Evaluation of the SRTM data over Argentina and its Implications to gravity field and geoid modelling

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Abstract. With the realization of the Shuttle Radar Topographic Mission (SRTM) and the distribution of the 3 arc-seconds (90 m) data over South America, a high-resolution digital elevation model (DEM) became available for Argentina. DEMs are an important source of data for g gravimetric geoid computation since they provide the high-frequency content of the gravity field spectrum. Gravimetric geoid undulations are usually calculated using the remove-compute-restore technique. This technique combines a global geopotential model, local gravity anomalies, and the topography, represented by a DEM. There are two main objectives in this paper. The first objective is to validate and assess the accuracy of the SRTM 90 m DEM over Argentina. This is performed through comparisons with existing global elevation models, like GLOBE, GTOPO30 and SRTM30. The second objective is to investigate the terrain aliasing effects on geoid determination for different gravimetric reductions. All available DEMs are used to compute terrain effects on both gravity anomalies and geoid heights at variable spatial resolutions. The following terrain reduction techniques are investigated in this study: Helmert's second condensation method, the Airy-Heiskanen topographic-isostatic reduction, the residual terrain model method and the Rudzki inversion method. Numerical tests are carried out in the most rugged area of Argentina, one of the most mountainous areas in the world. From the results acquired, the performance of the SRTM model is evaluated and conclusions are drawn on the effect of the DEM resolution on the accuracy of the gravimetric geoid.

Keywords. SRTM, gravity reductions, Argentina, DEMs.

1 Introduction

The gravimetric geoid models for Argentina have been computed using the remove-restore technique, which uses a high-resolution digital elevation model to supply the short wavelengths geoid information and also to take care of the mathematical demands to solve the boundary-value problem of physical geodesy. The global digital elevation model GTOPO30 with a resolution of 30" x 30" (LP DAAC, 2006) has been used for the determination of the current gravimetric geoid due to the lack of a national DEM available for Argentina.

The recently available SRTM3 DEM, with a resolution of 3" x 3" (JPL, 2006), and SRTM30 DEM, with a resolution of 30" x 30" (JPL, 2006), must be evaluated and validated in Argentina.

Another objective in this paper is to investigate the use of different DEM grid resolutions for the computation of various gravimetric terrain reductions within the context of gravimetric geoid determination.

The terrain aliasing is investigated for the Rudzki inversion method, the Airy-Heiskanen topographic-isostatic reduction, the residual terrain model reduction (RTM), and also for the classical terrain corrections.

2 Area and Digital Terrain Models

The numerical tests presented in this paper are carried out in an area near the Andes bounded by latitude 29º S and 32º S and longitude between 70º W and 67º W.

Four DEMs were investigated in the area under study: SRTM3, GTOPO30, GLOBE and SRTM30.

The SRTM data was acquired during the 11 day mission of the Space Shuttle Endeavour, launched in February 11, 2000. The data covers landmasses between 56º south to 60º north latitude, which comprises almost exactly 80% of Earth's total landmass. All elevations are in metres and referenced to the WGS84/EGM96 geoid. The absolute horizontal accuracy is 20 m and the absolute vertical accuracy is specified as 16 m (Bamler, 1999; JPL, 2006; and Farr and Kobrick, 2000).

In the area under study, SRTM3 consisted of a total of 12949757 elevations and contained a total of 17444 voids caused by shadowing, phase, unwrapping anomalies or other radar-specific causes so a first step consisted of making a regular grid to fill in the existing voids. The nearest neighbour gridding method, which assigns the value of the nearest point to each grid node, was used. This method is useful when data are already evenly spaced, or in cases where the data are nearly on a grid with only a few missing values for filling in the holes in the data. From here on, we will refer to the SRTM3 after the gridding as SRTM3ARG06 (SRTM3 Argentina 2006). Figure 1 shows the original SRTM3, where black dots represent undefined elevations, and Figure 2 depicts the corrected SRTM3ARG06. Table 1 presents the statistics for both models.

GTOPO30 is a global DEM developed by the U.S. Geological Survey's EROS Data Center and it was completed in 1996. Elevations in GTOPO30 are regularly spaced at 30 arc-seconds (approximately 1 kilometer). GTOPO30 is a global data set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30 arc-seconds. The horizontal coordinate system is decimal degrees of latitude and longitude referenced to the WGS84. The vertical units represent elevation in meters above mean sea level A subgrid was extracted over the study area and the elevation values can also be seen in Table 1.

SRTM30 is a near-global digital elevation model comprising a combination of data from the Shuttle Radar Topography Mission and the GTOPO30 data set. It can be considered to be either an SRTM data set enhanced with GTOPO30 or as an upgrade to GTOPO30 (JPL, 2006).

The Global Land One-Kilometer Base Elevation (GLOBE) DEM was released by NOAA‘s National Geophysical Data Center (NGDC). GLOBE is a global data set covering 180 degrees west to 180 degrees east longitude and 90 degrees north to 90 degrees south latitude. The horizontal grid spacing is 30 arc-seconds in latitude and longitude. The horizontal coordinates are referenced to WGS84. The vertical units represent elevation in metres above mean sea level. The statistics of SRTM30 and GLOBE are also listed in Table 1.

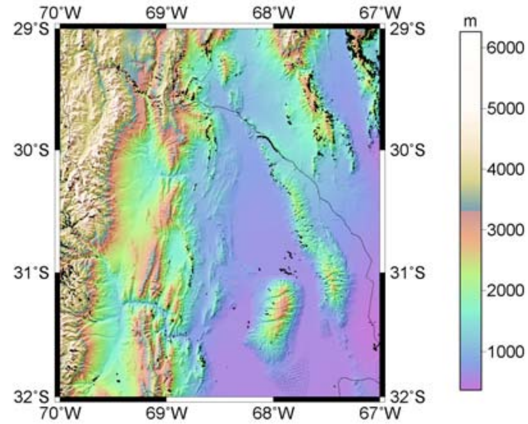

Figure 1: The original SRTM3 in the area under study

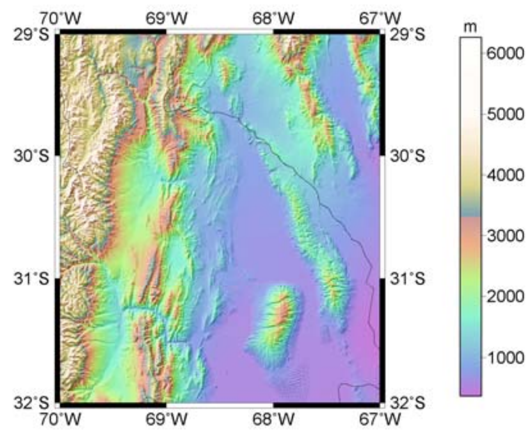

Figure 2: The corrected SRTM3ARG06 (SRTM3 Argentina 2006)

3 Numerical Tests

3.1 Evaluation of Digital Elevation Models

Digital elevation models play an important role in the accuracy of the precise gravimetric geoid; they are used to compute terrain corrections, direct topographical effects on gravity and indirect effects on geoid, and also to generate mean gravity anomalies (Featherstone and Kirby, 2000).

The four models available in the area under study are first evaluated making comparisons between them.

Even though SRTM30 can be considered as an upgrade to GTOPO30 the differences between both models are over 1000 m. The main differences are correlated with the rough topography in the west part of the area under study, between longitudes 69° W and 70° W as shown in Figure 3. The statistics of the differences are presented in Table 1. The differences between SRTM30 and GLOBE are of the same order of magnitude and again the largest values are located west the meridian 69° W. It is difficult to say that the differences are only a problem of longitude shifting as it was reported by Denker (2004) for Germany.

SRTM3ARG06 was evaluated by comparisons with GTOPO30, SRTM30 and GLOBE DEMs. Table 1 presents the statistics of the differences between SRTM3ARG06 and SRTM30, which have a mean value of 0.6 m and a standard deviation (STD) of 26 metres with maximum differences up to about 240 metres. The differences between SRTM3ARG06 and GTOPO30 and GLOBE are over the 1000 m and the largest differences are located again west the meridian of 69° W over the Andes mountain range

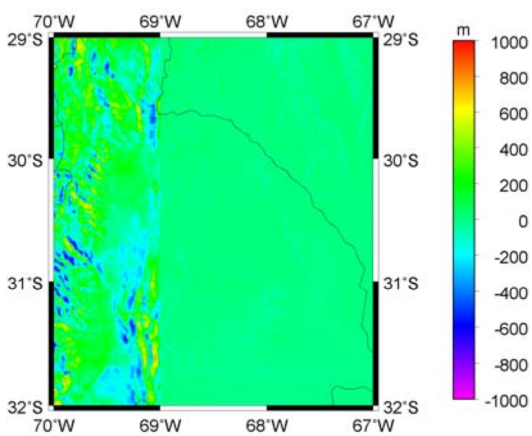

Figure 3: Differences between SRTM30 and GTOPO30 data. Unit: [m]

Table 1: Statistical of DEMs and their differences. Unit: [m]

DEM	*min*	*max*	*mean*	*STD*
SRTM3	370	6253	1927.1	1255.7
SRTM3ARG06	370	6263	1927.8	1255.6
GTOPO30	391	6253	1918.5	1240.4
SRTM30	393	6123	1927.0	1254.2
GLOBE	390	6253	1923.8	1240.6
SRTM30 - GTOPO30	-1168	1062	8.6	138.6
SRTM3ARG06-SRTM30	-234	238	0.6	26.7
SRTM3ARG06-GTOPO30	-1165	1157	9.1	143.1
SRTM3ARG06-GLOBE	-1165	1157	3.8	154.6

3.2 Terrain aliasing effects on geoid determination

To investigate the implications of the SRTM DEMs to gravity field and geoid modelling, all available models were used to compute different terrain effects on both gravity anomalies and geoid restore effects. The direct topographic effects on gravity and geoid restore effects, that will be use in the restore process, calculated were: full topographic effects (FTE) of all masses above sea level, assuming constant density, topographic-isostatic effects according to Airy-Heiskanen model (AH), gravimetric terrain corrections (TC), RTM effects (effect of the topographic irregularities with respect to a mean surface) and the direct topographical effect on gravity using Rudzki inversion gravimetric reduction scheme (constant density). These effects were computed using TC prism integration in the space domain (Forsberg, 1984; Forsberg, 1997) and with a modified version made by Bajracharya (2003) to compute the direct topographical effect on gravity using Rudzki's inversion method. The Rudzki inversion scheme can become a standard tool for gravimetric geoid determination since the Rudzki geoid performs as well as the Helmert and RTM geoids as it was demonstrated in rugged areas in the Canadian Rocky Mountains and in the Andes. It is the only gravimetric reduction scheme which does not change the equipotential surface and thus, it does not require the computation of the indirect effect.

As a second objective of this work SRTM3ARG06, was used to compute terrain effects on both gravity anomalies and geoid heights at variable spatial resolutions. The term aliasing means, in this contribution, the loss of detail information as terrain reductions are evaluated from a high resolution DEM to a coarse one (Bajracharya, 2003). The original grid resolution available in the area under study is 3 arc-seconds (SRTM3ARG06). Grids of 6", 15", 30", 1' and 2' were generated by simply picking point elevation values from the 3" grid. First, various types of topographic effects were computed using different DEM grid resolutions for each mass reduction technique. The topographic effects obtained by using the highest DEM resolution were regarded as the control topographic effects on gravity for each reduction scheme and the differences between these results and the results obtained from the lower resolution DEM were considered as aliasing effects.

The classical terrain corrections (effect of the topographic irregularities with respect of spherical

Bouguer plate) were computed using the integration prisms. Table 2 summarizes the statistics of the differences between terrain corrections (TC) using different DEMs resolutions with the 3" original grid. Table 2 also shows the statistics of the differences between TC computed from SRTM3ARG06 and TC computed from GLOBE, SRTM30 or GTOPO30.

Table 2: Statistics of the differences of the classical terrain corrections between the 3" grid and different grid resolutions and different DEMs. Unit: [mGal]

Grid resolution	*min*	*max*	*mean*	*STD*
3" - 6"	-2.37	3.36	0.01	0.13
3" - 15"	-3.50	6.88	0.11	0.46
3" - 30"	-4.72	12.94	0.33	1.02
3" - 1'	-7.65	18.50	0.68	1.77
3" - 2'	-68.98	29.05	-0.82	6.98
3" - GTOPO30	-75.07	23.38	-2.00	8.22
3" - SRTM30	-23.06	23.86	1.24	2.42
3" – GLOBE	-75.07	23.38	-2.17	8.27

The differences in TC using different DEMs resolutions are correlated with the topography as we can see in Figure 4.

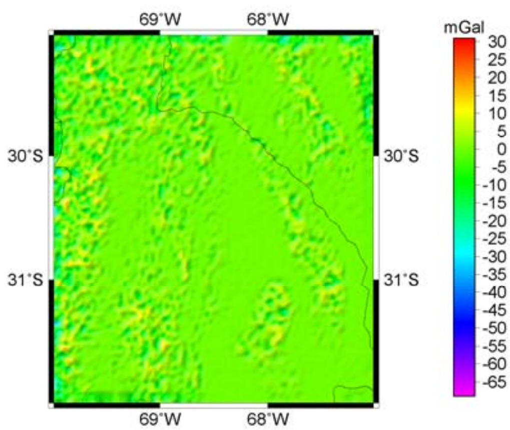

Figure 4: Differences in TC using 3" and 2' grid resolution [mGal]

TC varies from ±6.6 mGal to ±9.7 mGal in terms of standard deviation and from 55 mGal to 101 mGal in maximum, using a grid of resolution of 3" and 2', respectively.

The differences between the TC effects on gravity are almost four times bigger in magnitude of STD when comparing them computed from GTOPO30 and GLOBE with those computed from SRTM30.

Tables 3 and 4 show the difference in maximum value and standard deviation, respectively, between different topographic effects on gravity computed from SRTM3ARG06 and topographic effects on gravity obtained by using GTOPO30, SRTM30 and GLOBE. The differences between the full topographic effect and the isostatic effects on gravity computed from SRTM3ARG06 and SRTM30 are at ±3.1 mGal in terms of STD and for the RTM and the Rudzki direct topographical effect on gravity ±3.8mGal and ±3.5 mGal, respectively. The STD of the differences between these topographic effects on gravity computed from SRTM3ARG06 and those computed by either GTOPO30 or GLOBE are four times larger. They are at the ±12.2 mGal level for the full topographic effect, the isostatic effects on gravity and Rudzki. For RTM, these differences are slightly larger, at the ±14.6 mGal level.

Table 3: The difference in maximum value between topographic effects on gravity computed from SRTM3ARG06 and topographic effects on gravity obtained using other DEMs. Unit: [mGal]

Grid resolution	***FTE***	***AH***	***RTM***	***Rudzki***
3" – GTOPO30	82.63	82.39	97.97	75.89
3" – SRTM30	37.32	37.39	53.93	41.62
3" – GLOBE	82.63	82.39	97.97	75.89

Table 4: The differences in standard deviation between topographic effects on gravity computed from SRTM3ARG06 and topographic effects on gravity obtained using other DEMs. Unit: [mGal]

Grid resolution	FTE	AH	RTM	Rudzki
3" - GTOPO30	12.18	12.15	14.14	12.19
3" – SRTM30	3.09	3.09	3.79	3.46
3" – GLOBE	12.64	12.60	14.60	12.59

Comparing the different topographic effects from the generated resolutions grids (6", 15", 30", 1', and 2') to the original grid resolution of 3" of the SRTM3ARG06 some aliasing effects are clear. The maximum and STD values increase for all the terrain effects computed.

Figures 5 and 6 show the differences in maximum value and standard deviation, respectively, between control values (3") and coarser grid resolutions (6", 15", 30", 1', and 2').

From Figures 5 and 6, we can see that the maximum value and the standard deviation increase as moving from the dense DEM to the coarser DEM resolutions for all terrain effects computed.

The gravimetric geoids are usually computed with the remove-compute-restore technique. The indirect effect on the geoid, which depends on the mass reduction scheme used in the remove step, must be restored in the restore step.

The same topographic effects were computed for geoid restore effects.

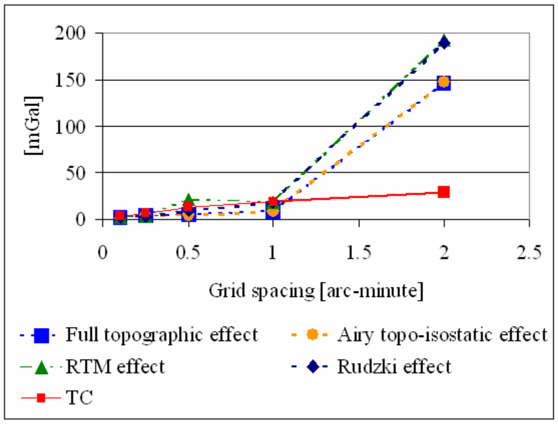

Figure 5: The differences in maximum value between control terrain effects on gravity and terrain effects on gravity obtained using different DEM resolutions

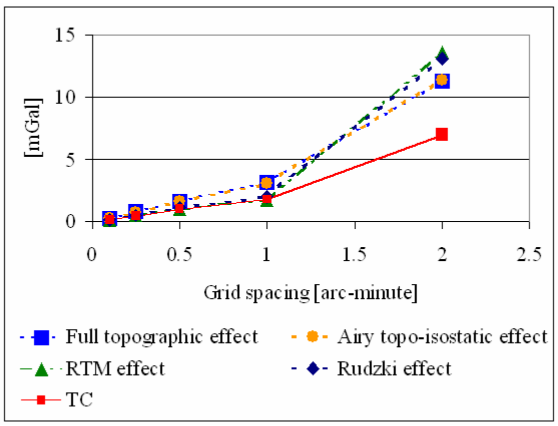

Figure 6: The differences in standard deviation between control terrain effects on gravity and terrain effects on gravity obtained using different DEM resolutions

Table 5 shows the standard deviation of the differences between TC, full topographic effect, AH isostatic, and RTM effects on geoid heights computed from the SRTM3ARG06 (3") grid and different DEMs. There is no indirect effect on geoid using the Rudzki inversion scheme.

Table 5: The differences in standard deviation between effects on geoid heights from 3" grid and geoid restore effects obtained with different DEM. Unit: [m]

Grid resolution	*TC*	*FTE*	*AH*	*RTM*
3" - GTOPO30	0.10	0.08	0.07	0.07
3" – SRTM30	0.04	0.07	0.01	0.01
3" – GLOBE	0.11	0.08	0.07	0.07

The differences between SRTM3ARG06 and SRTM30 are the smallest for all terrain effects on geoid. The differences between SRTM3ARG06 and GTOPO30 or GLOBE are larger in magnitude and similar between them.

For RTM effects on geoid (see Figures 7 to 9), the big differences between SRTM3ARG06 and GTOPO30 **a**re present in the west part of the area under study.

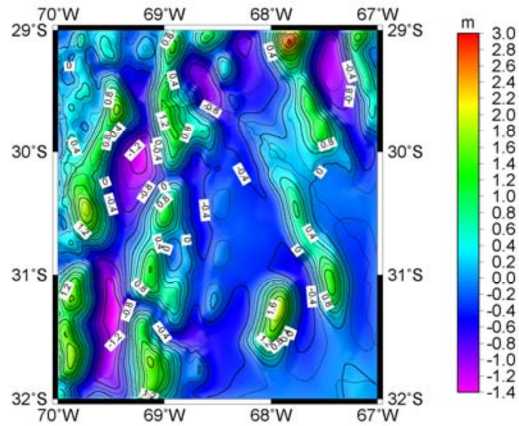

Figure 7: RTM effects on geoid computed with SRTM3ARG06

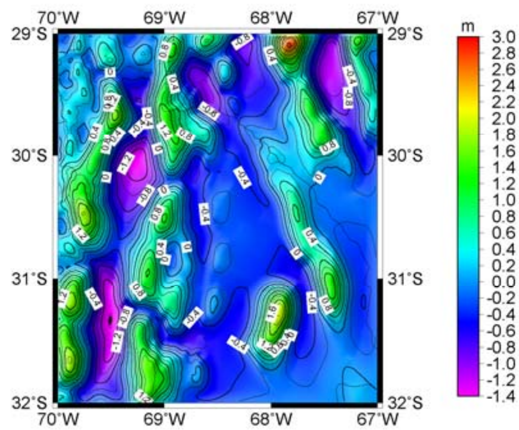

Figure 8: RTM effects on geoid computed with GTOPO30

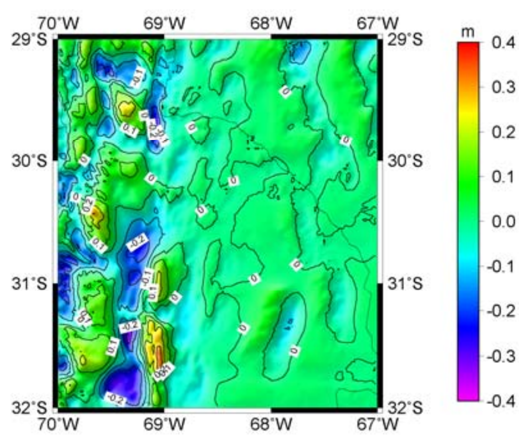

Figure 9: Differences of RTM effects on geoid between SRTM3ARG06 and GTOPO30

Figures 10 and 11 show the differences in maximum value and standard deviation, respectively, between control values (3") and terrain effects on geoid obtained using different DEM resolutions.

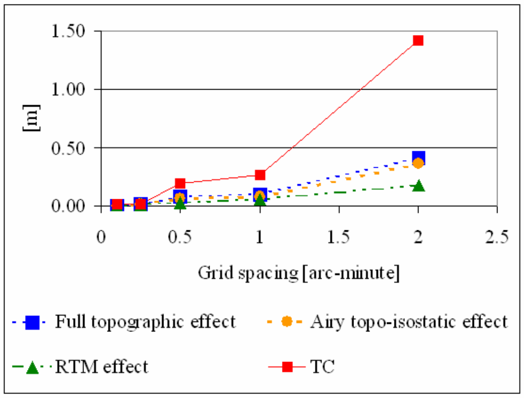

Figure 10: The differences in maximum value between control terrain effects on geoid and terrain effects on geoid obtained using different DEM resolutions

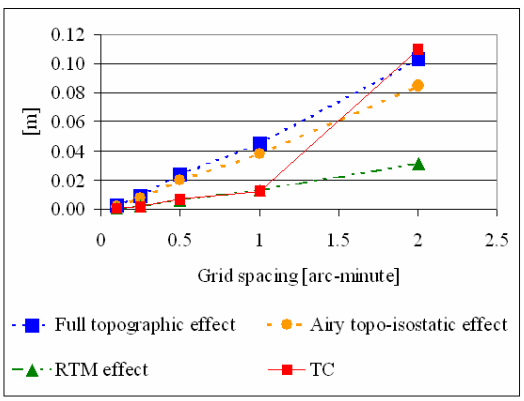

Figure 11: The differences in standard deviation between control terrain effects on geoid and terrain effects on geoid obtained using different DEM resolutions

From Figures 10 and 11, we conclude that aliasing effects are present when we use a coarse grid. The largest error will be introduced using a grid of 2'. The differences between the TC effects on geoid heights from the original SRTM3ARG06 model and the 2' DEM was at the ±11 cm level in terms of standard deviation, an error of this amount is introduced in geoid computation if a coarser grid of 2' resolution is used.

4 Conclusions

Various DEMs were evaluated in a rough area of Argentina, near the Andes. SRTM3, GTOPO30, SRTM30 and GLOBE global digital elevation models. GTOPO30 has been used until now to compute the gravimetric geoid models for Argentina.

SRTM3ARG06 is the result of the original SRTM3 DEM after the grid was converted into a regular grid by interpolation with elevations from the neighbouring data.

The differences between SRTM30 and GTOPO30 have a mean value of 9 m and a standard deviation of ±139 m. Even though, SRTM30 can be considered as an upgrade to GTOPO30, there is no doubt that the combination of the GTOPO30 data set and the data from the Shuttle Radar Topography Mission has modified the GTOPO30 original DEM.

This paper investigated the terrain aliasing effects introduced on both gravity anomalies and geoid heights by using various DEM resolutions.

The differences from the results computed from the densest grid (3") and the results from the sparser grids were considered as aliasing effects. First, the terrain effects were computed for terrain corrections, full topographic effects, RTM, Rudzki and AH isostatic effects on gravity at the generated grid resolutions and then, the same effects were computed for geoid heights. The results show that a high resolution DEM of 15" or finer should be used in mountainous areas like the Andes. If a 15" or finer DEM is used, the error introduced in the geoid heights does not exceed ±1 cm but if a lower resolution DEM is used the error in geoid heights will exceed ±11 cm. So a DEM not coarser than 15" is recommended for high-accuracy geoid determination.

As future work, a comparison of the SRTM data with the heights of gravity station from the gravity database and with the heights of GPS/levelling points must be evaluated. The height of gravity stations must be carefully revised. Also the geoid of Argentina should be recomputed by using the SRTM3ARG06 DEM for the topographic reductions. This DEM may also produce better gridded gravity anomalies, especially in the Andes area.

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