International Gravimetric Bureau (Bureau Gravimétrique International, BGI)

http://bgi.obs-mip.fr

Director: Sylvain Bonvalot (France)

Overview

The International Gravimetric Bureau (BGI) has been created in 1951 by the IUGG (International Union in Geophysics and Geodesy) with the aim to collect on a world-wide basis, all gravity measurements to generate a global digital database of gravity data for any public or private user. The technological and scientific evolutions which occurred over the last 50 years in the area of gravimetry (improvements in field, airborne and seaborne gravity meters, development of absolute gravity meters, space gravity missions, etc.) provided significant increases of the number, diversity and accuracy of the gravity field observables. Following these evolutions, BGI has contributed to provide original databases and services for a wide international community concerned by the studies of the Earth gravity field.

The BGI is an official service of the International Association of Geodesy (IAG) and since 2003 it is coordinated with others IAG services (IGeS, ICET, ICGEM, IDEMS) by the International Gravity Field Service (IGFS). It also directly contributes to the activities of the IAG Commission 2 "Gravity Field" and of the IAG Global Geodetic Observing System (GGOS). It is recognized by the International Council for Science (ICSU) successively as one of the services of the Federation of Astronomical and Geophysical Services (FAGS) and of the World Data System (WDS) created in 2008.

For more information:

- The International Gravimetric Bureau. In : "The Geodesist's Handbook, 2012", H. Drewes, H. Hornik, J. Adam, S. Rozsa Eds. (International Association of Geodesy). Journal of Geodesy, Volume 86, Number 10, October 2012, pp. 946-949.

- BGI website : http://bgi.obs-mip.fr/

Mission and objectives

As a service of IAG/IGFS, BGI aims ensuring the data inventory and the long term availability of the gravity measurements acquired on Earth. Hence, one of the main task of BGI is to collect all gravity measurements (relative or absolute) and pertinent information about the Earth's gravity field, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes.

The database of relative measurements contains over 12 million of observations compiled and computerized from land, marine and airborne gravity surveys. For several decades, it has been extensively used for the definition of Earth gravity field models and for many applications in geodesy, geophysics, oceanography, metrology, satellite orbit computation, etc.

More recently, a database for absolute gravity measurements was also set up and put into operation in joint cooperation between BGI and BKG (Bundesamt für Kartographie und Geodäsie, Germany). This new global database initiated in 2008, now displays and makes accessible data and information on available absolute gravity measurements.

In addition, BGI provides other additional services in the area of gravimetry (validation for regional or global projects, online access to reference gravity stations, expertise, bibliography database, etc.). It also contributes to R&D activities (global gravity modeling, data interpretation, software developments, etc.), to data acquisition (relative or absolute gravity surveys), and to educational activities (teaching and summer schools on gravity data acquisition and processing, tutorials and educational materials in gravimetry, etc.).

BGI activities are mostly carried out in the frame of national and international collaborations with many institutions involved in the acquisition or in the use of gravity measurements. For instance, new international collaborations have been initiated in the last few years in the area of absolute gravimetry, global gravity modeling, combination of satellite & surface data, etc.

Most of services provided by BGI such as consultations and requests of gravity database, products, documentations, etc. are accessible through the BGI website (http://bgi.obs-mip.fr/). Data, products or software available at BGI are mostly dedicated to support scientific and academic activities.

Structure and membership

National support

BGI has had its offices located in France (Paris, then Toulouse) since its creation. Since 1979, it has been housed in the premises of the Centre National d'Etudes Spatiales (CNES) / Groupe de Recherche en Géodésie Spatiale (GRGS) and of the Observatoire Midi-Pyrénées (OMP). Today, BGI is also recognized as a permanent service accredited by french Institut National des Sciences de l'Univers (INSU). In 2013, all BGI offices and staff will move to a new building within the OMP Toulouse. The address and contacts are unchanged.

The activities of BGI in France are supported by most of the national Institutions / Agencies and Universities involved in the acquisition or use of gravity data for a wide range of applications (research, education, exploration, reference system, metrology…). This comprises : Centre National d'Etudes Spatiales (CNES) / Groupe de Recherche en Géodésie Spatiale (GRGS), Institut National des Sciences de l'Univers (INSU), Institut Géographique National (IGN), Bureau de Recherches Géologiques et Minières (BRGM), Institut de Physique du Globe de Paris (IPGP), Institut de Recherche pour le Développement (IRD), Service Hydrographique et Océanographique de la Marine (SHOM), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Ecole Supérieure des Géomètres et Topographes (ESGT) and several laboratories of the Universities of Toulouse (GET), Montpellier (GM), and Strasbourg (EOST/IPGS). The contribution of each supporting institution is defined and updated each four years in a general agreement / MOU approved by all respective Directors.

International collaborations

International collaborations are mostly carried out with other IAG services or commissions in the frame of IGFS activities as well as directly with BGI users.

In 2008, a new partnership has been established between BGI and the Bundesamt für Kartographie und Geodäsie (BKG) Germany for the realization and the maintenance of the global database of absolute gravity measurements now operated jointly by BGI and BKG.

In the last few years, active collaborations also tool place with NGA (USA), DTU (Denmark) or Curtin University (Australia) for the computation or the validation of the global Bouguer and Isostatic gravity anomalies performed for the World Gravity Map project led by BGI.

The figure 1 summarizes the main structure and collaboration of BGI.

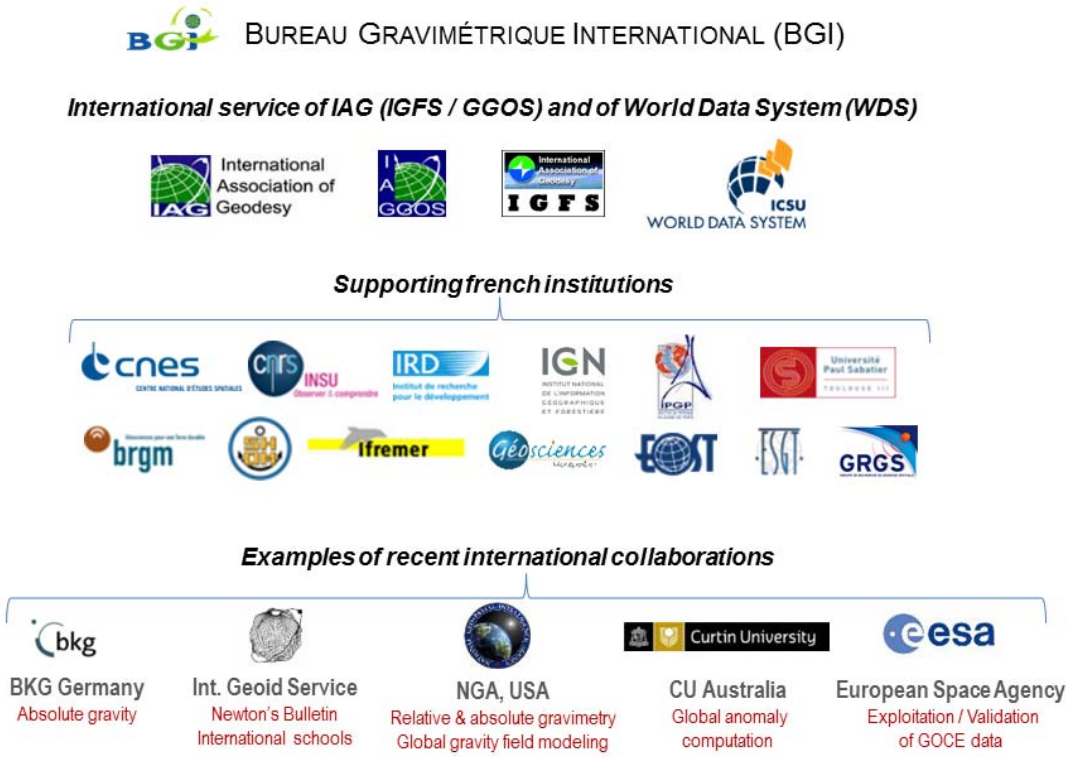

Figure 1 : International and national structure of BGI and main recent international collaborations

Permanent staff (full time or part time)

Central Bureau, Toulouse (CNES-GRGS, IRD, CNRS-INSU, OMP)

S. Bonvalot *Geophysics – absolute & relative gravimetry (Director)*
G. Balmino *Geodesist - space geodesy*
A. Briais *Geologist / Geophysicist – marine gravimetry*
R. Biancale *Geodesist - space geodesy*
N. Lestieu *Secretary*
G. Gabalda *Geophysicist – absolute & relative gravimetry*
L. Seoane *Geodesist - Satellite gravimetry (new permanent position since 2012)*
F. Reinquin *Geodesist - database manager / software developer*

Others teams and contributors (France)

Paris (IGN-LAREG I. Panet, G. Pajot, O. Jamet) ; Paris (IPGP : M. Diament, S. Deroussi, J. Penguen) ; Orléans (BRGM : G. Martelet, A. Peyrefitte) ; Strasbourg (EOST : J. Hinderer, S. Rozat, JP. Boy, JB. Daniel) ; Montpellier (Géosciences : N. Le Moigne, C. Champollion, S. Mazzotti) ; Brest (IFREMER : E. Moussat, L. Petit de la Villeon) ; Brest (SHOM : M.F. Lalancette, D. Rouxel) ; Le Mans (ESGT : J. Cali, J. Verdun).

Associated contributors (Germany)

Frankfurt / Leipzig (BKG : H. Wilmes, H. Wziontek)

Activities

According to the 2011-2015 project plan, the main BGI activities for 2011-2013 aimed (i) at consolidating the terrestrial gravity database (relative and absolute) and encouraging the collection and compilation of incoming datasets, (ii) at developing new products and services for the Earth's science community, and (iii) at making easier the consultation and diffusion of gravity data and products for end-users, through user-friendly Internet interfaces.

In the same time, BGI also continued operating with its supporting organizations other activities in gravimetry (research, software development, teaching, expertise, field surveys, etc.) with the aim to maintain a high level of competence and to improve the efficiency and the quality of its services.

We have thus contributed to the following activities:

- Processing and assistance to users regarding data requests
- Maintenance and modernization of the databases (absolute gravity data for instance)
- Maintenance and modernization of the website and development of new web-services
- Update of the data validation procedures for land gravity surveys
- Finalization of the World Gravity Map project realized for the Commission for the Geological Map of the World and UNESCO.
- Participation to IAG activities and scientific assemblies
- Contribution to outreach / educational activities
- Contribution to gravity surveys

The main results and activities are summarized hereafter.

Global gravity databases and related web services

Most of the databases and services provided by BGI are available from the BGI website (http://bgi.obs-mip.fr). An updated version has been realized in 2012. It gives access to four main global database of gravity observations : 1) Relative measurements from land surveys; 2) Relative measurements from marine surveys; 3) Reference gravity stations related to the former IGSN71 and Potsdam 1930 networks, 4) Absolute measurements.

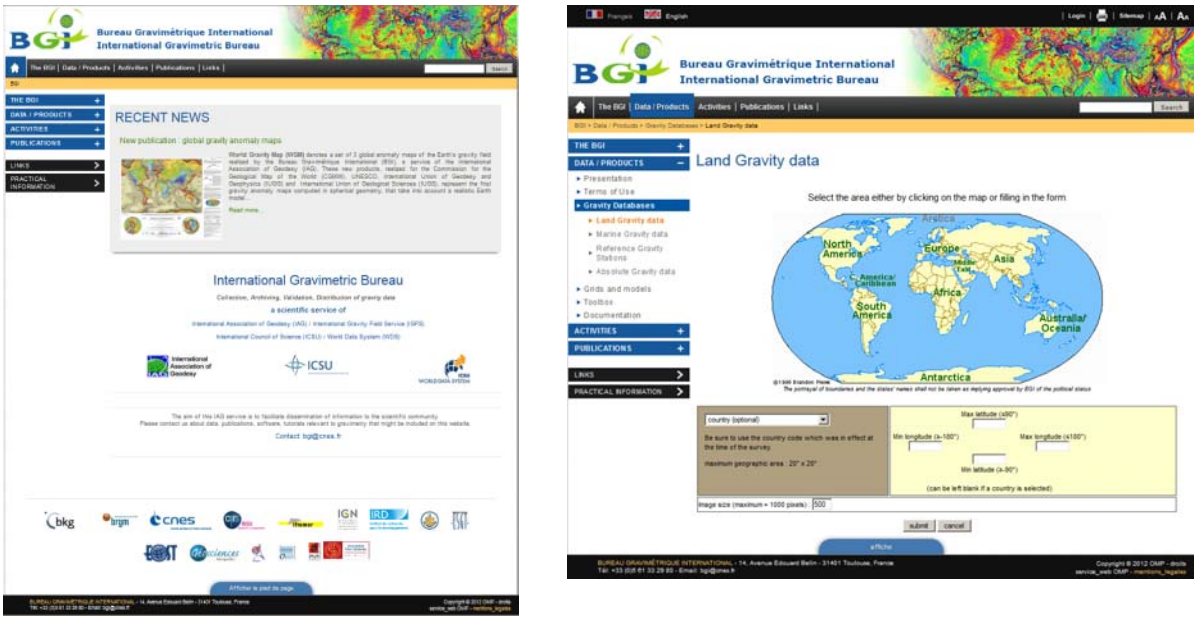

Figure 2: Left) Main page of the BGI website. Right) Data consultation/request page (http://bgi.obs-mip.fr)

Overview of the BGI gravity database

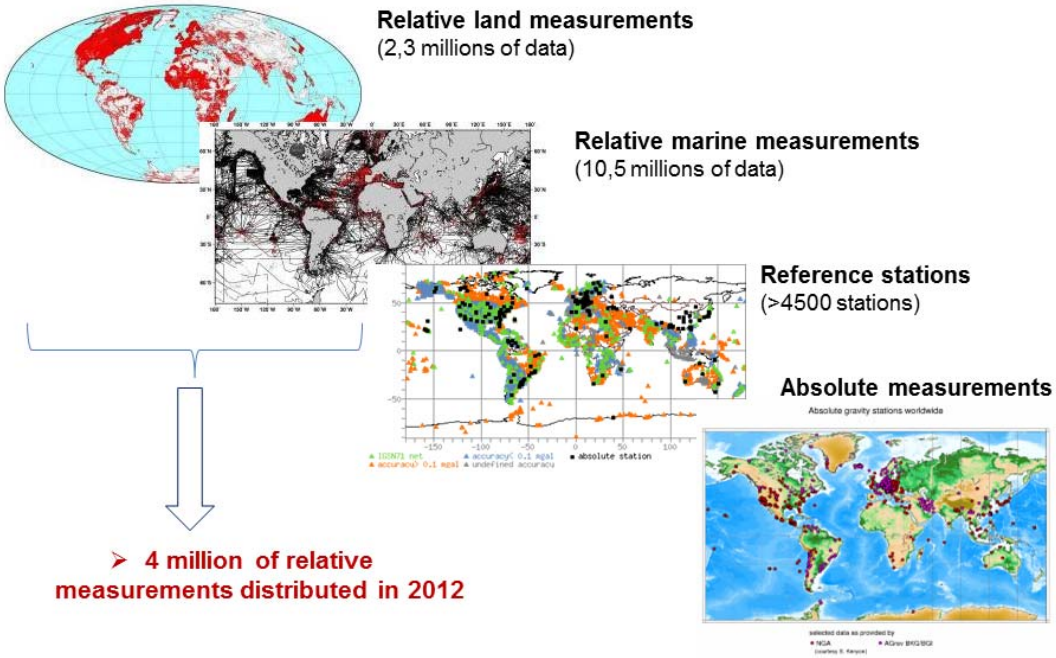

Figure 3: Overview of the global gravity database maintained at BGI

Relative gravity database

The most frequent service BGI can provide is the consultation and retrieval of gravity data and information over local or regional areas. Data requests are issued through the BGI website and are processed electronically (email, ftp transfer or direct download). A few millions of relative data are currently distributed each year to scientific users (over 4 million in 2012).

Absolute gravity database

The global database for absolute gravity measurements was set up and put into operation in 2008 in joint cooperation between BGI and BKG (Bundesamt für Kartographie und Geodäsie, Germany). This relational absolute gravity database (AGrav) is capable of storing information about stations, instruments, observations and involved institutions. By this, it allows the exchange of meta-data and the provision of contact details of the responsible institutions on the one hand and the storage and long term availability of gravity data and processing details on the other hand.

The database can be accessed by a web based interface (based on a Google map interface) at two mirrored sites at BGI (http://bgi.obs-mip.fr) and BKG http://agrav.bkg.bund.de/agrav-meta/). It provides publicly available meta-data as well as complete datasets for community of users contributing to the archive. A simple exchange format (project files) was selected which includes all relevant information and is known by the majority of users, avoiding additional effort. In this way the upload of data to the database is possible, using a web based upload form.

The provided information ranges from meta-data (localization of stations) up to full information on the absolute determination of the gravity field on a given site (raw or processed data, description of measurement sites, etc.). The collection and archiving of absolute gravity data is in progress. Scientists involved in the acquisition of absolute gravity measurements are invited to contribute with their own observations to this new global database. The database is expected to become the foundation for a future international gravity

reference system (replacing the obsolete IGSN71) and will serve as a pool for geophysical interpretation of absolute gravity observations on a global scale. More information can be found in Wziontek et al. (2011).

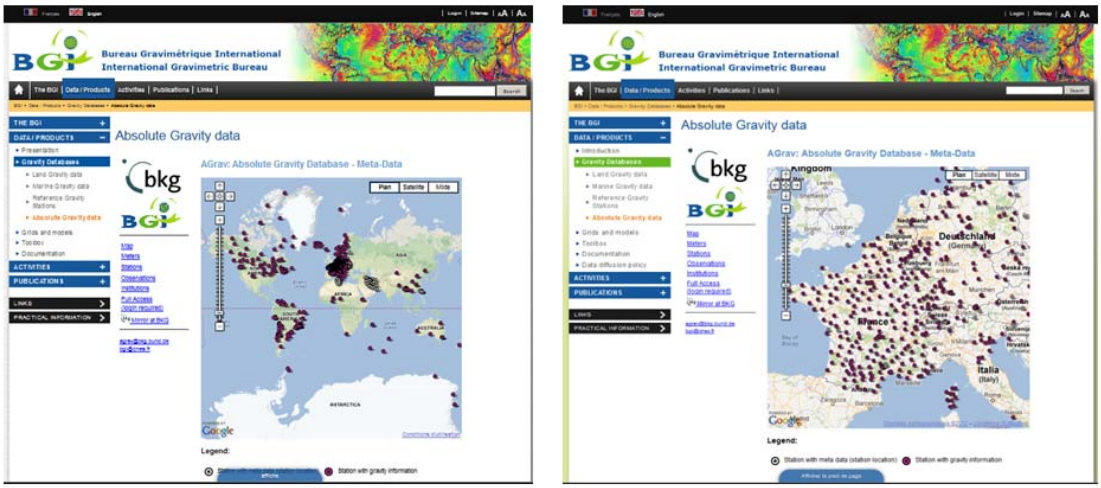

Figure 4: Internet Interface of the Absolute Gravity database (BGI-BKG)
(http://bgi.obs-mip.fr - http://agrav.bkg.bund.de/agrav-meta)

The database includes (summer 2013): 768 Stations, 2607 Observations (2424 with gravity value), 45 Gravimeters: 28 FG5, 6 A10, and 11 other (FGL: 1, GABL: 1, GBL-M: 1, IMGC: 2, JILA: 5, ZZG: 1), provided by 41 Institutions from 24 countries.

An improved database is currently in development at BKG. This new database, now based on open-source software (OpenStreetMap), keeps a similar structure but will provide new functionalities and a link to the superconducting gravity times series (interactive maps, plot of time series, link to SG observations from GGP network, etc.).

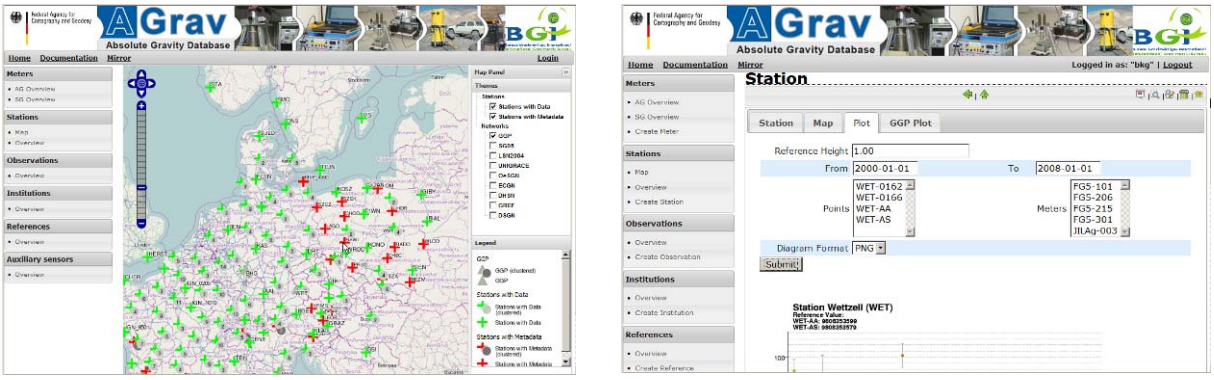

Figure 5: Snapshots of the future Internet Interface of the Absolute Gravity database (BGI-BKG)

New on-line services (data and products)

Prediction of gravity value from the BGI database

BGI also receive requests from users who need to know the expected gravity value at a given site for metrology purposes. A new application has thus been developed to predict the gravity value at any point on Earth for given geographic coordinates and altitude. The theoretical gravity is calculated in GRS80 system using the Somigliana formula. If enough gravity data are available from the relative BGI database in the surrounding area, a prediction of the expected gravity value is also computed at the same location from the interpolation of the available surface data. Both theoretical and predicted gravity values are computed at the geoid level and at the given elevation. Example of the resulting plot provided to the user is given on fig. 6.

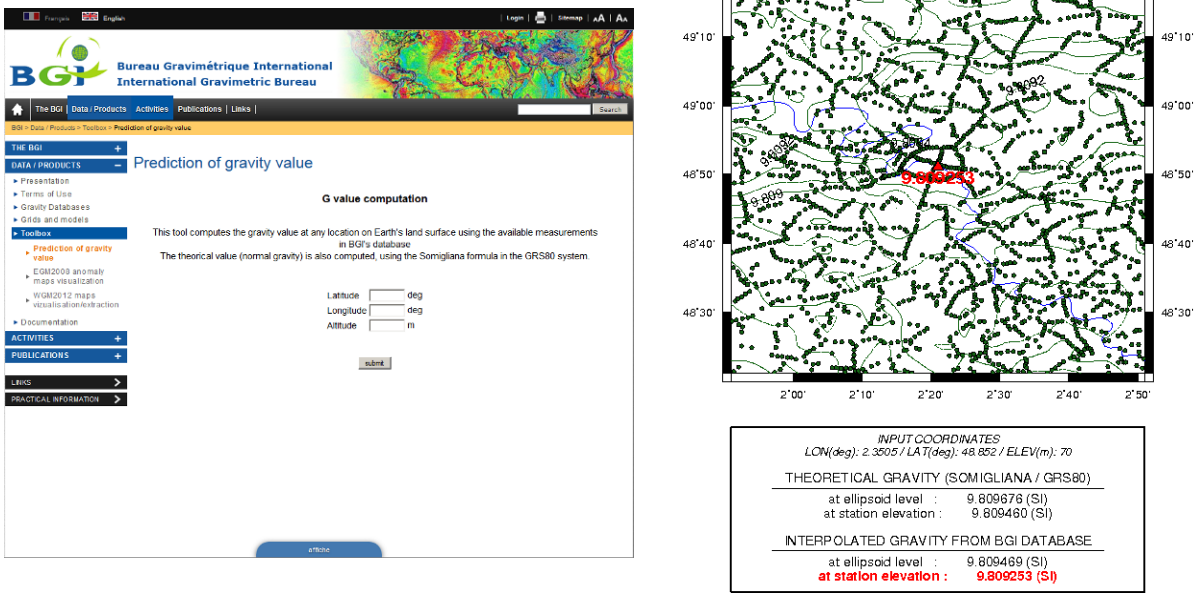

Figure 6 : Web page and resulting plot for the prediction of the gravity value at a given point
http://bgi.omp.obs-mip.fr/index.php/eng/Data-Products/Toolbox/Prediction-of-gravity-value

On-line availability of the BGI Bulletins collection (1959 – 2003)

For several decades (1959 to 2003), the BGI has edited a biennial publication of the BGI Bulletin containing both internal matters on BGI activities and contributing research papers in the area of gravimetry. We carried out the digitalization of the full series of the BGI Bulletins and summaries in order to provide on-line access (downloadable PDF files) on the BGI website (http://bgi.obs-mip.fr/publications/bgi_bulletin). This task has been achieved in August 2013.

The publication of the BGI Bulletins ended in 2003 and was replaced by the Newton's Bulletin published in collaboration with the International Geoid Service (IGeS) and distributed electronically. On-line versions of the issues of the Newton's Bulletins are available on both websites of IGeS (http://www.iges.polimi.it/Newton/newton.html) and BGI (http://bgi.obs-mip.fr/publications/newton_bulletin).

Global grids of Bouguer, Isostatic and free-air gravity anomalies (WGM2012 release)

We recently put an on-line access to any users the 2012 release of the Earth's gravity anomalies computed in spherical geometry at BGI for the WGM (World Gravity Map) project (see details below). The WGM2012 release includes digital grids of the complete Bouguer anomaly and isostatic anomalies (including terrain corrections up to 1 min resolution) and surface free-air anomaly.

The global digital grids (2'x2' resolution) are available to download. An interactive tool is also available to make regional extraction and plots of the gravity anomalies for a given region (http://bgi.obs-mip.fr/data-products/Grids-and-models/wgm2012).

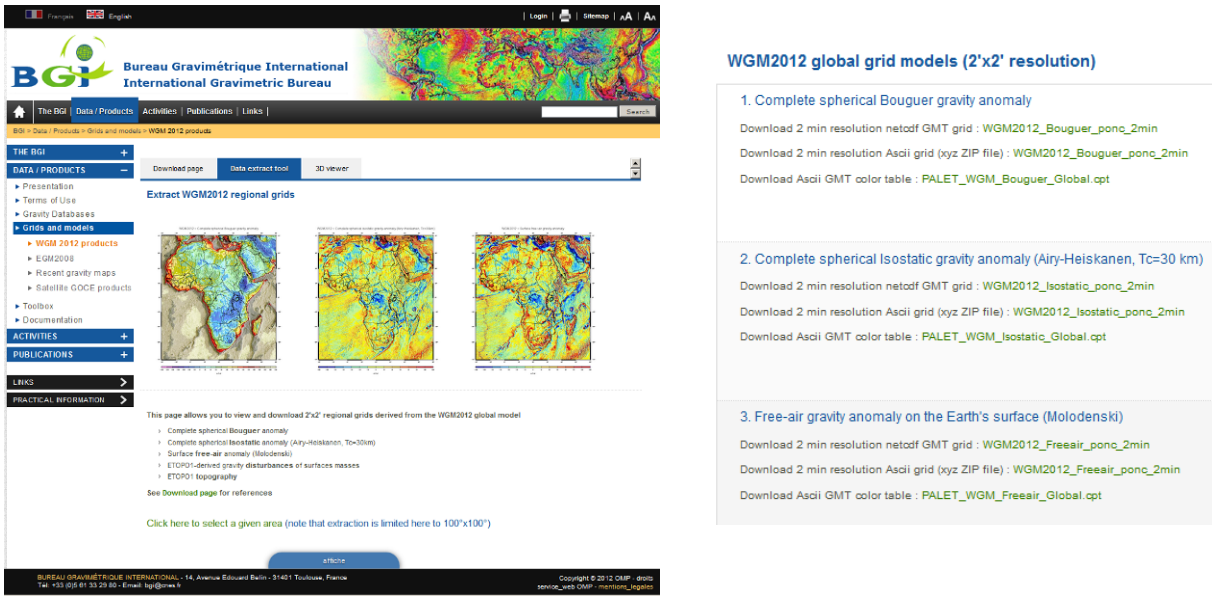

Figure 7 : Web page for the download and extraction of the WGM2012 Earth's gravity anomalies. http://bgi.obs-mip.fr/data-products/Grids-and-models/wgm2012).

World Gravity Map (WGM)

The WGM project, launched in early 2008 by BGI in collaboration with Commission for the Geological Map of the World (CGMW) and UNESCO, has been finalized in 2012 with its first release (WGM2012). The aim of the WGM project is to provide to the scientific community high-resolution digital maps and grids of the Earth's gravity anomalies (Bouguer, isostatic, free-air) using the best available gravity information and based on rigorous computations that are consistent with geodetic and geophysical definitions of gravity anomalies. This project, supported by the International Association of Geodesy (IAG/IGFS), the International Union of Geodesy and Geophysics (IUGG) and the International Union of Geological Sciences (IUGS), also aims to complement a set of global geological and geophysical digital maps published by CGMW and UNESCO for educative and research purposes.

In 2012, we published the first release of the World Gravity Map (Bonvalot et al., 2012). This set of 3 global maps represents the first anomaly maps of the Earth's gravity field computed in spherical geometry, that take into account a realistic Earth model. The anomaly maps (Bouguer, isostatic and surface free-air) were derived from the most recent reference Earth gravity models (EGM2008, DTU10). They include 1'x1' resolution terrain corrections derived

from the ETOPO1 relief model that consider the contribution of most surface masses (atmosphere, land, oceans, inland seas, lakes, ice caps and ice shelves).

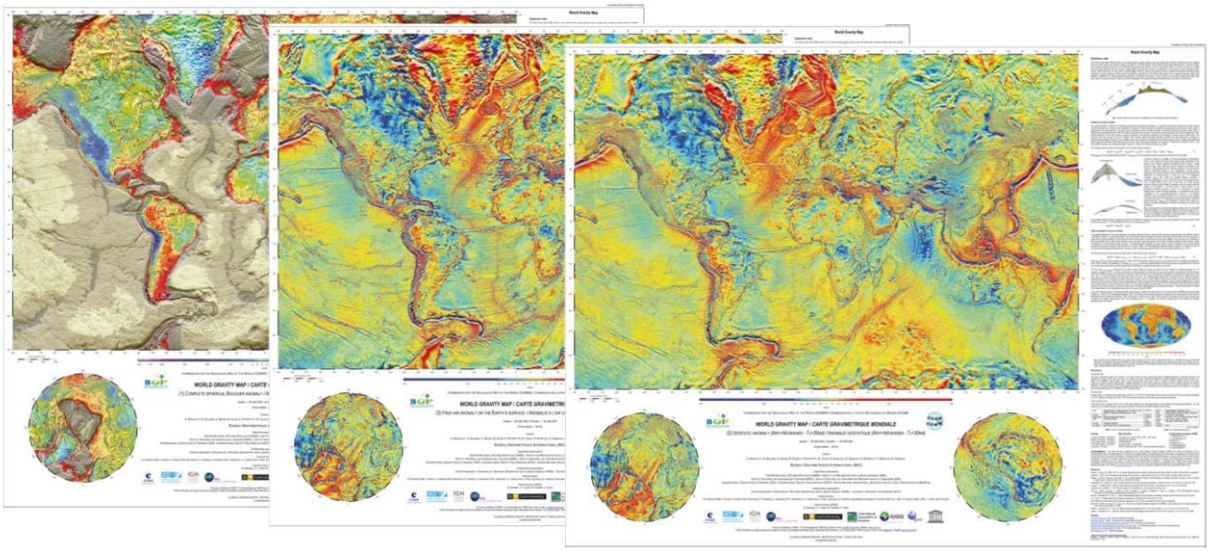

Figure 8: World Gravity Maps (Bonvalot et al., 2012). The 1:50 000 000 maps include Complete Spherical Bouguer anomaly, Complete spherical isostatic anomaly, Free-air anomaly on the Earth's surface (Molodenski).

Here, the complete spherical Bouguer anomaly is determined over the whole Earth by computing in a single step the gravity contribution of all mentioned surface masses above or below the mean sea surface. In the same way, the contribution of their compensation at the crustal-mantle boundary is also computed in spherical geometry on the base of isostatic equilibrium (Airy-Heiskanen model) to determine the corresponding isostatic anomaly. A spherical harmonic approach has been used to provide homogeneous and accurate global computations of gravity corrections and anomalies up to degree 10800 (1'x1' half-wavelength equivalent spatial resolution). To achieve this level of accuracy, new theoretical developments were required in order to handle spherical harmonics to ultra-high degrees (Balmino et al., 2011).

As these new products are believed to provide useful and homogeneous information on the Earth's static gravity field anomalies at regional and global scales in many applications for education or research, we made them available to any user on the BGI website. In addition, we also provide an interactive tool to enable users to perform their own extraction and plot of gravity anomalies derived from the WGM2012 model (see previous section "New on-line services").

Further releases are expected to include more surface data (field, marine or airborne surveys) as well as GOCE data to improve the short wavelengths of the gravity field.

Theoretical and software developments

Spherical Harmonic analysis and synthesis to ultra-high resolution (d/o 32400)

A specific algorithm was developed to enable the computation of associated Legendre functions to any degree (and order); it was successfully tested up to degree 32400. All analysis and synthesis were performed with it, in 64 bits arithmetic and with semi-empirical control of the significant terms in order to prevent from calculus underflows and overflows (according to IEEE limitations), also in preserving the efficiency of a specific regular grid processing scheme. See Balmino et al. (2011) for more details.

Interactive validation of land gravity surveys (NASA World Win application)

A new application is currently under development for the validation of land gravity surveys. This new application, developed in Java language and based on interactive interfaces and maps (based on NASA WorldWind application), aims at replacing the old data processing tool DIVA used at BGI for many years. Example of snapshots are shown on fig 9.

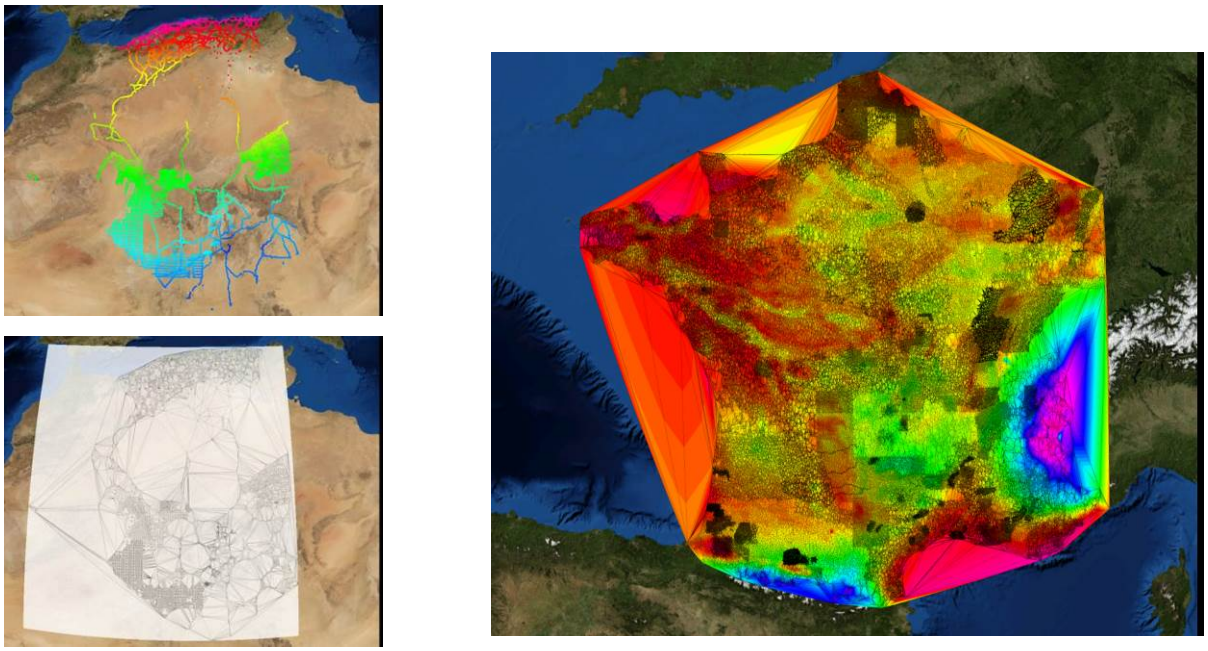

Figure 9: Snapshots of the interactive software for land gravity data validation

Contribution to relative and absolute gravity surveys

Scientific teams associated to BGI have also contributed during the last years to various field surveys for absolute or relative gravity measurements in South America (Chile, Peru, French Guiana), Africa (Niger, Benin, Djibouti), Asia (Bouthan) and Europe.

Participation to scientific conferences and workshops

- ESA Living Planet Symposium 2013 (Edinburgh, UK - 09/ 2013)
- IAG Scientific Assembly 2013 – 150 years of IAG (Potsdam, Germany - 09/2013)
- TGSMM Terrestrial Gravimetry (St. Petersburg, Russia - 09/2013)
- AGU 2013 (San Francisco, USA, 12/2013)
- IAG/IGFS Int. Symposium on Gravity, Geoid, Height Systems (Venice, Italie, 10/2012)
- EGU 2012 (Vienne, Austria, 04/2012)
- Workshop on Absolute Gravimetry (Boulder Co, USA, 09/2012)
- IUGG General Assembly (Melbourne, 08/2012)
- AGU Fall Meeting, (San Francisco, USA, 12/2011)
- 4th International GOCE User Workshop (Munich, Germany, 03/2011)

Contribution to Scientific Organizing Committees

- IGFS 3rd Scientific Assembly (Shanghaï, China, 2014)
- IAG Scientific Assembly 2013 – 150 years of IAG (Potsdam, Germany - 09/2013)
- TGSMM Terrestrial Gravimetry (St. Petersburg, Russia - 09/2013)

Perspectives

Here are listed the main perspectives for the next years.

Improvement of the global gravity databases and services

We will continue in collaboration with BKG Germany the development and set up of the new version of the of the Absolute Gravity database AGrav.

In the same time, we will continue the integration of incoming dataset from relative or absolute gravity surveys. We encourage any user or institution to contribute to the IAG databases. The status of information derived from airborne gravity surveys (grids for instance) should be discussed to be included in the BGI database to improve the global data coverage.

Global / Regional gravity modeling (new products incl. GOCE and surface data)

Within IGFS activities or other research projects, we are developing new collaborations with other groups also involved in the determination or analysis of global gravity field models as for instance with NGA (USA), Curtin Univ (Australia), IGN/IPG Paris (France). Through these collaborations, we expect to join research efforts for the future determination or the evaluation of global gravity models based on surface and satellite (GOCE for instance) gravity data.

Publications 2011-2013

Articles

Balmino, G., Vales, N., Bonvalot, S., Briais, A. (2012). Spherical harmonic modelling to ultra-high degree of Bouguer and isostatic anomalies. *Journal of Geodesy*, V86, 7, 499-520, DOI: 10.1007/s00190-011-0533-4.

Bonvalot, S. The International Gravimetric Bureau. In "The Geodesist's Handbook 2012" (2012). H. Drewes, H. Hornik, J. Adam, S. Rozsa Eds. (IAG). *Journal of Geodesy*, V86, 10. doi: 10.1007/s00190-012-0584-1.

Bruinsma S., Förste C., Abrikosov O., Marty J-C., Rio M-H., Mulet S., Bonvalot S. The new ESA satellite-only gravity field model via the direct approach: Confrontation with the GOCE mission objectives *Geophys. Res. Letters*, 40,1-6, DOI:10.1002/grl.50716, 2013.

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Wziontek, H., H. Wilmes, S. Bonvalot, 2011. AGrav: An international database for absolute gravity measurements. In "Geodesy for Planet Earth (S. Kenyon at al. eds)". *IAG Symposia Series*. 136, 1035-1040, Springer-Verlag, Berlin, doi:10.1007/978-3-642-20338-1_130.

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Ramillien G., Seoane L., Frappart F., Biancale R., Gratton S., Bourgogne S., 2012. Regional Recovery of Continental Water Mass Time-variations from GRACE-based Geopotential Anomalies over South America. *Surveys in Geophysics*, pp. 1-19., DOI:10.1007/s10712-012-9177-z.

Seoane L., Biancale R., Gambis D., 2012. Agreement between Earth's rotation and mass displacement as detected by GRACE". *Journal of Geodynamics*, Volume 62, pp. 49–55, DOI:10.1016/j.jog.2012.02.008.

Panet I., Flury J., Biancale R., Gruber T., Johannessen J., van den Broeke M. R., van Dam T., Gegout P., Hughes C. W., Ramillien G., Sasgen I., Seoane L., Thomas M., 2012. Earth System Mass Transport Mission (e.motion): A Concept for Future Earth Gravity Field Measurements from Space. *Surv Geophys*. DOI 10.1007/s10712-012-9209-8.

Frappart F., Seoane L., Ramillien G., 2013. Validation of GRACE-derived Terrestrial Water Storage from a regional approach over South America. *Remote Sensing of Environment* (in press).

Seoane L., Ramillien G., Frappart F., and Leblanc M. Regional GRACE-based estimates of water mass variations over Australia: validation and interpretation (2013), *Hydrol. Earth Syst. Sci. Discuss.*, 10, 5355-5395, 2013, doi:10.5194/hessd-10-5355-2013 (en revision).

Maps

Bonvalot, S., Balmino, G., Briais, A., M. Kuhn, Peyrefitte, A., Vales et al., M. World Gravity Map : Complete spherical Bouguer anomaly, 1:50000000 map, Eds. BGI-CGMW-CNES-IRD, ISBN 978-2-2917310-08-3, Paris, 2012.

Bonvalot, S., Balmino, G., Briais, A., M. Kuhn, Peyrefitte, A., Vales et al., M. World Gravity Map : Isostatic anomaly (Airy Heiskanen (Tc=30km), 1:50000000 map, Eds. BGI-CGMW-CNES-IRD, ISBN 978-2-2917310-09-0, Paris, 2012.

Bonvalot, S., Balmino, G., Briais, A., M. Kuhn, Peyrefitte, A., Vales et al., M. World Gravity Map : Surface free-air anomaly, 1:50000000 map, Eds. BGI-CGMW-CNES-IRD, ISBN 978-2-2917310-07-6, Paris, 2012.

Communications

2013

Bonvalot, S., Balmino, G., Reinquin, F., Briais, A., Gabalda, G., Seoane, L., Wilmes, H., Wziontek, H., 2013. Bureau Gravimetrique International (BGI) : role and services to Terrestrial Gravimetry. *IAG Symposium on Terrestrial Gravimetry: Static and mobile measurements (TG-SMM 2013)*. Sept., 2013., St Petersburg, Russia.

Bonvalot, S., Balmino, G., Reinquin, F., Briais, A., Gabalda, G., Seoane, L., Wilmes, H., Wziontek, H., 2013. Bureau Gravimetrique International (BGI) : Status of the IAG service. *IAG General Assembly.* Sept., 2013., Potsdam, Germany.

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