International Service for the Geoid (ISG)

http://www.isgeoid.polimi.it/

President: Mirko Reguzzoni (Italy)
Director: Giovanna Sona (Italy)

Structure

The Service is currently provided by two centers, one at the Politecnico di Milano (Italy) and the other at NGA (USA).

In addition to the president and the director, the ISG staff is composed by other scientists (F. Sansò, R. Barzaghi, A. Albertella, D. Carrion, C.I. De Gaetani and L. Rossi) as well as a secretary (C. Vajani).

The ISG advisory board is composed by the following scientists with expertise in the field of geoid determination:

- N. Pavlis (USA)
- M. Sideris (Canada)
- J. Huang (Canada)
- R. Forsberg (Denmark)
- U. Marti (Switzerland)
- H. Denker (Germany)
- L. Sánchez (Germany)
- I. Tziavos (Greece)
- W. Kearsley (Australia)
- D. Blitzkow (Brazil)

ISG is currently involved in the Joint Working Groups JWG 2.2.1 of Sub-commission 2.2 “Integration and validation of local geoid estimates”.

Overview

In the period 2015-2017, the main scientific activities of ISG have been related to the following research lines:

- local/regional geoid estimation;
- merging of local geoid estimates, defining a unified height datum;
- school organization and scientific support to researchers on geoid estimation;
- ISG geoid repository and website update.

As for the geoid estimation, the main effort has been devoted to the GEOMED-II project. The goal of this project is the computation of a high-accuracy and high-resolution geoid model for the Mediterranean Sea employing land and marine gravity data and GOCE/GRACE based global models. Moreover, the Italian geoid model has been recomputed, after validating the existing gravity database.

As for the local geoid merging, this activity has been performed in the framework of the JWG2.2.1 "Integration and validation of local geoid estimates" of IAG Commission 2. The output will represent a new product of ISG and aims to be a contribution in the frame of GGOS for the establishment of an International Height Reference System (IHRS).
According to tradition, during this two-year period ISG organized an international school on geoid determination and height datum definition. The school was held at the Geodesy Department of Mongolian University of Science and Technology (MUST), Ulaanbaatar, Mongolia, from 6th to 10th June, 2016. The total number of participant was 30, half of them coming from abroad.

Last but not least, to maintain the main ISG purpose of collecting, analysing and redistributing local and regional models, the ISG geoid repository has been continuously updated and the ISG website has been modified accordingly. In particular, the webpage of each model has been “standardized” in the sense of providing the same type of information. Moreover, all public models are redistributed with a unique ASCII format.

**Local/regional geoid estimation**

In the last two years, the activities on local/regional geoid estimation have been focused on the GEOMED-II project and the ITALGEO model update. The former is dedicated to the computation of a geoid model for the Mediterranean Sea. It is sponsored by the European Space Agency (ESA) and by all the participating Institutions. Apart from the IGFS, BGI and ISG services, the project partners are:
- Politecnico di Milano (Italy),
- GET, SHOM and OCA/Geoazur (France),
- Aristotle University of Thessaloniki (Greece),
- DTU Space (Denmark),
- General Command of Mapping (Turkey),
- University of Zagreb (Croatia),
- University of Jaén (Spain).

The processing methodology is based on the well-known remove-compute-restore approach using both stochastic and spectral methods for the determination of the geoid and the rigorous combination of heterogeneous data.

The input data come from the BGI database and from the project partners, in particular classified gravimetric data from Italy, Greece, Croatia and Turkey were used. In the preliminary phases of the processing, all the available gravity observations for the wider Mediterranean basin have been homogenized in terms of their horizontal system and are being validated and homogenized in terms of gravity system. An outlier rejection has been performed and some biases have been identified. These biases have a negative impact on the covariance function estimation and, of course, on the geoid estimation. Local analyses and comparisons are being performed to remove these biases.

The geoid grids will be computed by the collocation method using the GRAVSOFT software. The result will be compared with EGM2008 and DTU13 for blunder detection. Stokes and FFT-based geoid models will be also determined and compared with the collocation-based ones. The accuracy of the estimated geoid will be assessed through comparisons to GPS/levelling and altimeter data.

For the time being, preliminary computations have been performed to test the processing chain. In particular, a test of the collocation method and a test of the FFT-based method have been performed. The test consisted in first estimating the EGM2008 undulation residuals starting from EGM2008 gravity anomalies residuals ($\Delta g\text{[2190]} - \Delta g\text{[1100]}$) and then comparing the estimates to the actual EGM2008 undulation residuals ($N\text{[2190]} - N\text{[1100]}$, see Figure 1). This allowed to check the procedure and to choose the best FFT kernel modification for the GEOMED-II computation. A lot of effort has been dedicated to investigate and properly determine topographic effects over both land and marine areas to efficiently reduce land and marine gravity data towards geoid determination. In fact, over land areas, the latest SRTM-based DTMs offer high-accuracy
and high-resolution information on the topographic variations, in the sense that they properly model the high-frequency contributions of the topographic masses. Over marine regions, the situation is quite different, since the resolution of the available DBMs is not always capable to remove the high frequencies that are present in shipborne marine gravity data. On the other hand, marine gravity data do not often have the necessary spatial resolution to rigorously model the high frequencies depicted in the DBM. Aliasing effects on the estimated topographic effects will be also investigated and the corresponding errors introduced in gravity anomalies and geoid heights will be taken into account. Then, the DTM/DBM combination that provides the overall best results, in terms of the smoothness of the residual gravity anomalies, will be outlined along with the final topographically corrected gravity anomalies and geoid indirect effects.

The new Italian gravimetric geoid (ITALGEO15) has been computed after a thorough revision of the available gravity database. The database has been homogenized in terms of horizontal and gravity reference systems and an outlier rejection has been performed mainly through local consistency checks. This resulted in an improvement in the differences of the geoid with respect to the GPS/levelling data, after reference system adjustment, see Figure 2. The standard deviation of the differences decreases of two centimetres with respect to the previous release of the Italian geoid (ITALGEO05), see Table 1.
Fig. 2: Differences between GPS/levelling and ITALGEO15 gravimetric geoid after reference system adjustment (units in m).

<table>
<thead>
<tr>
<th></th>
<th>ITALGEO05</th>
<th>ITALGEO15</th>
</tr>
</thead>
<tbody>
<tr>
<td># Values</td>
<td>956</td>
<td>956</td>
</tr>
<tr>
<td>Mean [m]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>St. Dev. [m]</td>
<td>0.114</td>
<td>0.090</td>
</tr>
<tr>
<td>Min [m]</td>
<td>-0.292</td>
<td>-0.235</td>
</tr>
<tr>
<td>Max [m]</td>
<td>0.294</td>
<td>0.235</td>
</tr>
</tbody>
</table>

Table 1: Statistics of the differences of ITALGEO05 and ITALGEO15 gravimetric geoids with respect to the GPS/levelling over the continental territory.

**Merging of local geoid estimates**

The large availability of local/regional geoid/quasigeoid models in the ISG archive fosters the study and the development of a merging strategy to produce unified models between neighbour countries. The proposed method consists of first estimating biases and systematic effects by a least-squares adjustment of the local geoid residuals with respect to a satellite-only model, and then correcting the remaining distortions along the national borders to better join the local geoid models. This investigation is performed in the framework of the JWG2.2.1 "Integration and validation of local geoid estimates" of IAG Commission 2.
A preliminary test has been implemented on a subset of European models, including the following countries (the name of the used model in brackets):
- France (QGF98)
- Corsica (QGC02)
- Italy (ITALGEO05)
- Iberian Peninsula (IBERGEO2006)
- Belgium (BG03)
- Switzerland (CHGEO2004Q)
- Greece (GreekGeoid2010).

For each model, a subset of about 1000 points on land and inside the national borders has been selected for the bias and trend estimation. The digital terrain model (DTM) for each country has been derived from SRTM.

The reference geoid has been synthesized from the GOCO-05S satellite-only global model up to spherical harmonic degree and order 280 and has been subtracted to the local solutions. For the moment, neither the contribution of global models at higher degrees, e.g. using EGM2008, nor a residual terrain correction (RTC) has been further subtracted to the geoid residuals.

The geoid commission error of the reference model has been modelled by propagation from the block-diagonal error covariance matrix of the GOCO-05S coefficients, while the omission error above degree 280 has been modelled by using EGM2008 degree variances. A white noise with a standard deviation of 5 cm has been attributed to each local geoid model.

By using the computed geoid residuals and this stochastic modelling, a bias and a trend for each local model have been estimated by least-squares adjustment. The systematic effect $S$ included into each local geoid has been modelled as follows:

$$ S(\varphi, \lambda) = b_1 + b_2 (\varphi - \varphi_0) + b_3 \cos(\lambda - \lambda_0) $$

where $\varphi_0$ and $\lambda_0$ are the mean latitude and longitude, respectively. The result of this adjustment is reported in Table 2. The estimated biases and trends are shown in Figure 3, while the residuals before and after the de-trending procedure are displayed in Figures 4 and 5.

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Corsica</th>
<th>Italy</th>
<th>Iberia</th>
<th>Switzerland</th>
<th>Belgium</th>
<th>Greece</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{b}_1$</td>
<td>-1.067</td>
<td>0.344</td>
<td>0.246</td>
<td>-0.930</td>
<td>-0.617</td>
<td>-0.140</td>
<td>0.305</td>
</tr>
<tr>
<td>$\hat{b}_2$</td>
<td>1.466</td>
<td>21.090</td>
<td>-10.247</td>
<td>-1.826</td>
<td>-3.492</td>
<td>2.452</td>
<td>-0.733</td>
</tr>
<tr>
<td>$\hat{b}_3$</td>
<td>-4.753</td>
<td>-81.137</td>
<td>-0.873</td>
<td>-0.697</td>
<td>-2.379</td>
<td>-0.261</td>
<td>11.248</td>
</tr>
<tr>
<td>$\hat{\sigma}_{b_1}$</td>
<td>0.002</td>
<td>0.042</td>
<td>0.004</td>
<td>0.002</td>
<td>0.004</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>$\hat{\sigma}_{b_2}$</td>
<td>0.056</td>
<td>6.459</td>
<td>0.121</td>
<td>0.069</td>
<td>0.975</td>
<td>1.656</td>
<td>0.229</td>
</tr>
<tr>
<td>$\hat{\sigma}_{b_3}$</td>
<td>0.069</td>
<td>16.943</td>
<td>0.140</td>
<td>0.060</td>
<td>0.476</td>
<td>1.459</td>
<td>0.333</td>
</tr>
</tbody>
</table>

Table 2: Estimated biases and trends with their error standard deviations (units in m).
Fig. 3: Estimated biases and trends (units in m).

Fig. 4: Geoid residuals with respect of GOCO-05S before the de-trending procedure, i.e. as the models are stored in the ISG archive (units in m).

Fig. 5: Geoid residuals with respect of GOCO-05S after the de-trending procedure (units in m). Discontinuities at national borders are significantly reduced.
School organization and scientific support to researchers on geoid estimation

One of the main tasks of ISG consists in organizing or supporting technical schools on geoid estimation and related topics. The XII International IGS School was held in Mongolia from 6th to 10th June, 2016, at the Geodesy Department of Mongolian University of Science and Technology (MUST), Ulaanbaatar. This was the second geoid school held in Asia after the one in Johor-Baru, Malaysia, at the Department of Survey and Mapping, from 21st to 25th February, 2000.

The Local Organizing Committee (LOC) was composed by representatives from the following institutions/organizations:
- Mongolian University of Science and Technology (MUST),
- MonMap Engineering Services Co., Ltd,
- Mongolian Association of Geodesy, Photogrammetry and Cartography (MAGPC),
- Administration of Land Affairs, Geodesy and Cartography (ALAGAC),
- Ministry of Construction and Urban Development (MCUD).

A dedicated website was setup at the address: www.monmap.mn/geoidschool2016/ reaching more than 300 accesses by June. Over 100 online registration form submissions were collected, but many of willing participants from developing countries were not able to attend the school due to lack of budget and travel support. In the end, 30 participants coming from 9 different countries (Bhutan, China, India, Latvia, Mongolia, Philippines, Poland, Russia and Sri Lanka) attended the school, see Figure 6.

As usual, the program was structured to be self-contained for any participant at graduate level with basic knowledge of geodesy, including theoretical lectures and computer exercises based on the available software. The invited teachers were:
- Prof. F. Sansò, Politecnico di Milano, Italy,
- Prof. R. Barzaghi, Politecnico di Milano, Italy,
- Prof. M. Sideris, University of Calgary, Canada,
- Prof. R. Forsberg, National Space Institute, Denmark,
- Dr. S. Holmes, SGT Inc. USA.

The school program was the following:
- General theory on gravity field (6th June),
- The height datum unification (6th June),
- Terrain effect computation and remove/restore - theory and practical exercises (7th June),
- Residual geoid estimation - theory and practical exercises (8th June),
- Global geopotential models - theory and practical exercises (9th June),
- Presentations and case studies (10th June).

During the last day, a final session was given to summarize the school topics and distribute training certificates to the participants. Lecture notes of the courses were also distributed, as well as a CD-ROM containing software and data for exercises. The CD-ROM was freely distributed to the participants after a declaration of non-commercial use. An ice-break dinner and two sightseeing tours were organized by LOC, just before and after the school.

Apart from organizing the XII International Geoid School in Mongolia, in the last two years ISG provided educational activities and supported studies related to geoid estimation theory and in general to physical geodesy by hosting at Politecnico di Milano, Italy, the following students and researchers:
- A PhD student of the Center of Geodesy and Geodynamics of Nigeria, who is developing his thesis on the national gravity field estimation. For his studies he was hosted at Politecnico di Milano during two periods: 7-11 September 2015 and in spring 2016.
- A researcher of the Faculty of Petroleum and Renewable Energy and Earth Sciences at the University of Ouargla, Algeria. He was interested in the precise local geoid determination from the GRACE and SRTM satellite data with the aim of studying the tectonic activity in Algeria. He was hosted at Politecnico di Milano in autumn 2015.
- Two researchers of the Service of Surveying of the National Institute of Cartography of Cameroun, who came at Politecnico di Milano in November 2015 for a first training session on geoid computation. After that, they maintained frequent contacts with ISG staff, and a second training session was scheduled for the end of 2016, now shifted in September 2017.
- A PhD student from the University of Curitiba, Brazil, who spent three months at Politecnico di Milano, from March to September 2016, developing studies on the height datum problem.
- A PhD student from the Technical University of Denmark (DTU) spent three months at Politecnico di Milano, from October to December 2016, working together with ISG staff on radar-altimetry, gravimetry and gravity field estimation.

Usually, further contacts follow the hosting period, to strengthen the cooperation and to provide scientific support when researchers and students come back to their countries.

**Fig. 6**: Group photo of people organizing and attending the XII International IGS School.

**ISG geoid repository and website update**

In the last two years, the ISG archive of local/regional geoid models has been continuously updated. Not only the latest release of a model is stored in the archive, but also outdated versions are collected in order to keep memory of the work done in the past and to allow for comparisons. The full (or almost the full) series of the official geoid models are available for some countries, like US, Canada, Italy, France, Norway, Japan, Australia, New Zealand. Three possible policy rules are considered for the model distribution: “public” if it can be freely downloaded from the website, “on demand” in case the authors asked to be informed before distributing the model, and “private” if it is just included in the archive but it cannot be distributed to the users. Therefore, the aim of the "private" policy is to inform users that a model exists without publishing any data through the ISG service. More than 150 models are currently available in the ISG database, whose composition is reported in Tables 3, 4 and 5 (last update of the statistics was on 30th June 2017). The global coverage of the available gridded geoid models, together with their spatial resolution, is shown in Figure 7. Metadata of all models are managed through Data Citation Index by Clarivate Analytics.
<table>
<thead>
<tr>
<th>Continent</th>
<th>Number</th>
<th>Continent</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>62</td>
<td>&lt; 1991</td>
<td>4</td>
</tr>
<tr>
<td>Africa</td>
<td>17</td>
<td>1996 – 2000</td>
<td>39</td>
</tr>
<tr>
<td>Asia</td>
<td>15</td>
<td>2001 – 2005</td>
<td>21</td>
</tr>
<tr>
<td>Oceania</td>
<td>13</td>
<td>2006 – 2010</td>
<td>45</td>
</tr>
<tr>
<td>South America</td>
<td>9</td>
<td>2011 – 2015</td>
<td>33</td>
</tr>
<tr>
<td>Antarctica</td>
<td>4</td>
<td>&gt; 2015</td>
<td>3</td>
</tr>
<tr>
<td>Arctic</td>
<td>3</td>
<td><strong>Total</strong></td>
<td>159</td>
</tr>
</tbody>
</table>

Table 3: Number of models per continent in the ISG archive.

<table>
<thead>
<tr>
<th>Policy Rule</th>
<th>Number</th>
<th>Policy Rule</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>113</td>
<td>&lt; 1991</td>
<td>4</td>
</tr>
<tr>
<td>On-Demand</td>
<td>18</td>
<td>1991 – 1995</td>
<td>14</td>
</tr>
<tr>
<td>Private</td>
<td>28</td>
<td>1996 – 2000</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2001 – 2005</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2006 – 2010</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2011 – 2015</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 2015</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>159</td>
<td><strong>Total</strong></td>
<td>159</td>
</tr>
</tbody>
</table>

Table 5: Number of models per policy-rule in the ISG archive.

Fig. 7: Spatial coverage of the gridded geoid models available at ISG. Colourbar shows the highest spatial resolution per location (log10 scale, unit: arc-minutes).

The ISG website is updated simultaneously to the ISG archive. For each geoid model that is stored in the archive a dedicated webpage is available on the website, containing information about the model name, year, authors, contact person, type (gravimetric, geometric or hybrid, geoid or quasi-geoid) and policy rule. There is a short description of the model characteristics, at least one bibliographic reference and a model figure.
If the model is classified as “public”, the corresponding data file can be downloaded from the webpage in a unique ASCII format (.isg), whose specifications are provided in the website. After authors’ authorization, the “on demand” models can be distributed to users in the same ASCII file format. The webpage of each model can be reached from a complete list of available geoids or by clicking on a geographical map. Apart from the geoid repository, the website has been updated in the home page, in the section dedicated to the geoid schools and in the one on the on-going projects. News section has been continuously kept up-to-date. No papers have been submitted to Newton’s Bulletin in the last two years. The current home page of the ISG service is shown in Figure 8. Some statistics on the website access are displayed in Figure 9.

![Fig. 8: Home page of the ISG website.](image)

![Fig. 9: Statistics on the number of visitors and page views of the ISG website.](image)
JWG 2.2.1: Integration and validation of local geoid estimates

Chair: M. Reguzzoni (Italy)
Vice Chair: G. Vergos (Greece)

Members:
• G. Sona (Italy)
• R. Barzaghi (Italy)
• F. Barthelmes (Germany)
• M.F. Lalancette (France)
• T. Basic (Croatia)
• H. Yildiz (Turkey)
• N. Kuhtreiber (Austria)
• H. Abd-Elmotaal (Egypt)
• W. Featherstone (Australia)
• Jianliang Huang (Canada)
• Cheinway Hwang (Taiwan)
• Shuanggen Jin (China)
• G. Guimaraes (Brazil)

Overview

A detailed description of the activities performed by this working group during the period 2015-2017 can be found in the report of the Sub-commission 2.2, also including numerical results and publications.