International Geoid Service (IGeS)

http://www.iges.polimi.it

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Overview

In the period 2011-2013, the main scientific activities of IGeS have been related to the following research lines:
- methods for merging local geoid estimates;
- methods for defining a global height datum;
- support to research centres and national institutions on geoid estimation;
- organization of schools on geoid and height datum estimation;
- IGeS website update.

High accuracy and reliable satellite based global geopotential models can be used either to merge local geoid solutions and to properly define a unified global height datum. This second issue is particularly relevant and is one of the GGOS themes (i.e. Theme 1: Unified Height System). Both problems are strictly related to the IGeS mission that is focused on local/regional geoid estimation and evaluation.

The new methodologies that were developed for merging local geoids and for defining a global height datum are based on space-wise GOCE global geopotential model.

The procedure for merging geoids assumes that a bias exists between local estimates due to inconsistencies in defining the local height datum. By comparing these solutions with the GOCE derived model, this bias can be estimated and removed. The global height datum definition method which has been devised relies on GOCE geopotential model too. As for the method used in combining local geoids, height datum biases are assumed among areas covering the whole Earth. It can be proved that they can be estimated using a fully satellite derived global geopotential model which is not affected by these biases. Some numerical tests were performed on both methodologies and the results were presented at the EGU General Assembly 2012.

Furthermore, the support activity on geoid computation continued. IGeS has co-operated with the Centre for Geodesy and Geodynamics of Nigeria. Four researches of this Centre were hosted at IGeS in 2011 for two weeks. They attended a dedicated training course on geoid estimation theory and geoid estimation software. IGeS was also supporting the computation of the geoid in the San Paolo state in Brazil by hosting for one year (September 2011 to August 2012) a USP PhD student. A new geoid school was also organized during 2012. This school will be held in October 7th-11th, 2013 at the Universidad Tecnica Particular de Loja in Loja, Ecuador. This school will be devoted to geoid estimation and height datum definition. Contacts were also established with the International Centre for Theoretical Physics (ICTP) in Trieste (Italy) and with the Benha University in Cairo (Egypt) for organizing geoid schools in 2014. These two schools, if organized, will be important for involving in the geodetic community new researchers from Africa. Due to its location, the Cairo school will be possibly attended by a large number of people coming from Africa and Middle East. The same could be for the school at ICTP in Trieste because travelling supports and grants are expected from...
this institution (as a matter of facts, one of the missions of ICTP is to support scientific activities in developing countries).

Finally, in 2012, IGeS web site has been totally renewed and the local geoid solution database has been improved by adding new local solutions.

Activities

1. A method for merging local geoid estimates

Local geoid estimated in neighbouring countries often display inconsistency that can be mainly described by biases between the local solutions. Sometimes, it is required to define a unique solution merging two different geoid estimates thus removing the local biases. This can be properly done by using satellite only models that are not perturbed by local datum effects entering in the local geoid estimates. A two steps procedure has been devised based on GOCE geopotential model assuming that the residuals in geoid after removing the GOCE model can be represented as

\[ N_{\text{res}} = N - N_L = b + N_H + e_{\text{GOCE}} + \nu \]

where \( b \) is the bias related to the local solution, \( N_L \) is the low frequency geoid component (the one that is assumed to be described by the GOCE model), \( N_H \) is the high frequency geoid component, \( e_{\text{GOCE}} \) is the GOCE model error and \( \nu \) is the noise implied by the local geoid estimate. In the first step, by least squares, one can get the bias estimate as

\[ b = \left( D^T Q^{-1} D \right)^{-1} D^T Q^{-1} N_{\text{res}} \]

with

\[ Q = C_{N_H} + C_{e_{\text{GOCE}}} + C_{\nu} \]

This bias is then removed from \( N \) thus computing an unbiased geoid, i.e.

\[ N'_{\text{res}} = N - N_L - b \]

This is done for the two geoid estimates to be merged. Then the two unbiased estimates can be combined via a standard collocation procedure to get a common geoid over the computation area. The final merged solution is then obtained by adding back the \( N_L \) component implied by the GOCE model. This procedure has been tested by merging the Swiss and the Italian geoids. In Figure 1 a North-South section is plotted: the effectiveness of the procedure is clearly visible.
This method has been described in the paper “A least-squares collocation procedure to merge local geoids with the aid of satellite-only gravity models: the Italian/Swiss geoids case study”, by Gilardoni, Reguzzoni and Sampietro, which has been accepted for publication on Bollettino di Geofisica Teorica ed Applicata in 2013.

2. A method for global height datum estimation

The height datum problem has been revised in terms of the scalar Molodensky approach. It has been assumed that different height systems refer to their own benchmarks. So, the earth surface can be patched into domains having different reference height systems. For each patch, a bias in the gravity potential is assumed, so that it holds

$$ W(P_0^i) = W_0^i = W_0^i + \delta W_0 = U_0 + \delta W_0 $$

where the patch $S_j$ is referred to the benchmark point $P_0^i$. By developing this equation, one can get

$$ \tilde{\zeta}^j = -\delta W_0^j = \tilde{\zeta}(P_0^i) - \frac{T(P_0^i)}{\gamma} \tilde{\zeta}(P_0^i) - \frac{T_h(P_0^i)}{\gamma} \quad l = 1, \ldots, M \quad j = 1, \ldots, J $$

In this equation, the height anomaly biases $\tilde{\zeta}^j$ of the different patches can be estimated using the observed (biased) height anomalies ($P_0^i$ earth surface point, $\tilde{P}_0^i$ point on the biased telluroids)

$$ \tilde{\zeta}(P_0^i) = h(P_0^i) - h(\tilde{P}_0^i) \quad l = 1, \ldots, M $$

and the anomalous potential estimate

$$ T(P) = T_h(P) + T_h(P) = \sum_{n-2}^{\infty} \sum_{m-n}^{n} T_{mn} Y_{nm}(P) + \sum_{n-200}^{\infty} \sum_{m-n}^{n} T_{mn} Y_{nm}(P) $$
Here the $T_L$ component (the low frequency part) is given by the unbiased GOCE only model while the $T_L$ component (the high frequency part) is assumed to be accounted for by the EGM2008 model up to $n=2160$ (indeed this component is biased by the height datum but it can be proved that the induced error is of few millimetre).

Using this approach, an error budget has been performed. The earth surface has been divided into 158 patches and a data distribution has been assumed in order to have at least one point per patch. Also, different precisions for ellipsoidal and normal heights have been considered on the different patches. Assuming to estimate the $\delta W^{ij}$ by least squares, their standard deviation can be obtained. In Figure 2, the bias standard deviations are plotted.

![Bias estimation error - std [cm]](image)

The standard deviation values range from 1-2 cm up to 15 cm in limited areas of the earth. This procedure seems to be feasible and will be applied in the near future to local/regional areas, such as the whole Europe, to estimate a unified height system.

3. The support to researches and activities on geoid estimation

In spring 2011, from May 30th to June 14th, four researchers of the Centre of Geodesy and Geodynamics (National Space Resource and Development Agency, Nigeria) attended at IGeS a Special Course on Determination and Use of the Geoid. Every day, there were lectures for two or three hours. The rest of the day was devoted to individual learning with tutoring and to practice on geoid computation software using the computer facilities at IGeS. The detailed program is listed below:

- May 30th: Basic concepts in geodesy and geoid computation
- May 31st: Study of Lecture Notes with tutoring
- June 1st: Global Models
- June 6th; morning: Terrain effect in geoid computation
- June 6th; afternoon: Residual Terrain Correction
- June 7th: Practical examples on Terrain Effect computation
- June 8th morning: The core solution: theory of Collocation
June 8th afternoon: The core solution: Stokes and FFT
June 9th Practical examples on core solution computation
June 10th Local geoid computation: review of all the steps
June 13th Comparison of residual undulation computation methods
June 14th Practical examples on geoid computation

The aim of this special course was, as requested from the researchers of the Centre of Geodesy and Geodynamics, to have an intensive training on geoid estimation allowing them to have the basic notions for estimating their own national geoid based on the available data in Nigeria. Contacts between them and IGeS have been frequent since this course.

In 2012, one PhD student from USP, San Paulo, Brazil, was hosted at IGeS in the framework of a co-operation between the two Institutions. He was involved in a project aiming at estimating the geoid in the San Paulo State. During his stay at IGeS, he was trained in geoid estimation procedure based on collocation and the “remove-restore” method. In order to estimate the RTC effect, a detailed DTM/bathymetry model was set up. This has been accomplished by merging the SRTM DTM with the available NOAA bathymetry of the Atlantic Ocean in the computation area. A check for possible outliers both in the gravity and in the GPS/levelling databases to be used in the geoid estimation process was also performed. Different global geopotential models (including those based on GOCE data) were tested to check for their impact on the estimate. The final geoid estimate based on collocation has been then compared to GPS/levelling data and previous geoid computations obtained with different methods (i.e. Helmert-Stokes). The collocation estimated geoid proved to be equivalent to the existing ones and close to the GPS/levelling independent data. Statistics related to this comparison are detailed in Table 1.

Table 1: San Paulo geoid statistics. Residuals between geoid estimates and GPS/levelling (363 points)

<table>
<thead>
<tr>
<th>Geoid Model</th>
<th>E(m)</th>
<th>R.m.s. (m)</th>
<th>Max. (m)</th>
<th>Min. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT(EGM2008-360)</td>
<td>0.13</td>
<td>0.23</td>
<td>0.58</td>
<td>-0.41</td>
</tr>
<tr>
<td>LSC(EGM2008-360)</td>
<td>0.16</td>
<td>0.25</td>
<td>0.72</td>
<td>-0.47</td>
</tr>
<tr>
<td>FFT(GOCE-DIR_R3)</td>
<td>0.11</td>
<td>0.21</td>
<td>0.49</td>
<td>-0.44</td>
</tr>
<tr>
<td>LSC(GOCE-DIR_R3)</td>
<td>0.09</td>
<td>0.20</td>
<td>0.56</td>
<td>-0.50</td>
</tr>
<tr>
<td>FFT(GOCE-TIM_R3)</td>
<td>0.11</td>
<td>0.22</td>
<td>0.51</td>
<td>-0.43</td>
</tr>
<tr>
<td>LSC(GOCE-TIM_R3)</td>
<td>0.09</td>
<td>0.20</td>
<td>0.58</td>
<td>-0.47</td>
</tr>
<tr>
<td>FFT(GOCO03S)</td>
<td>0.12</td>
<td>0.22</td>
<td>0.51</td>
<td>-0.43</td>
</tr>
<tr>
<td>LSC(GOCO03S)</td>
<td>0.09</td>
<td>0.20</td>
<td>0.54</td>
<td>-0.47</td>
</tr>
<tr>
<td>FFT(EIGEN-6C)</td>
<td>0.11</td>
<td>0.22</td>
<td>0.51</td>
<td>-0.45</td>
</tr>
<tr>
<td>LSC(EIGEN-6C)</td>
<td>0.09</td>
<td>0.20</td>
<td>0.51</td>
<td>-0.49</td>
</tr>
</tbody>
</table>

The geoid estimate based on Least Squares Collocation is displayed in Figure 3
4. The organization of schools on geoid and height datum estimation

A new school on geoid computation and height datum definition has been organized in Ecuador. This school will be held in October 7th-11th, 2013 at the Universidad Tecnica Particular de Loja in Loja and will be quite different with respect to the previous geoid schools. Besides the standard methods on geoid computation new items on height systems will be taught. The draft program has been set up and it is listed in the following.

**Heights, height datum and Boundary Value Problems**

Definition of ellipsoidal, dynamical and orthometric heights and their observation equations; geoid and telluroid; the GBVP, reduction to the ellipsoid, mapping to the sphere, spherical harmonics.

**Global geopotential models and their use**

Creation of a Global Geopotential Model; computation of different functional; exercises on Global Models.

**Modelling the topographic effect**

Terrain Correction, Helmert reduction; from TC to Residual TC

**Local improvements of the geoid**

Remove-Restore method; Collocation; Geoid computation using FFT; Exercises on local geoid computation

**Height datum unification**

Modelling and estimation of offsets
**Vertical Datum Standardization**

Vertical Datum establishment, standardization and unification: the South American case.

According to the present day registrations, more than thirty students will attend the school. The teachers of this school are: F. Sansò, N. Pavlis, D. Blitzkow, R. Barzaghi, M. Sideris and L. Sanchez.

Also, new forthcoming schools are going to be organized in Trieste and/or in Cairo. As already underlined, these schools will be particularly devoted to Africa with the aim of improving researches on physical geodesy in this continent.

5. **The new IGeS website**

During 2012, the IGeS website has been completely revised and improved. The geoid repository has been enriched with new local solutions, namely the Switzerland, the French, the new European EGG2008 and the US geoids. As usual, these geoid estimates can be downloaded from the web site according to a defined policy. Geoids can be freely available if coded as public, available on demand in case the authors asked to be informed before made them available, private if the geoid owners decided not to distribute them.

In the new web page, the IGeS Bulletins’ archive has been made available. Any single issue can be downloaded directly from the web page. Also, the Newton’s Bulletin issue are now available on line. In this case, both the full issue or single papers of the issue can be downloaded. The new IGeS web page is shown in Figure 4.

Figure 4: The new IGeS web page