VALIDATION OF EGM2008 OVER ARGENTINA

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Abstract. The EGM96 geopotential model (Lemoine et al., 1998) was for long time the most accurate reference model for many applications in Earth's sciences.
Taking advantage of recent terrestrial gravity, elevation and altimetry data as well as the results from satellite gravity missions, a new global gravity model, EGM2008, has been calculated by the National Geospatial-Intelligence Agency (NGA) of the USA.
The official Earth Gravitational Model EGM2008 has been publicly released by the U.S. National Geospatial-Intelligence Agency (NGA) EGM Development Team. This model is complete to degree and order 2159, and contains additional spherical harmonic coefficients extending to degree 2190 and order 2159.
This contribution is a report of the validation results of the preliminary pre-released combined geopotential model PGM07A and the final model EGM2008 (Pavlis et. al., 2008) over Argentina. Comparisons with other well-known Earth Gravity Models like EGM96 (Lemoine et. al., 1998) and EIGEN-GL04C (Förste et al., 2006) are also presented.

Keywords. EGM2008, Global Gravity Models (GGMs), Argentina

1. Introduction

One method for assessing the accuracy of the global geopotential models is through comparisons with gravity anomalies and geoid undulations as derived by e.g. GPS and spirit leveling. The main objective of this paper is to validate EGM2008 over all Argentina.
Also the Argentinean regional gravimetric geoid model: ARG06_egm96 has been used for checking the EGM2008 accuracy over Argentina where strong gravity field variations are present.

2. Data description

The validation has been carried out using four data sets: Point land gravity, point shipborne gravity data, GPS/levelling data over Argentina and the Argentinean regional gravimetric geoid model: ARG06_egm96.

2.1. Land Gravity Data

The Argentina Gravity Data Base contains more than 180,000 data points (Figure 1).
Nevertheless, since they come from different sources and were acquired using different procedures, for consistency reasons only the data from IGM (*Instituto Geográfico Militar*) is taken for this evaluation.
In 2002, IGM finished the measurements of the national levelling network, which coincids with the first order national gravity network. It consists of 370 levelling lines containing 16,320 benchmarks, and 225 network nodes, see Figure 2.
The distances between adjacent benchmarks range from 3 km to 9 km. Almost every benchmark in the network has geocentric coordinates. Their accuracy varies from a few centimetres for the most recent ones determined by GPS, up to a few thousand meters in case the coordinates were digitized of those coming from topographic maps, a usual procedure in older days (Pacino et al., 2005).
Most of the gravity values in the network originally referred to the old Potsdam datum, but today they have been converted to IGSN71 through the application of a shift of –14.93 mGal to the measured values. This conversion formula has been tested on more than 800 points that have been measurements

in both systems which results in a mean difference of 0.2 mGal. Apart from the methodology and instrumentation, the overall accuracy for the gravity measurements is better than 0.5 mGal.
Free Air gravity anomalies were calculated in the classical sense as "gravity on the geoid minus normal gravity on the ellipsoid".

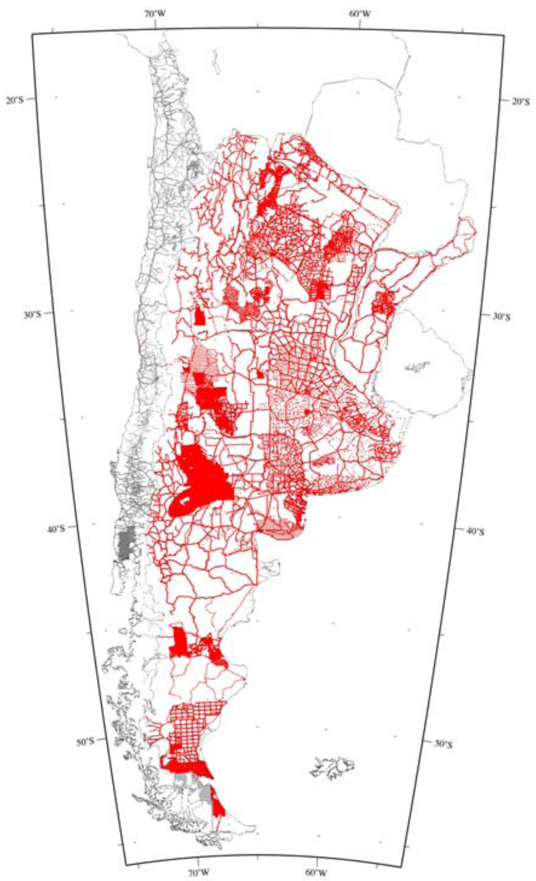

Figure 1: Argentina land gravity data

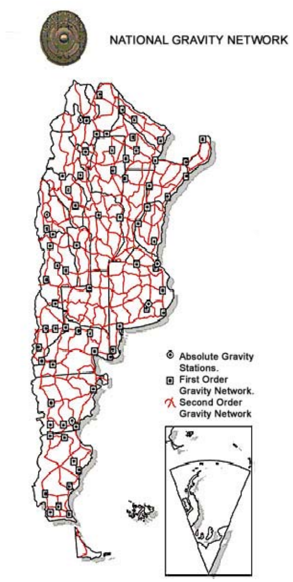

Figure 2: National Gravity Network

The WGS84 gravity formula is used to define normal gravity for each station, according to:

$$\gamma_{84} = 978032.67714 \frac{(1+0.00193185138639\sin^2\varphi)}{\sqrt{(1-0.00669437999013\sin^2\varphi)}} \text{mGal} \qquad (1)$$

where φ is the latitude

The normal gravity field is generated by a rotating ellipsoid of revolution that includes the atmospheric masses.
The empirically derived atmospheric correction δg_A is:

$$\delta g_A = 0.87 e^{-0.116 h^{1.047}} mGal \qquad (2)$$

where the height h is in km.

The detailed variation of the free air gradient is not known well enough and hence an equation derived from the normal gravity field is used, which depends on height and latitude:

$$FAC = (0.3083293357 + 0.0004397732 \sin^2 \varphi)\, h + 7.2125 \times 10^{-8}\, h^2 \qquad (3)$$

where h is the height in meters.

2.2. Shipborne gravity data

The marine gravity data available are 12823 free-air gravity anomalies provided by the Bureau Gravimétrique International (BGI). In Figure 3, the distribution of the shipborne gravity data is depicted for visualization purposes.

2.3. GPS/Levelling Data

Many institutions in Argentina have developed geodetic networks, mainly for cadastral purposes. Some of these points are coincident with levelling benchmarks (Figure 4). These data were acquired in different times using different equipment, techniques and procedures, and are related to different reference frames. The heights of the benchmarks are simple levelling heights without gravity related corrections. Thus, there are neither orthometric nor normal heights.

In order to make a coherent validation, all data was converted into POSGAR94 (**POS**iciones **G**eodesicas **AR**gentinas), the official national reference frame, that realizes the WGS84 system. It was also necessary to clean the data, identifying outliers and blunders.

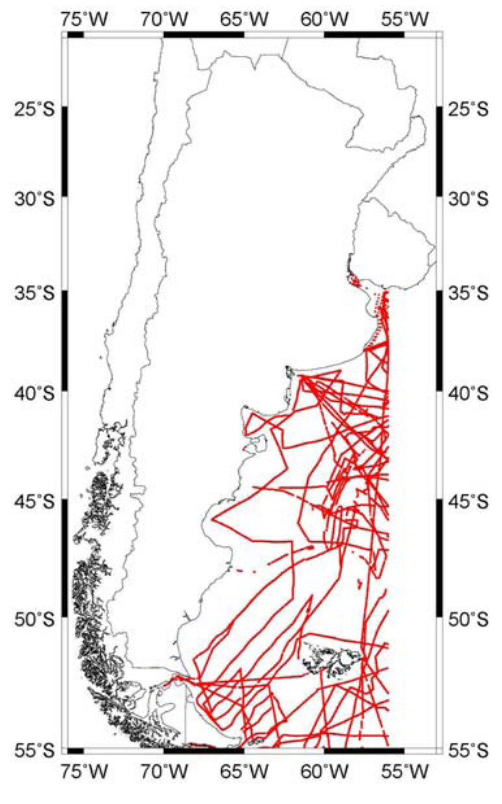

Figure 3: Distribution of shipborne gravity data

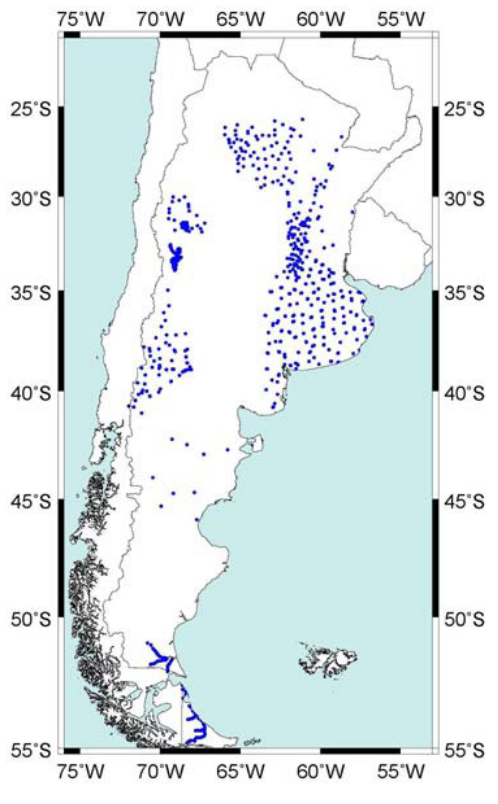

Figure 4: Location of GPS/Levelling points in Argentina

2.4. Argentinean gravimetric geoid model: ARG06_egm96

The gravimetric geoid for Argentina ARG06_egm96 (5´ by 5¨grid) (Tocho et. al., 2005) is based on terrestrial and satellite altimetry - derived gravity anomalies from the KMS02 model (Andersen et al., 2005), which are used to fill in the sparse shipborne data in the Atlantic and Pacific Oceans, offshore Argentina.

The gravimetric geoid was computed using the remove-compute-restore technique, employing Stokes's formula for the prediction of residual geoid heights. Before the prediction of the residual geoid, the free-air gravity anomalies are reduced by the geopotential model EGM96 (Lemoine et. al., 1998) up to degree 360. Furthermore, the effect of the topography is taken into account by Helmert's second method of condensation. The contribution of the local data to the geoid is computed using FFT.

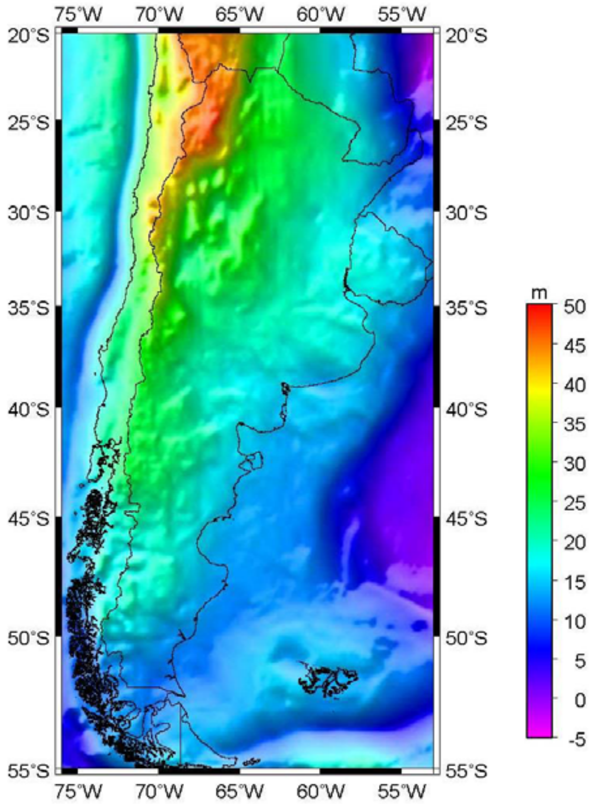

Figure 5: Gravimetric geoid solution ARG06_egm96

3. Results

All the computations are done using the program HARMONIC_SYNTH provided by the EGM2008 development team with the coefficients of EGM2008, EGM96 and EIGEN-GL04C up to different maximum degrees. The computed quantities are spherically approximated gravity anomalies and height anomalies at zero height. No orthometric heights at the computation points are available.
Besides, geoid undulations with respect to WGS 84 are computed using the EGM2008 Tide Free Spherical Harmonic Coefficients and its associated height anomaly to geoid undulation correction model plus a zero-degree term for the height anomaly equal to 41 cm. Geoid undulations are also computed in the same way using EGM96.

3.1. Comparisons with Argentinean GPS/levelling data

Table 1 shows the results in terms of Mean Value, Standard Deviation (σ), Maximum and Minimum of the absolute differences between the 715 GPS/Levelling height anomalies and the Argentinean Geoid Model ARG06_egm96 as well as EGM96, EIGEN-GL04C and EGM2008 up to degree 60, 120, 360, and 2159.
The statistics of the differences between the GPS/levelling derived - geoid and EGM96 and EGM2008 before and after 4-parameter transformation are given in Table 2. The values in parentheses are the results after 4 parameter transformation.
Figure 6 shows the histograms for some comparisons. From Figure 7, we can see that the differences are higher in areas close to mountains.

Table 1: Statistics of the absolute differences between GPS/Levelling and height anomalies computed from Global Gravity Models and the Argentinean geoid model ARG06_egm96. Unit: [m]

n/m	*Model*		*Σ*	*max*	Min
60/ 60	EGM96	-1.60	±1.87	2.46	-7.65
	EIGEN-GL04C	-1.66	±1.97	2.64	-8.02
	PGM07A	-1.66	±1.97	2.64	-8.03
	EGM2008	-1.66	±1.97	2.64	-8.02
120/ 120	EGM96	-0.29	±1.10	4.54	-3.28
	EIGEN-GL04C	-0.60	±1.09	3.46	-4.30
	PGM07A	-0.51	±1.02	3.51	-4.11
	EGM2008	-0.59	±1.09	3.47	-4.16
360/ 360	EGM96	0.13	±0.78	2.29	-1.88
	EIGEN-GL04C	-0.26	±0.38	1.58	-1.94
	PGM07A	0.04	±0.61	2.17	-2.01
	EGM2008	-0.08	±0.44	1.74	-2.10
2159/2159	EGM2008	0.05	±0.48	1.85	-1.41
2159/2190	PGM07A	0.17	±0.67	2.05	-1.58
	EGM2008	0.05	±0.48	1.85	-1.41
	ARG06_egm96	-1.38	±0.53	0.32	-4.41

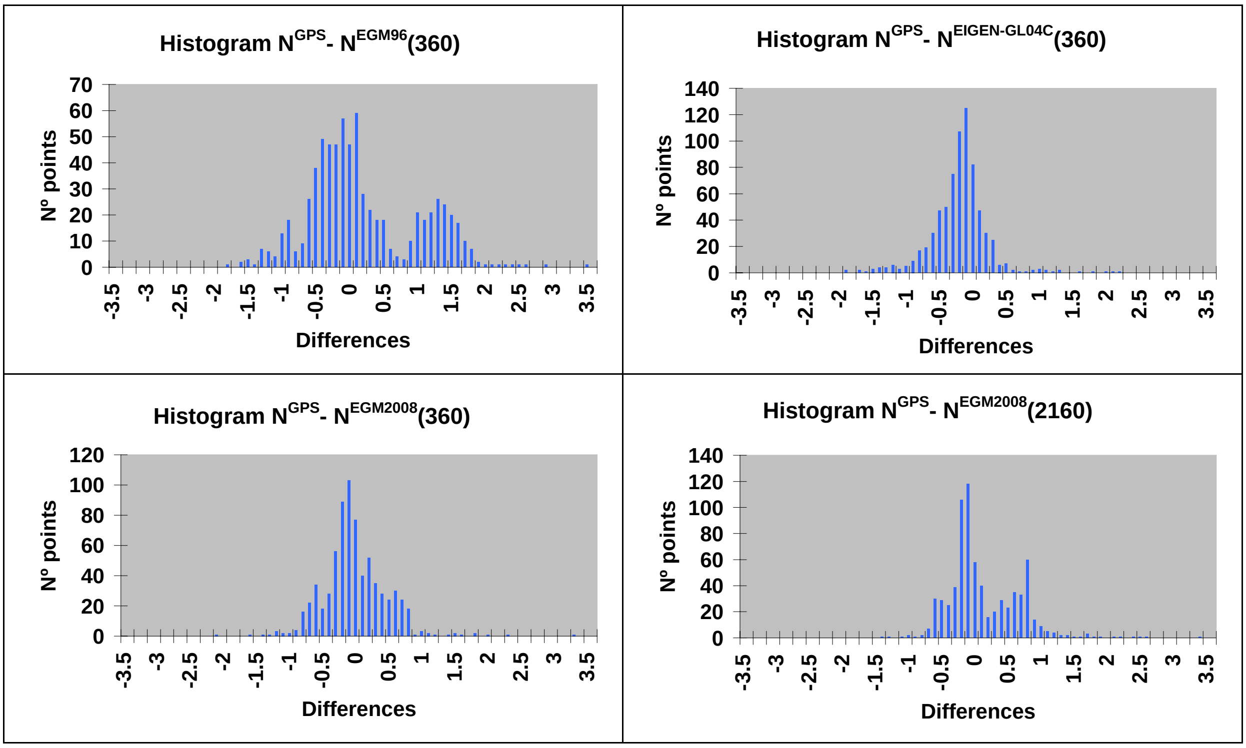

Figure 6: Histograms of the differences between Geoid Undulations from GPS/Levelling Data and from Argentine Geoid Model and Global Gravity Models

Table 2 shows that the global gravity field EGM2008 the long-wavelength structure of the gravity field in Argentina better than EGM96. After transformation EGM2008 fits the GPS/levelling derived geoid with a standard deviation (σ) of near 37 cm while EGM96 fits with a standard deviation of 60 cm. Before the fit, EGM2008 alone reduces the standard deviation of the differences with 40% compared to EGM96 alone.

Table 2: Statistics of the absolute differences between GPS/Levelling and the geoid computed using EGM2008 and EGM96 before and after a 4-parameter transformation. The values in parenthesis are after transformation. Unit: [m]

n/m	*Model*	*mean*	*Σ*	*max*	Min
	N^{GPS}-EGM2008	0.503 (0.000)	±0.510 (±0.374)	2.484 (1.420)	-0.979 (-1.800)
	N^{GPS}-EGM96	0.726 (0.000)	±0.811 ±(0.604)	3.103 (2.21)	-1.313 (-2.19)

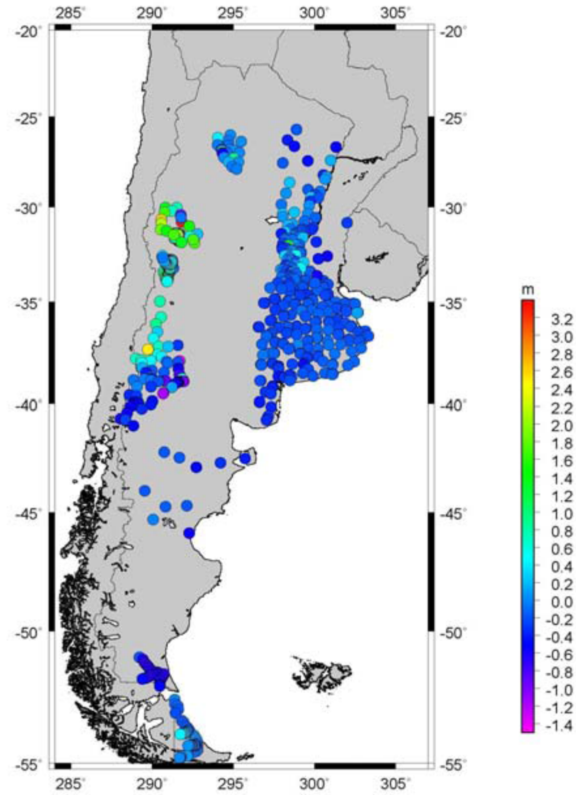

Figure 7: Differences between height anomalies from 715 GPS/levelling and EGM2008

3.2. Comparisons with Argentinean gravity data

Table 3 shows the results in terms of Mean Value, Standard Deviation, Maximum and Minimum of the differences from the comparison of gravity anomalies from shipborne data and gravity anomalies computed using the Global Gravity Models EGM96, PGM2007A and EGM2008 up to different maximum degrees. In Tables 3 and 4, n is the maximum degree and m is the maximum order.

Table 3: Statistics of the differences between shipborne free-air gravity anomalies and EGM96, PGM07A and EGM2008 spherical gravity anomalies. Unit:[mGal]

n/m	*Model*	*mean*	*Σ*	*max*	Min
360 /360	EGM96 PGM07A EGM2008	0.61 0.93 0.91	±12.55 ±12.89 ±12.82	62.03 64.71 65.45	-81.12 -67.98 -69.07
2159 /2159	EGM2008 PGM07A	1.40 1.43	±10.42 ±*9.68*	68.68 66.84	-57.05 -49.23
2159/2190	EGM2008	1.40	±*9.59*	64.72	-50.25

Table 4 shows the statistics from the differences from the comparison between gravity anomalies from land data and gravity anomalies computed using the Global Gravity Models: EGM96, EIGEN-GL04C, PGM2007A and EGM2008 up to degree 60, 120, 360 and 2159. Figure 8 displays the histograms for some of these comparisons.

Table 4: Statistics of the comparisons between gravity anomalies from land data and gravity anomalies computed using Global Gravity Models with different maximum degrees and orders. Unit: [mGal]

n/m	*Model*	*mean*	*Σ*	*max*	*Min*
60/60	EGM96	-6.68	±35.67	411.69	-298.35
	EIGEN-GL04C	-7.15	±35.75	414.51	-297.76
	PGM07A	5.92	±34.43	498.16	-267.33
	EGM2008	-7.15	±35.75	414.51	-297.76
120/120	EGM96	-5.64	±33.11	389.14	-278.69
	EIGEN-GL04C	-6.33	±33.26	397.02	-276.94
	PGM07A	-6.39	±33.21	396.20	-277.86
	EGM2008	-6.32	±33.22	396.56	-277.85
360/360	EGM96	-5.08	±28.08	390.13	-278.55
	EIGEN-GL04C	-6.02	±28.67	399.64	-271.12
	PGM07A	-5.12	±26.89	388.23	-280.87
	EGM2008	-5.11	±27.09	400.90	-281.15
2159/2159	EGM2008	0.10	±21.59	424.45	-285.09
2159/2190	PGM07A	0.06	±21.21	395.87	-259.23
	EGM2008	0.07	±21.53	426.85	-285.58

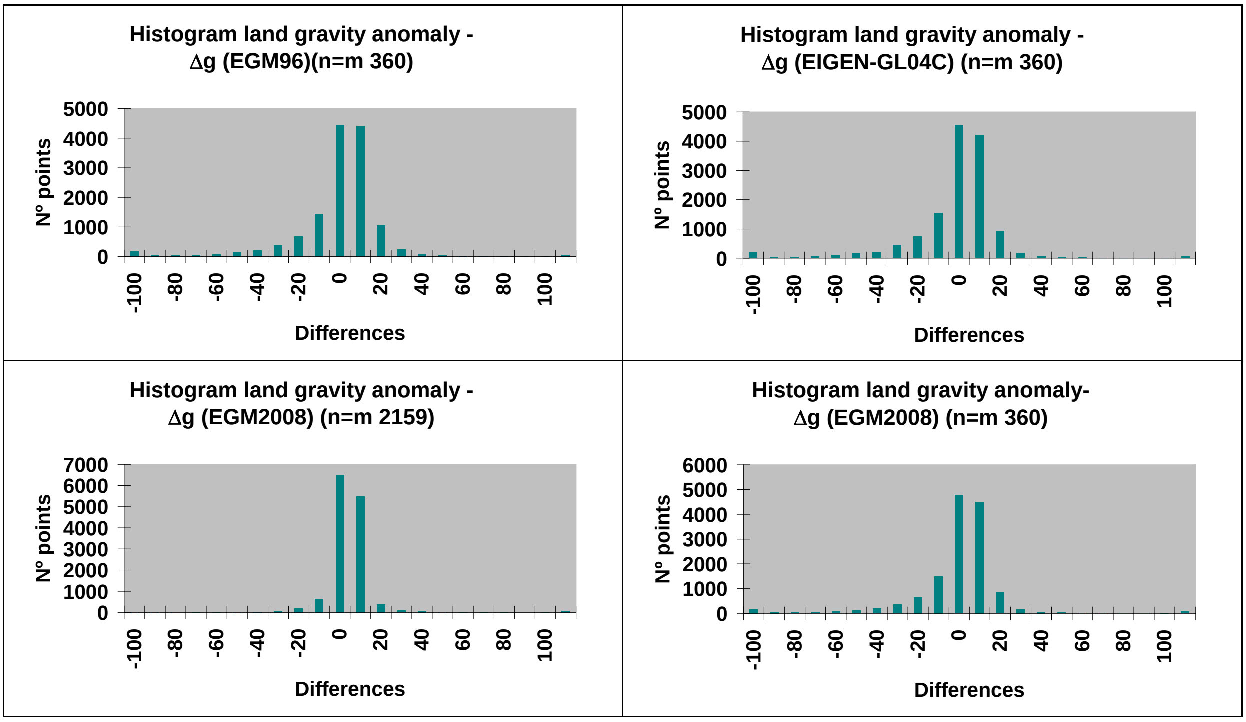

Figure 8: Histograms of the differences between Gravity anomalies from land data and gravity anomalies computed from Global gravity Models

3.3 Comparisons with ARG06_egm96

Height anomalies are first computed using EGM2008 up to degree 2160 on a 5' x 5' grid, which is then compared directly with the gravimetric-only ARG06_egm96 solution (Tocho et. al., 2007). The result can be seen in Figure 9 and Table 5. This Table also shows the statistics of the differences between height anomalies computed from EGM2008 and EGM96 (used in ARG06_egm96) and the differences between EGM96 and GGM02C.

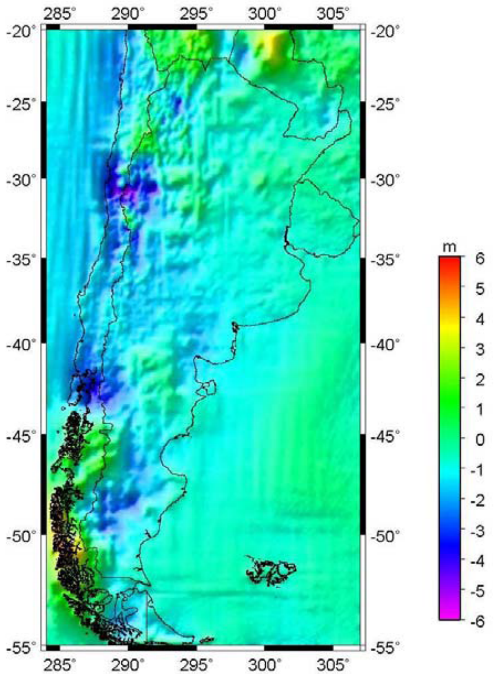

Figure 9: Differences between height anomalies computed from EGM2008 and ARG06_egm96

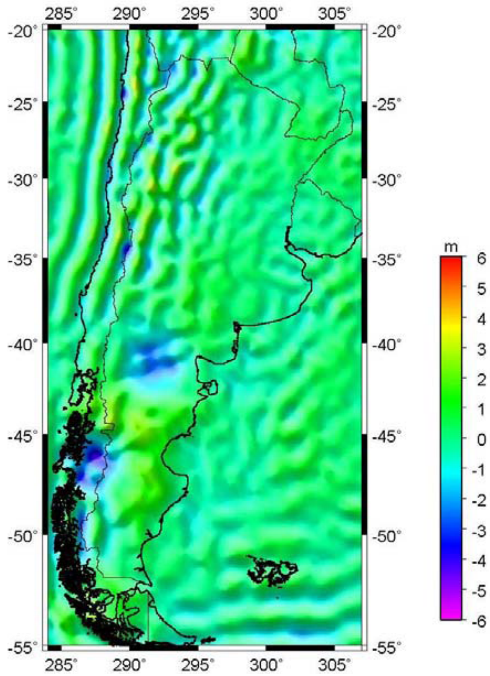

Figure 10: Differences between EGM96 and GGM02C height anomalies over the ARG06_egm96 area

From Figure 9, we conclude that the differences are very high, mainly over the Andes and in a special mainland area located between latitudes 40º S to 42º S and longitudes 70º W to 65 ºW. The gravimetric geoid ARG06_egm96 was computed with EGM96. Then a comparison between the differences between EGM96 and GGM02C (Tapley et al., 2005) height anomalies was performed as we can see in Figure 10. This result shows that the main differences are in the same mentioned areas,we can conclude that probably they are due to the GRACE data-

Table 5: Statistics of the differences between height anomalies computed from EGM2008 and ARG06_egm96 on grid, EGM2008 and EGM96 and EGM96 with GM02C.Unit:[m]

	mean	***Σ***	***max***	Min
EGM20008 minus ARG06_egm96	-0.78	±0.93	5.407 (75.08ºW, 50.33ºS)	-5.642 (70ºW, 30.92ºS)
EGM20008 minus EGM96	0.01	±0.67	5.259 (70.42ºW, 30.42ºS)	-8.044 (72.33ºW, 46.17ºS)
EGM96-GGM02C	0.00	±0.72	3.033 (69.67ºW, 23.83 ºS)	-4.454 (72.42ºW. 46.25 ºS)

4. Summary

A validation of the tide-free version of the geopotential model EGM2008 is carried out over Argentina in terms of:

- Comparison with surface gravity anomalies.
- Comparison with shipborne gravity anomalies.

Comparison with the regional gravimetric geoid model ARG06_egm96

- Comparison with GPS/Levelling points.

In addition, the global gravity models EIGEN-GL04C and EGM96 are also evaluated.
All comparisons are performed up to different degrees and orders.
From the statistics of the differences between the tested geopotential models and GPS/Levelling height anomalies on benchmarks, the best agreement is obtained with EGM2008 (n=m=360) in terms of the mean value and with the EIGEN-GL04C in terms of the standard deviation of the differences.
Geoid undulation values with respect to WGS 84 are calculated using EGM2008 and EGM96. These values are compared with the GPS/levelling derived geoid heights. The global gravity field EGM2008 describes the long-wavelength structure of the gravity field in Argentina better than EGM96. After a 4-parameter transformation, EGM2008 and EGM96 fit the GPS/levelling derived geoid with a standard deviation (σ) of near 37 cm and 81 cm, respectively.
From the comparisons performed using land free-air gravity anomalies, the best results are obtained from the anomalies predicted using EGM2008 up to its maximum degree and order. The main discrepancies are correlated with the high and rough topography, especially over the Andes. Gravity comparisons between free-air shipborne gravity anomalies and gravity anomalies predicted using EGM96 and PGM07A show that the best approximation is obtained with EGM96 (n=m=360) in terms of mean values and with PGM07A in terms of standard deviations.
As future work, new calculations have to be done using the option when the orthometric height is not supplied, and instead it has to be computed for each point by harmonic synthesis of a spherical harmonic model of the elevation, which represents the topographic elevations above mean sea level.

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