

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.

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 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. Collaborations within IAG Services and Commissions and within IGFS activities are also very active in areas such as absolute gravimetry, global gravity modeling, combination of satellite & surface data, etc.

Most of services provided by BGI (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 moved in 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.

A new partnership has been established in 2008 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. This database will provide the support for the new International Reference Gravity Network that will replace the old IGSN71.

In the last few years, active collaborations also took place with NGA (USA), DTU (Denmark) or Curtin University (Australia) for the computation or the validation of the 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*
 S. Bruinsma *Geodesist - Space geodesy*
 G. Gabalda *Geophysicist – Absolute & relative gravimetry*
 N. Lestieu *Secretary*
 F. Reinquin *Geodesist - Database manager / software developer*
 L. Seoane *Geodesist - Satellite gravimetry*

Others teams and contributors (France)

Paris (IPGP - IGN-LAREG : M. Diament, I. Panet, G. Pajot) ; Orléans (BRGM : G. Martelet) ; Strasbourg (EOST : J. Hinderer, S. Rozat, JP. Boy, JB. Daniel) ; Montpellier (Géosciences : N. Le Moigne, C. Champollion, S. Mazzotti) ; Brest (IFREMER : E. Mousat, 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 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.

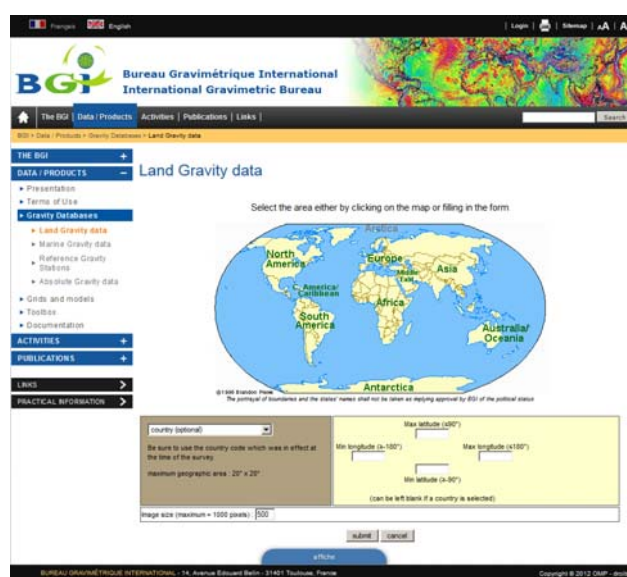
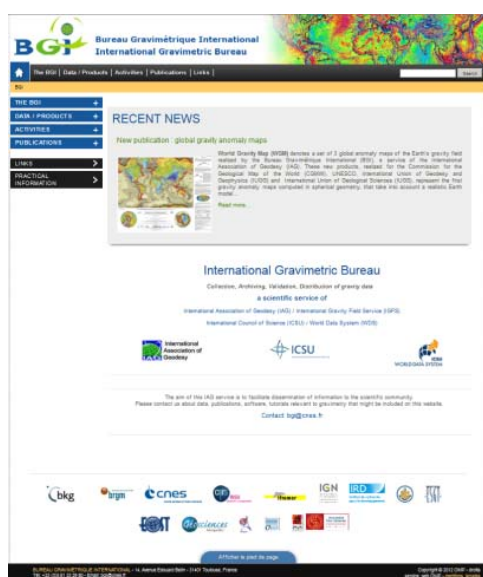


Figure 2: Left) Main page of the BGI website. Right) Data consultation/request page (<http://bgi.obs-mip.fr>)

Overview of the BGI gravity database

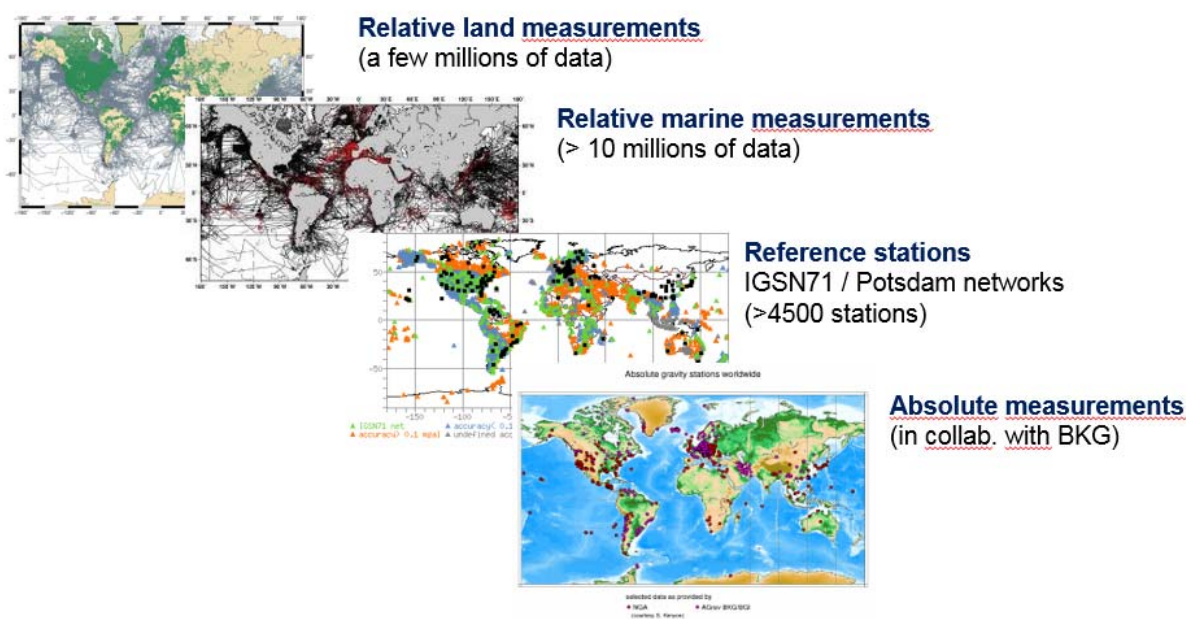


Figure 3: Overview of the global gravity database maintained at BGI (<http://bgi.obs-mip.fr>)

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). Few millions of relative data are currently distributed each year to scientific users.

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).

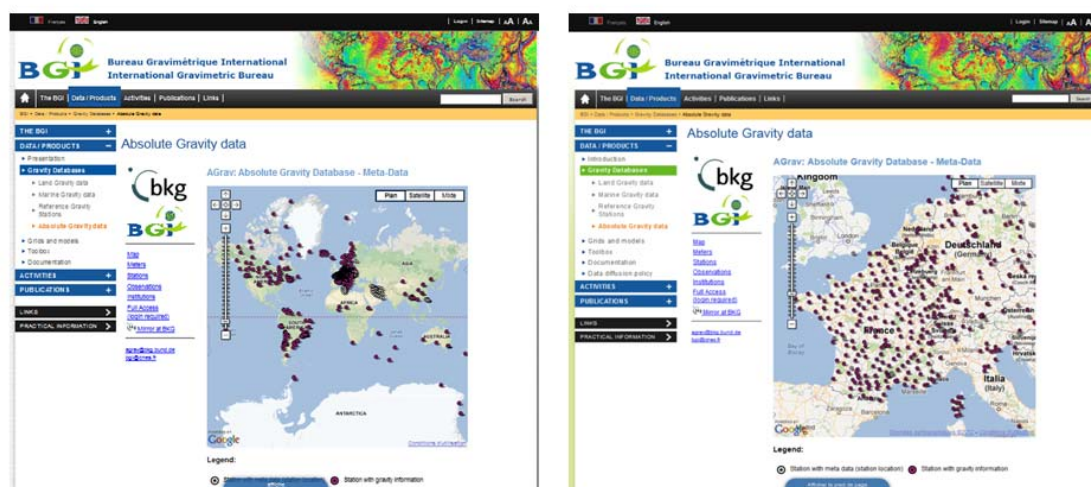


Figure 4: Internet Interface of the Absolute Gravity database (BGI-BKG)
 Current status (30/5/2015) : 1121 stations / 3344 observations / 51 instruments / 44 institutions
 (<http://bgi.obs-mip.fr> - <http://agrav.bkg.bund.de/agrav-meta>)

The database includes (summer 2015): 1121 Stations, 3344 Observations from 51 Gravimeters provided by 44 Institutions from more than 25 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.).

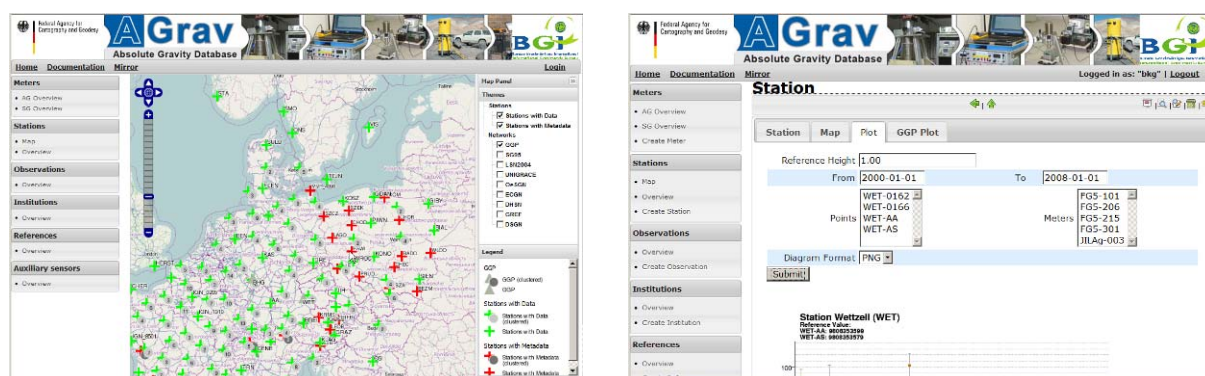


Figure 5: Snapshots of interface of the 2nd generation of the Absolute Gravity database (BGI-BKG)

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 (see example of resulting plot provided to users on fig. 6).

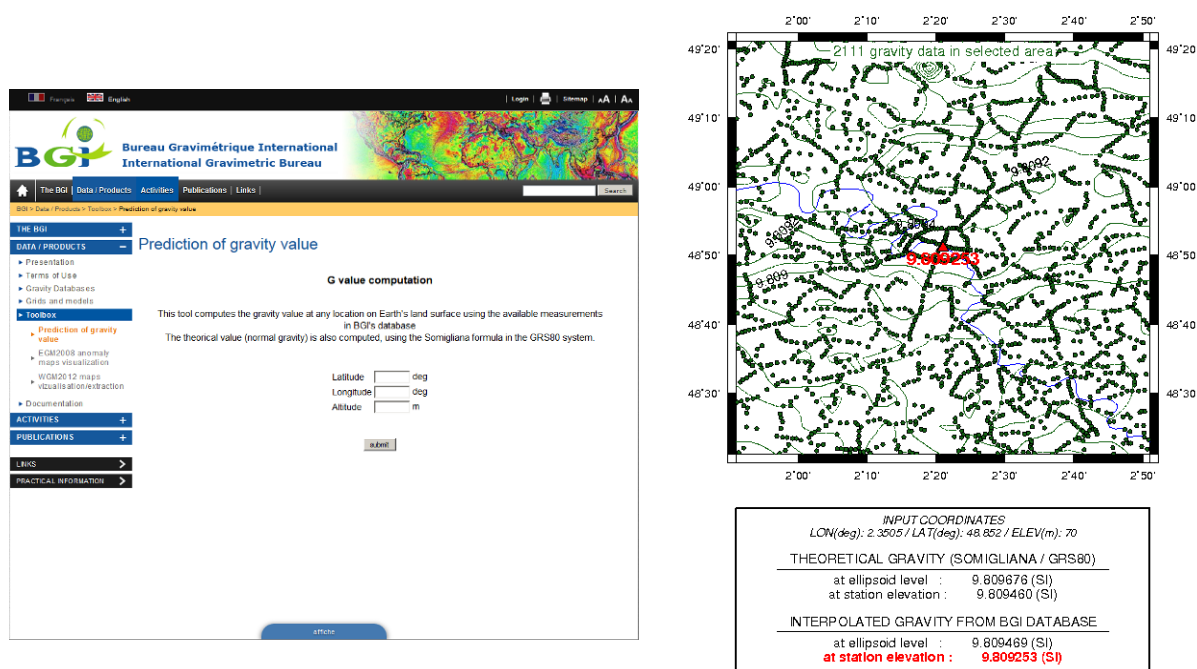


Figure 6 : Web page and resulting plot for the prediction of the gravity value at a given point
<http://bgi.omp.obs-mip.fr/index.php/eng/Data-Products/Toolbox/Prediction-of-gravity-value>

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>).



WGM2012 global grid models (2'x2' resolution)

1. Complete spherical Bouguer gravity anomaly
 Download 2 min resolution netcdf GMT grid : WGM2012_Bouguer_ponc_2min
 Download 2 min resolution Ascii grid (xyz ZIP file) : WGM2012_Bouguer_ponc_2min
 Download Ascii GMT color table : PALET_WGM_Bouguer_Global.cpt

2. Complete spherical Isostatic gravity anomaly (Airy-Heiskanen, Tc=30 km)
 Download 2 min resolution netcdf GMT grid : WGM2012_Isostatic_ponc_2min
 Download 2 min resolution Ascii grid (xyz ZIP file) : WGM2012_Isostatic_ponc_2min
 Download Ascii GMT color table : PALET_WGM_Isostatic_Global.cpt

3. Free-air gravity anomaly on the Earth's surface (Molodenski)
 Download 2 min resolution netcdf GMT grid : WGM2012_Freeair_ponc_2min
 Download 2 min resolution Ascii grid (xyz ZIP file) : WGM2012_Freeair_ponc_2min
 Download Ascii GMT color table : PALET_WGM_Freeair_Global.cpt

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.

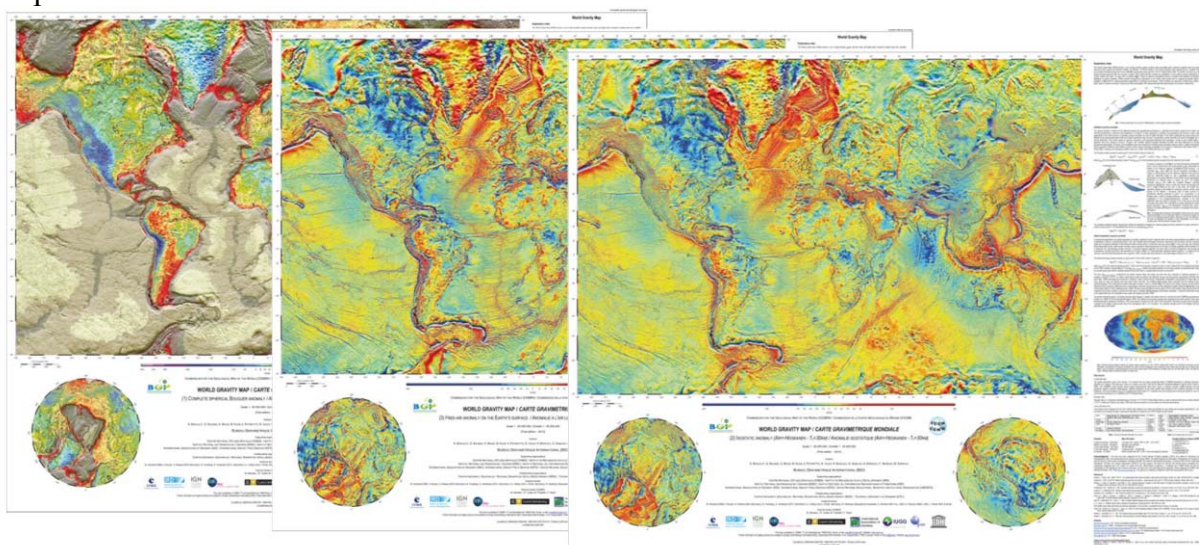


Figure 8: World Gravity Maps (Bonvalot et al., 2012). The 1:50 000 000 maps include Complete Spherical Bouguer anomaly, Complete spherical isostatic anomaly, Free-air anomaly on the Earth's surface (Molodenski).

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).

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 achieved to handle spherical harmonics to ultra-high degrees (Balmino et al., 2011).

These new products, providing useful and homogeneous information on the Earth's static gravity field anomalies at regional and global scales for many applications, have been made available on the BGI website. An interactive tool also enables 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 will be done to include more surface data (field, marine or airborne surveys) as well as satellite data.

Software : *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.

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, Argentina, Peru, French Guiana), Africa (Niger, Benin, Djibouti), Asia (Bouthan) and Europe.

Participation to scientific conferences and workshops

- [IAG/IGFS Int. Symposium](#) (Shanghai, China - 07/2014)
- [AGU 2014](#) (San Francisco, USA, 12/2014)
- [ESA GOCE Users Workshop](#) (Paris, France -11/2014)
- [EGU 2014](#) (Vienne, Austria, 04/2014)
- [AGU 2013](#) (San Francisco, USA, 12/2013)
- [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)
- [International Symposium on Earth Tides](#) (Varsaw, Poland – 04/2013)
- [EGU 2013](#) (Vienne, Austria, 04/2013)
- [IAG/IGFS Int. Symposium on Gravity, Geoid, Height Systems](#) (Venice, Italy, 10/2012)

- Workshop on Absolute Gravimetry (Boulder Co, USA, 09/2012)
- IUGG General Assembly (Melbourne, 08/2012)
- EGU 2012 (Vienne, Austria, 04/2012)
- 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 (Shanghai, China, 2014)
- IAG Scientific Assembly 2013 – 150 years of IAG (Potsdam, Germany - 09/2013)
- TGSMM Terrestrial Gravimetry (St. Petersburg, Russia - 09/2013)

Perspectives

BGI will benefit of the continuing support (long term financial and personal support) from the French research Authorities. Activities of the service will thus be ensured according to the BGI missions and objectives and to the positive evaluation resulting from the IAG Service Assessment. Some evolutions in the service and its organization will be also proposed according to the recent recommendations made the IAG Service Assessment team. Here are listed the main perspectives for the next years.

Improvement of the global gravity databases and services

BGI 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, BGI 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. Products derived from airborne gravity surveys (grids for instance) are also very welcome to be included in the BGI database for improving the global data coverage.

Contribution to new global gravity models

BGI will strength within IAG/IGFS activities its collaboration with other groups also involved in the determination or analysis of global gravity field models as for instance with NGA (USA), ISG Polimi (Milan), DTU (Denmark), Curtin Univ (Australia), IGN/IPG Paris (France). The contribution of the BGI surface gravity database for the determination and evaluation of the future Earth Gravity Model is expected.

Establishment of the new global absolute gravity reference system

BGI will contribute, within IAG Commission 2 and IAG/IGFS activities, to the working group for the Establishment of the future global absolute gravity reference system. The main contributions will concern : (i) the establishment of a global network of reference stations linked to the international comparisons of absolute gravimeters ; (ii) the initiation of the replacement of the International Gravimetric Standardization Network 1971 (IGSN71) by the new Global Absolute Gravity Reference System ; (iii) the archiving and distribution of the absolute measurements through the existing AGrav database jointly with BKG. BGI may also provide its recent expertise in absolute gravity measurements using cold-atom gravimeters.

Publications by BGI team (2011-2015)

2015

Balmino, G. et S. Bonvalot. Gravity anomalies. In: *Encyclopedia of Geodesy*, Springer (submitted).

Rigo, A., C. Adam, M. Grégoire, M. Gerbault, R. Meyer, M. Rabinowicz, F. Fontaine, S. Bonvalot. Insights for the melt migration, the volcanic activity and the ultra-fast delamination of lithosphere related to the Yellowstone plume (Western USA). *Geophys. Journal Int.* (in press).

Driussi, O., Briais A., Maillard A., Evidence for transform motion along the South Balearic margin and implications for the kinematics of opening of the Algerian Basin, 2015. *Bull. Soc. Géol.,Fr.* Volume 186 Number 4-5 July-October 2015.

Pallero, J.L.G., Fernandez-Martinez, J.L., Bonvalot, S., Fudym, O. 2015. Gravity inversion and uncertainty assessment of basement relief via Particle Swarm Optimization. *Journal of Applied Geophysics*. Doi: 10.1016/j.jappgeo.2015.03.008

Perrouy, S., Moussirou, B., Martinod, J., Bonvalot, S., Carretier, S., Gabalda, G., Monod, B., Herail, G., Regard, V., Remy, D. Geometry of two glacial valleys in northern Pyrenees estimated using gravity data. *Comptes Rendus Geosciences*. Doi: 10.1016/j.crte.2015.01.002

2014

Bruinsma S., Förste C., Abrikosov O., Lemoine, J-M., Marty J-C., Mulet S., Rio M-H., Bonvalot S. ESA's satellite-only gravity field model via the direct approach based on all GOCE data". *Geophysical Research Letters*. 2014GL062045R.

Panet, I., Pajot-Metivier, G., Lefftz, M., Metivier, L., Diament, M., Mioara, 2014. Mapping the mass distribution of Earth's mantle using satellite-derived gravity gradients. *Nature Geosciences*, 7, 2, 131-135, <http://dx.doi.org/10.1038/ngeo2063>

Mikhailov, V.O, Panet, I., Hayn, M. Timoshkina, E.P., Bonvalot, S., Lyakhovsky, V., Diament, M. Viron, O.de. Comparative study of temporal variations in the earth's gravity field using GRACE gravity models in the regions of three recent giant earthquakes, 2014. *J Izvestiya, Physics of the Solid Earth*, March 2014, Volume 50, Issue 2, pp 177-191. doi:10.1134/S1069351314020062

2013

Bruinsma S., Förste C., Abrikosov O., Marty J-C., Rio M-H., Mulet S., Bonvalot S. (2013). 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.

Martin, M., Monteiller, V., Komatitsch, D., Perrouy, S., Jessell, M., Bonvalot, S., Lindsay, M. (2013). Gravity inversion using wavelet-based compression on parallel hybrid CPU/GPU systems: application to SW Ghana region. *Geophysical Journal International*. Volume 195, Issue 3, pp. 1594-1619, doi:10.1093/gji/ggt334, 2013.

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*. Volume 137, October 2013, Pages 69–83. doi:10.1016/j.rse.2013.06.008

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

2012

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., 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.

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.

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