Activities Related to the Materialization of a New Vertical System for Argentina

M. C. Pacino
Facultad de Ciencias Exactas, Ingeniería y Agrimensura
Universidad Nacional de Rosario, Av. Pellegrini 250, (2000) Rosario, Argentina
mpacino@fceia.unr.edu.ar

D. Del Cogliano, G. Font, J. Moirano, P. Natalí
Facultad de Ciencias Astronómicas y Geofísicas
Universidad Nacional de La Plata, Paseo del Bosque s/n, (1900) La Plata, Argentina
daniel@fcaglp.unlp.edu.ar

E. Lauría, R.Ramos
Instituto Geográfico Militar
Cabildo 391, Buenos Aires, Argentina
elauria@igm.gov.ar

S. Miranda
Facultad de Ciencias Exactas, Físicas y Naturales
Universidad nacional de San Juan
San Juan, Argentina
s_mirandaar@yahoo.com

Abstract. The Geodesy Subcommitee of the National Commitee of IUGG created the working group "Geopotential Origin" in December 2000 in order to coordinate the national activities, establish and set down a new Vertical Reference System and to interact with Group III of SIRGAS (Geocentric Reference System for the Americas) Project.
For that, all the activities were organised in four items. This contribution describes the main results obtained in each of them as well as future tasks for the near future:

- Tide Gauges: The origin of the Argentine Vertical Reference System, defined by means of tide gauge records, is affected by the sea surface topography at the gauge locations. A project to observe and model the sea level variations using both, tide gauges and satellite altimetry, is being carried out since 1998. Four permanently observing GPS stations have already been installed close to gauges along the Argentine Atlantic coast and integrated in the International GPS Tide Gauge (TIGA) Monitoring Project.
- Geopotential Numbers: All first order levelling network unadjusted height differences were migrated to digital media and merged with the benchmark positions and gravity values. The resulting database consists of 16,000 level differences distributed along about 3,170 lines. Gravity values are missing for 20 percent of the benchmarks. The data set is currently being checked for consistency.
- Linking of Altimetric Networks from Neighbour Countries: During 2002 the first link between the altimetric networks of Chile and Argentina was done. The result was a difference of 22 cm, the higher value corresponding to Argentine levelling lines. The border point, where the levelling lines of both countries are connected, is *Puesto Monte Aymond*, near *Estrecho de Magallanes* in the south extreme of South America. The corresponding activities in order to make two or three new comparisons along the 5,000 km long borderline between these countries are being coordinated.
Recently, the determination of a natural water surface (Fagnano Lake) was used like an equipotential surface to connect the altimetric networks of Chile and Argentina where the classical spirit levelling is not accessible due to the lack of roads.
- Compensation of Height and Gravity Networks: Adjustment of the national gravity and altimetric networks and their linking with the nets of neighbouring countries are in progress, including both new absolute and relative gravity

determinations, which are necessary for the adjustment and optimisation processes.

Keywords. Tide Gauges, Geopotential Numbers, Altimetric Networks.

1 Introduction

The Vertical Reference System for Argentina was realized through a short series of tide gauge observations collected in *Mar del Plata* in the year 1924. During the 1940s, the reference mark on the tide gauge was connected by high precision geodetic levelling to a highly more stable mark in *Tandil*, located approximately 200 km away from the coastline. This point remains today as the origin of the national height system. This reference frame was extended to the whole country by high precision geodetic levelling. The first order network was completed in 2001 by *Instituto Geográfico Militar* (IGM). It consists of roughly 16,000 points distributed along several tens of thousands of kilometres of high precision geodetic levelling lines.

Since 1997, SIRGAS Working Group III, vertical datum, has striven towards the establishment of a unified vertical reference frame for the American Continent (Lauría et al., 2002). This involves the revision and unification of both the national vertical reference realisations and their densifications. In connection with the latter, GTIII has recommended the participating countries to compute the geopotencial numbers corresponding to their high precision levelling networks whenever measured gravity information is available. As this is the case for Argentina, the Geodesy Subcommitee of the National Commitee of IUGG has been working to produce a consistent set of geopotencial numbers for the national first order levelling network.

2 Tide Gauges

The Facultad de Ciencias Astronómicas y Geofísicas (FCAG) and the Deutsches Geodätisches Forschungsisntitut (DGFI) are engaged in a project called "*Sistema de Referencia Vertical en Argentina por Mareógrafos y Altimetría Satelital*" (SIRVEMAS) since December 1998. The main aim of this work is to contribute to the South American Vertical Reference System realisation; in particular, to a reference frame consistent with modern space geodetic techniques.

2.1 Permanent Stations and SIRVEMAS Campaigns

A group of twelve tide gauges maintained by the *Servicio de Hidrografía Naval* (SHN) lie along the Argentina coastline. A subgroup among these stations was selected for GPS monitoring. Several selection criteria were applied, having been considered some key factors such as: existence of a long history of measurement series, continuity of operation, their location, and the possibility of installing a permanent GPS station near the tide gauge. Based on this criteria *Mar del Plata, Puerto Belgrano* and *Puerto Madryn* tide gauges were selected.

In 1998 a permanent GPS station was installed in *Bahía Blanca.* Since then, episodic GPS campaigns at the tide gauges in *Mar del Plata* and *Puerto Belgrano* were carried out. At the end of 1999 a second permanent station at *Rawson* and a new GPS station at the tide gauge of *Puerto Madryn* were introduced. Finally in 2002, a third permanent station was installed close to Mar del Plata tide gauge. Figure 1 shows the distribution of the tide gauges, new permanent stations and also the IGS stations involved in the processing.

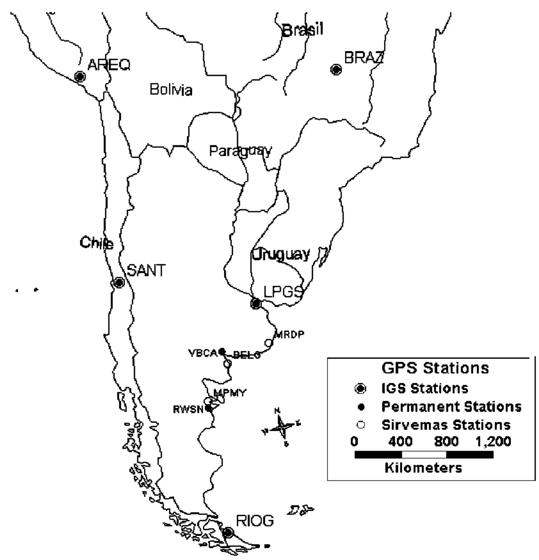

Fig. 1: SIRVEMAS Stations

Until now nine episodic campaigns were carried out, each of the measurement campaigns consisted of a minimum of seven consecutive days of simultaneous 24-hour GPS observations.

2.2 GPS Data Processing

All data sets were uniformly processed with the Bernese GPS Software V4.2 (Hugentobler et al., 2001). The main characteristics of the data processing can be summarised as follows:

- Final IGS products for orbits, Earth orientation parametres and phase centre variations were used;
- The L1 and L2 phase ambiguities were resolved using the QIF strategy. No ionospheric model was introduced at any stage of the processing;
- Ocean tide loading corrections following the FES 95.5 model were applied to each station;
- An a priori tropospheric delay was computed using the Saastamoinen model (Saastamoinen, 1973) and the dry mapping function by Niell (Niell, 1996), both available as standard options in the Bernese software version 4.2. In addition corrections to the zenith delay were estimated in the adjustment every two hours (Kaniuth, 1998);
- The elevation cut off angle in the daily adjustment was set to 10°, and no elevation depending weighting was applied in order to fully exploit the low elevation data;
- In many cases a baseline per baseline processing involving a careful residual analysis and introduction of new ambiguities was necessary.

After the pre-processing phase, the daily solutions were held free, that is, only low weights were applied to the fiducial points. After that, for each campaign, an almost free solution of the entire network was obtained, for which ephemeris defined the reference frame.

2.3 Results

The purpose is to obtain precise coordinates for the tide gauge benchmark related to the International Terrestrial Reference System (ITRS). The introduction of the reference frame through the fiducial stations with their weights is a critical issue in order to obtain a reliable set of velocities. The reference frame was introduced by applying suitable weights to the fiducials. In this case BRAZ, LPGS, SANT and RIOG were selected as fiducial stations. These IGS stations were considered to be the most reliable in the region as they are processed by several global and regional IGS analysis centres. We estimated vertical velocities for the SIRVEMAS network using the following solutions:

- the ITRF realisations 1997 and 2000 of the International Earth Rotation Service (IERS);
- the regional GPS solution generated by DGFI, SSC(DGFI)04P01.

The vertical velocities resulting from the uniform processing of nine episodic campaigns spanning five years is summarized in Table 1.

Table 1: Summary of height velocities [mm/yr].

Station	ITRF97	ITRF2000	SSC(DGFI)04P01
MPLA	+0,9 ± 0,1	-1,8 ± 0,1	-1,3 ± 0,1
BELG	+1,1 ± 0,1	-1,9 ± 0,1	-1,6 ± 0,1
MPMPY	-0,2 ± 0,2	-2,8 ± 0,2	-2,3 ± 0,2

The table comprises the estimates and their standard deviations.

The velocities estimated using the solutions ITRF97 are different compared with the other two sets. These differences might come from the fact that ITRF97 has less data than the other two solutions. From these results we can not claim which solution is the most reliable, but just show the sensitivity of the results to variations in the reference frame realisation.

3- Geopotential numbers

The complete national levelling database is by now in digital format. It consists of 370 levelling lines composed by 16,320 benchmarks, including 225 nodes (Fig. 2).

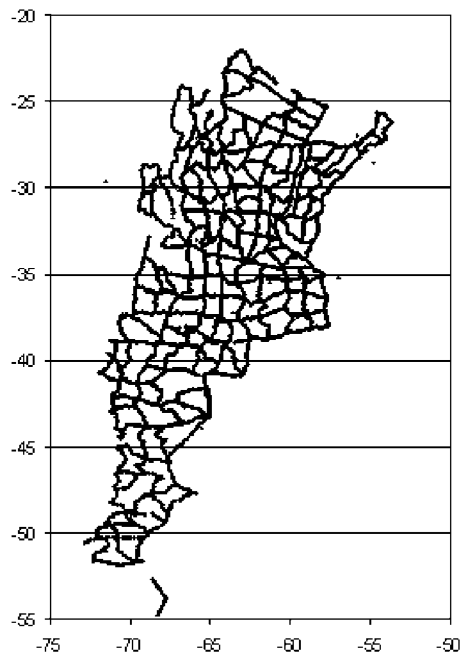

Fig. 2: First Order National levelling network

The distances between adjacent benchmarks range from 3km to 9 km. The level difference precision depends on the distance between adjacent benchmarks as 3mm times square root of the levelled distance in km.

Almost every benchmark in the network has geocentric coordinates. Their accuracy however varies from centimeters for the most recent ones determined by GPS, to a few thousand meters in the case of those coming from topographic maps, an usual procedure in older days.

Approximately 84% of the benchmarks in the network have measured gravity values. One of the problems to solve prior to the geopotential number computation is to fill the gravity "holes" properly. The analysis of the gravity data indicates that there are 1,200 gravity "holes" on the lines. Among them, 75% are only one isolated missing value and 50 cases consist of large gravity holes including a few cases of complete lines with no gravity observation at all.

Most of the gravity values in the network were originally referred to the Potsdam frame 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 measurements on both systems, being the mean difference 0.2 mGal -/+ 0.3 mGal. Apart from the reported measuring methodology and instrumentation, this fact leads us in principle to assume an accuracy for the gravity measurements of at least 0.5 mGal. The nodes of the network show a mean occupation of 3.2 times. Indeed, 76% was occupied more than once.

Up to now, both levelling and gravity networks datasets provided by IGM, were analyzed and checked in order to:

- compute all closures within the levelling network in terms of raw or measured height differences;
- compute geopotential numbers along all levelling lines;
- compute orthometric and normal heights along all levelling lines.

Besides, some software has been written in order to handle the levelling network definition in a flexible way that allows the introduction of changes and a fast re-computation of all closures for quality check purposes. (Font et al., 2004).

On the other hand, a precise GPS geodetic network has been established in *Buenos Aires* province with benchmarks belonging to the IGM first order Argentinean levelling network.

The geodetic network has been related to the reference frames POSGAR 94 and POSGAR 98 (epoch 1995.4). The latter is the materialization of the ITRF in Argentine (Moirano, 2000). In these conditions a height transformation model was developed. This model, named FCAG98 (Perdomo and Del Cogliano, 1999) constitutes an approximate representation of the geoid in *Buenos Aires* and has been used to transform ellipsoidal heights into IGM heights and compared with the geopotential model EGM96 (Perdomo et al., 2001).

Recently,

- geopotential numbers,
- normal heights, and
- quasi-geoid heights

were evaluated for the above-mentioned net points.

These results show comparisons between geoid undulations and quasi-geoid heights in the GPS/Benchmarks points. (Font and Perdomo, 2004).

4- Linking of Altimetric Networks

Several activities related to altimetric networks of different countries in South America started from the IAG meeting that took place in Cartagena (Colombia), where Argentina and Chile decided to compare their respective altimetric nets in different points along their border line, extended for about 5,000 km in the *Cordillera de los Andes*.

Field works to achieve the first comparison were done during 2002. The meeting took place at *Monte Aymont*, a border step next to *Estrecho de Magallanes*, in the southernmost continental zone of both countries (Fig. 3). A difference of 0,22 ± 0,025 metres was found.

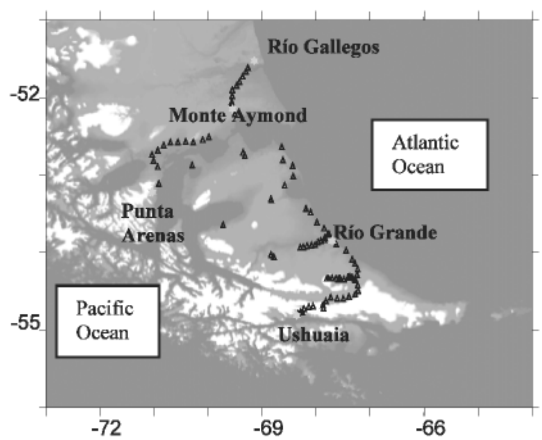

Fig. 3: studied area. (▲) GPS/levelling points. (•) Cities

Some considerations have to be taken into account: The altimetric network of Argentina is referred to a point located 3,000 km north of *Monte Aymond*, while the altimetric network of Chile is referred to the tide gauge in *Punta Arenas*, 180 km far from the comparison point. Furthermore, the result is the same order of the differences between the Argentine network and several tide gauges (D'Onofrio et al., 1999).

Another comparison was made using the levelling line between *Monte Aymond* and *Río Gallegos*

(Argentina). In this case, the levelling line is referred to a tide gauge located 80 km from the border point. The difference decreased to 0,06 ± 0,025 metres

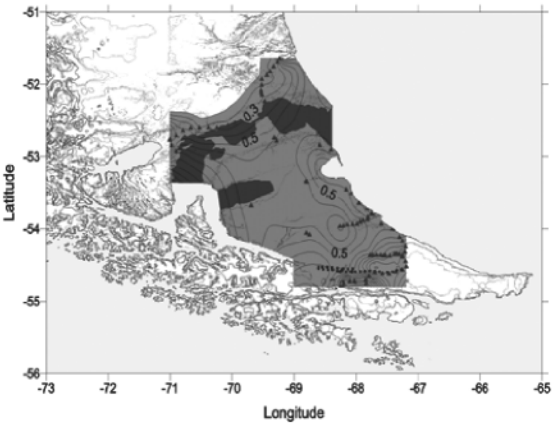

Fig 4. Differences between the new regional geoid model and the global geopotential model EGM96 (Lemoine et al. 1998). Isolines in meters every 0.1 m.

Recently a new geoid model for *Tierra del Fuego* (Fig.4) was performed by means of the GPS levelling and the level surface of the Fagnano Lake (Del Cogliano et al, 2005).

The lake extents 105 km wide in E-W direction and connects Argentina with Chile. There, the classical spirit levelling is not accessible due to the lack of roads.

The determination of the lake level was based on measurements of a GPS buoy and permanent operation of three pressure tide gauges during two years. The integration of the MLL (mean lake level) information contributed notably to the representation of the local geoid.

The next task is to link the Chilean altimetric network to a benchmark close to the lake in order to compare both, Argentine and Chile altimetric networks, in the southernmost zone of the American continent.

Continuing with the tasks related to the neighbouring countries altimetric networks link, driven by the SIRGAS Project, and aiming at the determination of the Continental vertical Datum between the years 2003 and 2004, the Argentine IGM measured four levelling lines (*Paso Tromen, Paso Icalma, Paso Samoré* and *Paso Futaleufú*) closer to the Republic of Chile. The Chilean IGM has showed the same result with regard to its levelling line at *Paso Huemules*.

This year both IGMs are considering finishing the link between their respective networks at "*Paso Caracoles*" (International Tunnel at "*Paso Cristo Redentor*" for the Argentine Republic).

5- Compensation of Height and Gravity networks.

Compilation of the original levelling data has been concluded. Meanwhile the recovery of gravity primitive records is in progress. With regard to the network compensation, different robust methodologies are being tried in order to adjust data that have been measured using different instruments for nearly a century. In this sense, Miranda et al. (2004) have settled a local experimental gravity network in *San Juan* (Argentina). The net was designed to form a chain of triangles in order to hold redundant measurements to the adjustment by the robust method of Becker (1990). The network inner adjust is better than 7 μGal.

Besides, in scientific cooperation with Brazilian and Uruguayan institutions, several research projects have been proposed, one of them just launched, with the view to set up new absolute gravity stations in Argentina. These stations will be used as fix points in the gravity network adjustment process. On the other hand, a special care will be attempted to get measurements on existing sites where other geodetic observations are available (continuous GPS for instance), so that a repetition network of precise reference geodetic stations can be set up. These sites include five existing absolute gravity stations established in Argentina in 1988 and 1991, which will contribute to better characterise possible ground deformations and gravity temporal changes.

Furthermore, strategies for linking the national gravity network with the nets of Brazil and Uruguay are being designed.

5. Conclusions and further work.

The results on tide gauges presented in this paper are based on six episodic GPS campaigns spanning over the last three years. The results obtained show that the methodology used in the processing of the GPS data to determine vertical crustal movements is correct. However, the velocities estimated are simply first approximations and a longer series of observation is required. A careful analysis in the realisation of the reference frame is still necessary.

The next step is to analyse the tide gauge records for the gauges involved in this project.

There are several remaining tasks on geopotential numbers calculation. Firstly, a convenient way to interpolate the gravity values where they are missing will be selected. Secondly, geopotential number differences between benchmarks will be computed. Misclosures of polygons within the network will then be analysed as a consistency check for the measurements. Next, a consistent set of geopotential values will be derived through an adjustment on the nodes. Finally, a set of heights will be derived following the adoption of a vertical reference frame and a height definition. These will be selected in accordance with the SIRGAS recommendations in order to ensure the maximum compatibility of the national height systems in the America Continent.

Once the link between Argentina and Chile is established, there are views to running similar projects with the rest of the neighbouring countries.

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