The New Argentinean Gravimetric Geoid Model - GEOAR

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1. Introduction

A new gravimetric geoid model for Argentina named **GEOAR** was developed using the remove-compute-restore technique and incorporating an optimal global geopotential model (GGM) with approximately 230,000 land and marine gravity measurements. Terrain corrections were calculated for all gravity observations using a combination of the SRTM_v4.1 digital terrain model (DTM) and SRTM30_Plus bathymetric models. For those regions that have gravimetric observations within a distance of 20 km, the observed gravity anomalies were gridded using the inverse square distance weighting method; while for all the regions that lacked of such observations, the world gravity model WGM2012 was utilised for the determination of gravity information. The resultant gravity anomaly grid was applied in the Stokes' integral using the spherical multi-band FFT approach and the deterministic kernel modification proposed by Wong and Gore. The accuracy of **GEOAR** was assessed by comparing it with GPS-levelling derived geoid undulations at more than 1,000 locations. Results showed that the new Argentina geoid model can achieve an accuracy of better than 10 centimetres.

2. Gravity reductions

GEOAR was developed using the **remove-compute-restore** (RCR) technique (Schwarz, Sideris & Forsberg 1990), and therefore, the GGM and terrain topography contributions to the gravity field of the Earth were subtracted from the gravity measurements. Then, the residual gravity anomalies required for the geoid model computation are given by

$$\Delta g_{res} = g - \gamma + \delta g_A + \delta g_{FA} + \delta g_B + C_T - \Delta g_{GGM}$$

Where:

- g is the observed gravity referred to the **IGSN71** gravity system;
- γ is the normal gravity formula proposed by Somigliana (1929);
- δg_A is the atmospheric correction given by Hinze et al. (2005);
- δg_{FA} is the first order formula of the free-air correction presented by Heiskanen and Moritz (1967);
- δg_B is the planar approach of the Bouguer correction given by Heiskanen and Moritz (1967);
- C_T is the terrain correction introduced by Moritz (1968) and it was determined up to a distance of **166.7 km** using the **SRTM_v4.1** (Jarvis et al. 2008) and **SRTM30_Plus v10** (Becker et al. 2009) models in the **TC** software (Forsberg 1984), which applies the rectangular prism integration method (Nagy 1967); and
- Δg_{GGM} is the long-wavelength contribution to the gravity field from the **GOCO03S** satellite-only GGM (Mayer-Gürr et al. 2012) and it was determined complete to **degree and order 250** using the **GEOEGM** software from the **GRAVSOFT** package (Forsberg & Tscherning 2008).

3. Gridding procedure

Since the Stokes' integral was solved by means of the fast Fourier transform (FFT) technique, the **~230,000** gravity anomalies were converted into gridded anomalies. Figures 1 and 2 show land and marine gravity measurements. It can be clearly seen in this figured that the gravity measurements are not homogeneous distributed in Argentina. Instead, they are usually at sparse points or along spirit-levelling and prospecting lines. Moreover, mountainous regions (e.g. Andes Mountains), where the gravity field usually varies the most, lack of a regular distribution of gravity observations due to the complex accessibility.

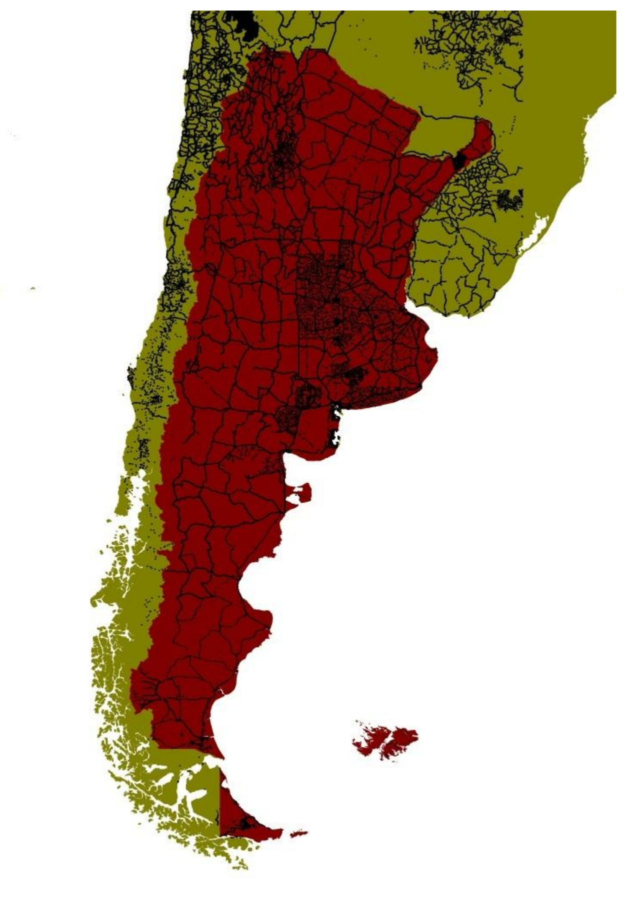

Fig. 1: Land gravity observations

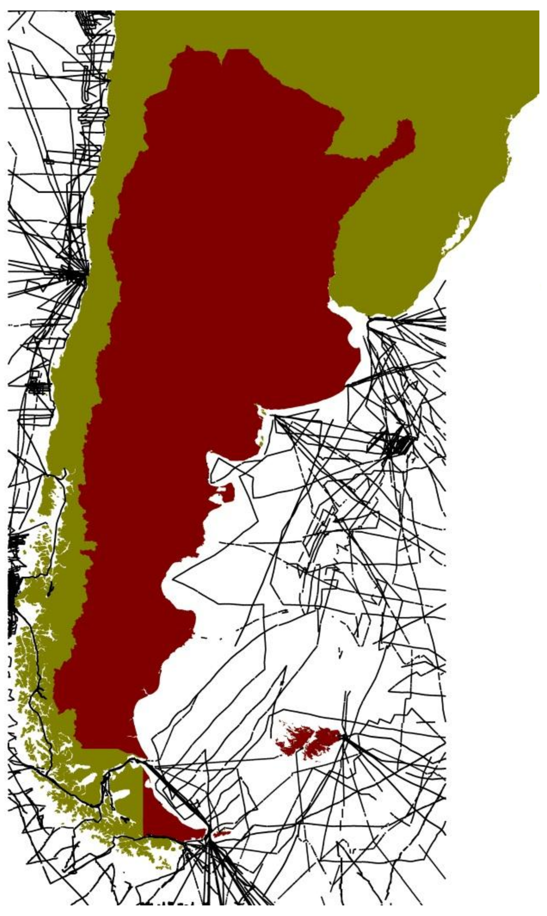

Fig. 2: Marine gravity observations

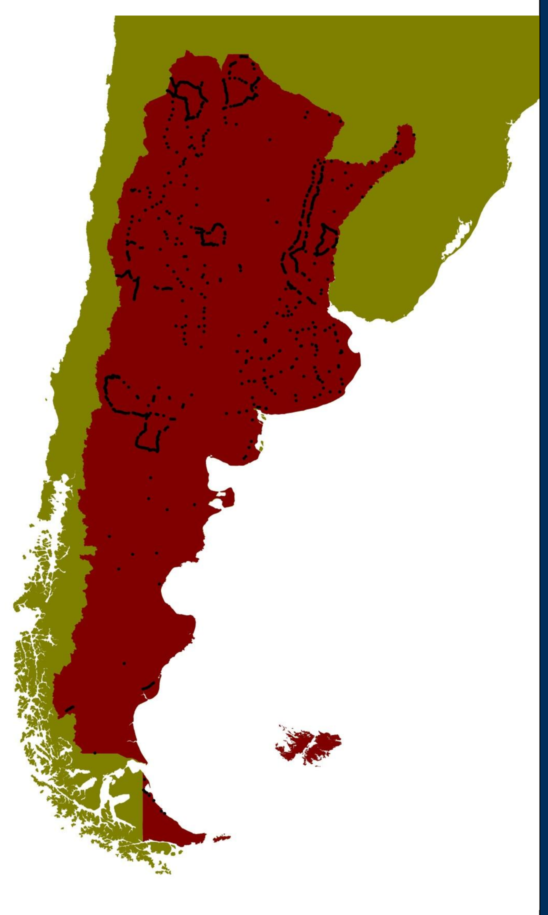

Fig. 3: Co-located GPS-levelling benchmarks

The **moving weighted average** method (Shepard 1968), a commonly used gridding approach from irregularly-distributed data, was applied for determining the residual gravity anomaly gridded values and the **square of the inverse distance** function ($1/r^2$) was used for the determination of the weight.

The gridded area was extended up to **20 km** from every gravity point measured, and therefore, the gravity anomaly grid presented big gaps or blanks due to the inhomogeneous distribution of the gravity points (Fig. 4). Consequently, the **WGM2012** gravimetric model (Bonvalot et al. 2012) was used to fill the voids (Fig. 5).

Then, the **residual Faye anomaly** grid was **reconstructed** (Fig. 6) by adding the negative Bouguer plate reduction, which was generated using the DTM, to the above grid results (Featherstone & Kirby 2000).

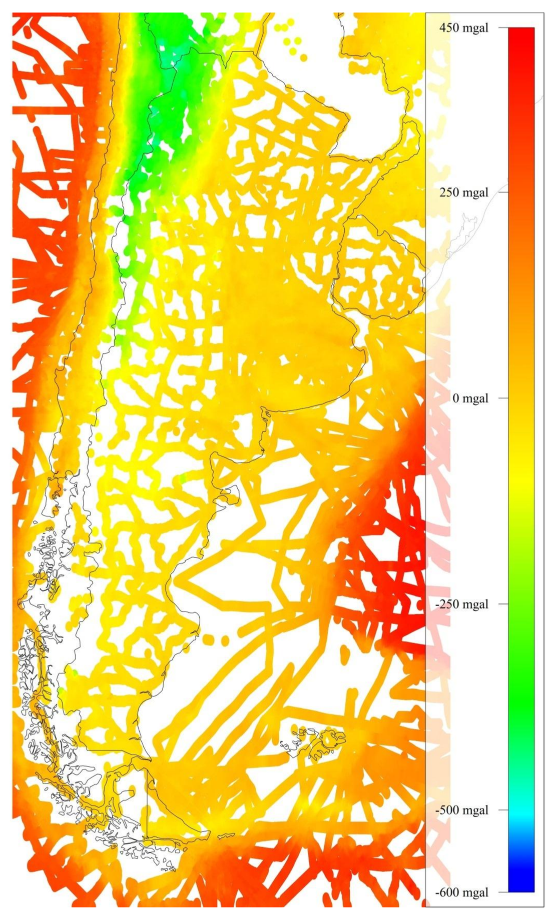

Fig. 4: Refined-Bouguer anomaly grid

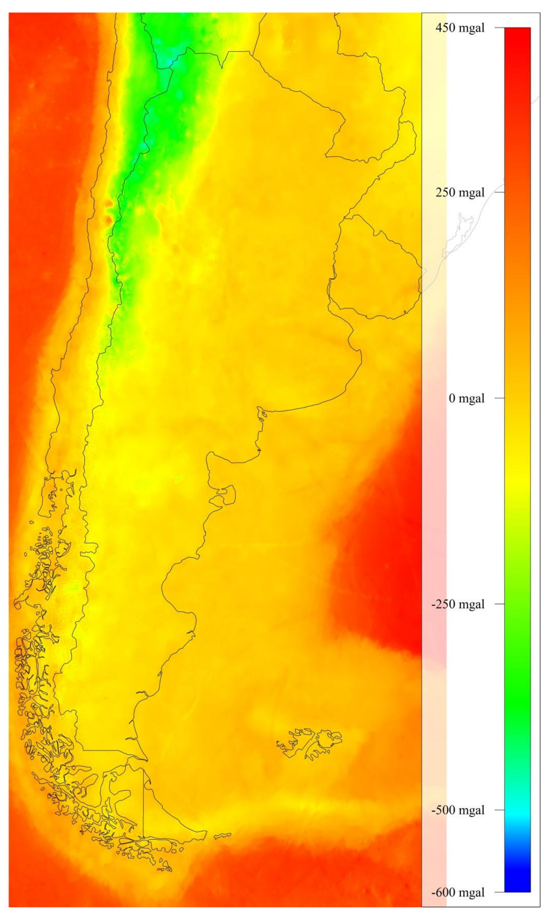

Fig. 5: Filled-in refined-Bouguer anomaly grid

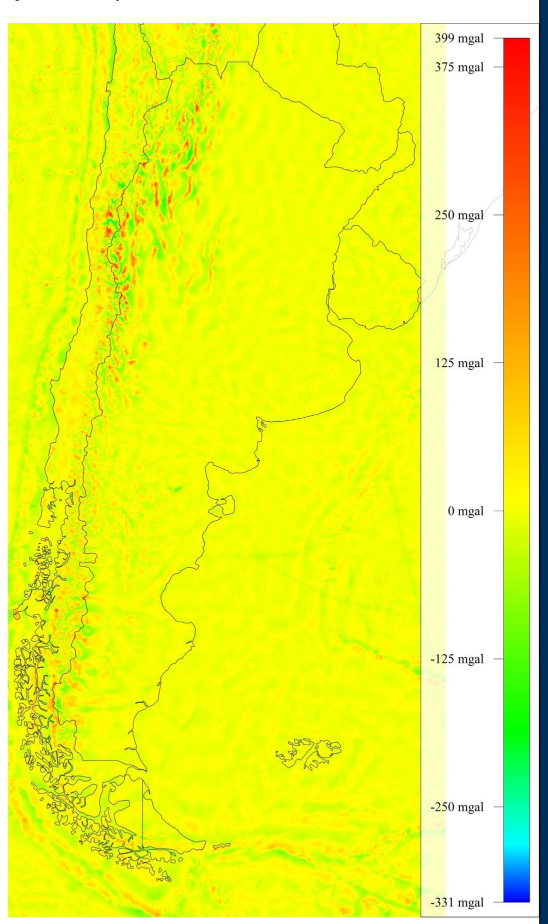

Fig. 6: Residual Faye anomaly grid

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4. Geoid determination

Since the geoid was determined using the **RCR** technique in the **Stokes'-Helmert** approach, the gravity field was spectrally decomposed into three parts: the **long-wavelength** contribution from the GGM, the **medium-wavelength** signal from regional gravity observations and the **short-wavelength** part from the topography. As a result, the geoid undulation N can be expressed as follows (Forsberg 1993)

$$N = N_{GGM} + N_T + N_{RES}$$

Where:

- N_{GGM} represents the **spherical harmonic expansion** of the GGM, which was computed using the **GOCO03S** satellite-only GGM complete to **degree and order 250** in the **GEOEGM** software;
- N_T is the **terrain indirect effect** from the **Helmert's second method of condensation**, which was determined using the planar approximation proposed by Wichiencharoen (1982) in the **GCOMB** software from the **GRAVSOFT** package; and
- N_{RES} denotes the residual **geoid** resulting from the Stokes' integration, which was computed using the **multi-band spherical FFT** approximation technique (Forsberg & Sideris 1993) in the **SPFOUR** software. The **Wong and Gore** modification to Stokes' kernel was adopted, where the low harmonics were completely **removed up to degree 30** and then linearly **tapered to degree 40**.

5. Comparison with GPS-levelling and fitting

GEOAR's accuracy was evaluated using **1,173** co-located **GPS-levelling** benchmarks (Fig. 3). The benchmarks' geoid undulations were determined through the application of the following well-known relationship

$$N = h - H$$

Where:

- h is the **ellipsoidal height** referred to the Argentinean **POSGAR 07** reference frame, which is based in the **ITRF 2005** (Altamimi et al. 2007) at epoch 2006.6; and
- H is the **orthometric height** (Mader 1954) of the Argentinean vertical datum (AVD).

The statistics of the differences are shown in columns (a) and (b) of Table 1, while the histograms of the differences can be seen in graphics (a) and (b) of Fig. 7. Moreover, the GPS-levelling geoid undulations were also compared with those from the **EGM08** (Pavlis et al. 2012) GGM complete to **degree and order 2160**.

Table 1: Statistical results of the differences between co-located GPS-levelling geoid undulations, EGM08 and GEOAR

	(a) GPS-levelling – EGM08	(b) GPS-levelling – GEOAR (not fitted)	(c) GPS-levelling – GEOAR (fitted)
Minimum	-1.42 m	-0.96 m	-0.31 m
Maximum	1.53 m	1.55 m	0.32 m
Average	0.52 m	0.65 m	0.00 m
Std. dev.	**0.41 m**	**0.34 m**	**0.05 m**

Finally, the **trend surface** best **fitting the AVD** was determined using the 4-parameter fit method. The statistics of the differences are shown in the column (c) of Table 1, while the histograms of the differences can be seen in the graphic (c) of Fig. 7.

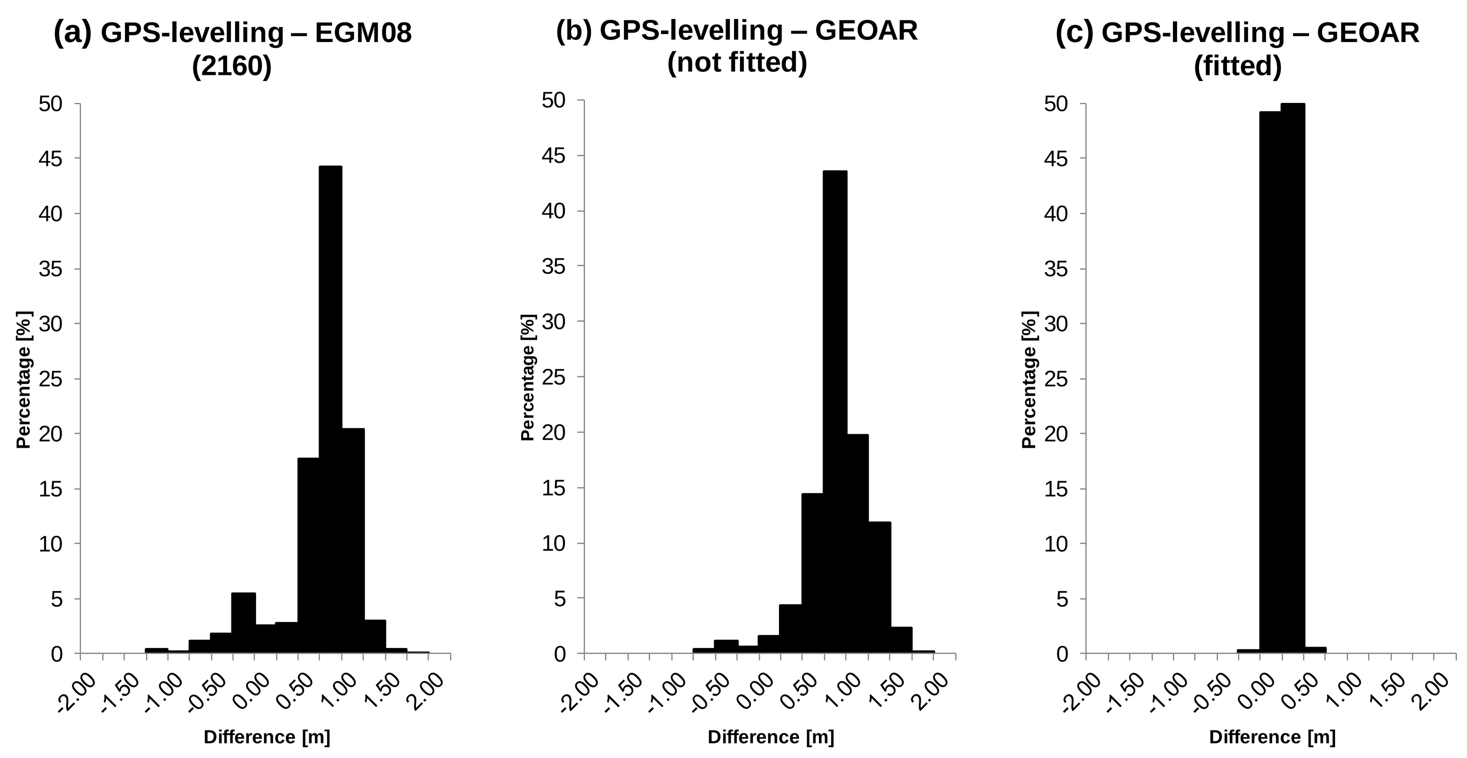

Fig. 7: Histograms of the differences between co-located GPS-levelling geoid undulations, EGM08 and GEOAR derived geoid heights

6. Conclusions and future work

The new **Argentina** geoid model uses recent releases of DTM and GGM models, as well as the latest gravity and GPS-levelling measurements. The results show that it fits the Argentinean vertical datum significantly better than EGM08 and the previous Argentinean geoids, even though many outliers in the datasets have not been detected and eliminated yet at this stage.

More land and marine gravity observations, held by several universities and public agencies, will be incorporated to the next version of the **GEOAR** geoid model. Moreover, a new project to densify the Argentinean gravity measurement led by the **Instituto Geográfico Nacional** (National Geographic Institute) has been recently approved for the period 2016 −2018. This is expected to be significantly beneficial to the next generation geoid determination for Argentina.

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