which includes a depository of software, relevant-publications-list and the possibility of making discussions.

### Software tools

The goal is to create a set of software tools useful in gravity inverse and forward modeling. The software should have passed validation criteria, so as to achieve a control on reliability. The software shall have the following requisites:

- it runs on Windows or Linux.
- It is freely distributed
- It must include a documentation with description of routines and usage, and a set of testing files, that allows all routines to be tested by the user.
- The person or group of persons that provide the software also demonstrate that the SW has been validated on a standard dataset. The WG will house a few standard models that contain a density model and the gravity and gradient field it produces, which will be the means to validate the software.
- The SW will be distributed by its owner, the IAG WG accepts the SW as having been validated by the standards set up by the WG.

It is intended to set up some benchmark models. The first standard model will be a lithospheric model of North Atlantic margin. It will be created by Jörg Ebbing.

The home-page will also house a collection of commercial software considered to be useful in this scientific context.