The Vertical Reference System in the Argentine Republic

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Abstract. This paper is a summary of the tasks that have been developed and the ones that are under development in the Argentine Republic by means of joint activities, agreements and cooperation among institutions, together with national and international scientific and educational agencies, related to:

- Completion, calculation, unification and link to planialtimetric networks.
- Gravity activities and procedures used for heights correction.
- Linking to neighboring countries networks.
- Initial leveling experiences by means of GPS technology, and results obtained.
- Regional and national geoid modeling.
- Determination of vertical crustal movements, evaluation of sea technology, variations of the mean sea level and its influence over the zero of the argentine height system.

Keywords. Classical height system, vertical reference system.

1 Completion, Calculation and Link to Planialtimetric Networks

1.1 Planimetric network

The Military Geographic Institute (IGM) is, in the Argentine Republic, responsible for the maintenance and operation of the national geodetic networks. The National Geodetic Reference Framework, named POSGAR94 (Argentine Geodetic Positions) materializes the WGS84 Reference System in the country, and was adopted by the IGM in May 1997 replacing its old local system Campo Inchauspe 69.

Measurement of the POSGAR network was performed during two extensive field campaigns in the years 1993 and 1994, where 127 points were determined with special technical characteristics. These points are centers of circles that cover the whole territory and have an average radius of 130 km. The positions of about 50% of these stations are also available in the Inchauspe 69 datum, allowing to determine the transformation parameters between both systems. At the beginning of 1995 the calculation of the network was finished at La Plata University using a commercial program. An average network precision better than 1ppm and an accuracy better than 50 cm (Brunini et al, 2002) was obtained.

The 10 POSGAR 94 points coincident with SIRGAS, allowed the new POSGAR processing (Moirano et al., 1997) which gave rise to POSGAR 98 network. Although the quality of the 98 coordinates is noticeably better than the 94 ones, mainly for the vertical component, differences are not so important for most uses in topography and cartography (Brunini et al., 2002). The processing was performed by using the Bernese software (Rothacher and Mervart, 1996). From 1998 on the RAMSAC (Argentine Network for Continuous Satellite Monitoring) project is operational in the Argentine Republic. It is a network of permanent GPS stations, at present composed of nine stations distributed over the entire national territory under the coordination of the Military Geographic Institute.

1.2 Altimetric network

The national altimetric network is referred to the mean sea level and consist of 87,529 km of high precision and precision leveling, of 72,805 km of topographic leveling, and 3,250 km of auxiliary leveling for photogrammetric control.

H. Drewes et al. (eds.), *Vertical Reference Systems*

The high precision leveling lines divide the Argentine Republic territory into closed polygons or grids and into peripheral polygons along the seashore or international borders. The high precision leveling lines start and close nodals. Nodals are 1st category altimetric benchmarks and are mainly placed at the squares of villages or cities. Precision leveling lines are developed within grids and divide each of them from 6 to 8 polygons. Precision leveling lines start and close at altimetric benchmarks of high precision lines.

The topographic leveling lines densify the grid and start and close at altimetric benchmarks of high precision lines. The 3 networks develop along roads. That is the reason for the irregular tracing of polygons.

1.3 National gravity network

The national gravity network is composed as follows:

- The Zero Order Network with 5 points of absolute gravity which were measured during 2 stages in the years 1989 and 1991 by using the JILAG3 interferometric gravity meters belonging to the University of Hannover (Germany). These points are: Miguelete and Tandil (Buenos Aires), San Lorenzo (Salta), Comodoro Rivadavia (Chubut) and San Juan (San Juan)
- The First Order Network with 86 points placed at airfields that are part of the BACARA Network (Argentine Republic Calibration Base). This network was measured in 1968.
- The Second Order Network is coincident with the high precision leveling network .The gravity measurement of the 15,905 points that make up this network was completed in 1998.
- The Third Order Network is made by part of the topographic leveling network. Up to now, 2,175 points were measured.

Up to 2001, the total number of gravity points measured by the IGM is 18,248.

2 Gravity Activities and Procedures Used for Heights Correction

In order to preserve the 1st order network, it is anticipated to link said points to nearby nodals placed at the crossings of high precision leveling lines. It is also anticipated to link the BACARA network to absolute gravity stations measured using the JILAG03 interferometric gravity meter.

In order to complete the adjustment of the leveling network, and as soon as the height system to be used is defined, the IGM anticipates the general compensation of the network by means of the use of measured gravity values.

Finally, considering the need to link the planimetric and altimetric systems and easiness in the use of satellite technology, the IGM has begun the supply of coordinates to leveling benchmarks.

3 Linking to Neighboring Countries Networks

The Argentine Republic, being conscious of establishing a global altimetric system, has extended its leveling network up to international borders in order to have the respective link of the neighboring countries.

In order to fulfill this goal, the following links have been completed at the following points.

With the Republic of Paraguay:
- Paso de la Patria-Itá Pirú
- Itá Pirú-Isla.Cerrito
- Itá Ibaté-Yabebirí
- Isla.Paraguaya-Yabebirí
- Puerto.Nuevo - Pto.Pirapó
- Pilcomayo - Itá Enramada
- Candelaria - Campichuelo
- Formosa - Alberdi

With the Republic of Uruguay
- Concordia - Salto
- Monte Caseros – Bella Unión

With the Republic of Brazil
- Iguazú-Meira
- S.Javier-P.Xavier
- Paso de los Libres-Uruguayana

With the Republic of Chile
- Icalma
- Mamuil Malal
- Samoré
- Copahue
- Pehuenche

With the Republic of Bolivia
- La Quiaca
- Aguas Blancas

4 Initial Leveling Experiences by Means of GPS Technology, and Results Obtained

Two types of results obtained by means of GPS leveling are included at this report. As the first one there are eight examples of height calculation by means of GPS observations (table 1).

Table 1. Height calculation by means of GPS leveling.

h [m]	Δh [m]	ΔN [m]	Difference [m]	Distance [km]
32,78	-9,44	0,06	0,07	14
32,78	-3,22	0,46	0,40	60
32,78	-10,25	0,36	0,08	40
280,44	-13,92	0,22	-0,05	8
619,63	-9,51	-0,02	-0,01	1
544,77	65,66	0,16	0,12	7
619,63	6,18	0,01	-0,02	1
544,77	81,35	0,19	0,11	8

The calculation was performed by extracting the ellipsoid unevenness (Δh) from the vector processing result, and process the transfer by means of the expression

$$H_{(arrival)} = H_{(departure)} + \Delta h - \Delta N ,$$

which is deducted from the approximate formula

$$h = N + H$$

having calculated the values of ΔN from the EGM96 model.

The second experience was the comparison between the unevenness obtained by using GPS and corrected by using the afore mentioned procedure and the respective unevenness obtained by means of geometric leveling. The analyzed sample involves 60 points distributed within a region with a relatively smooth topography (figure 1).

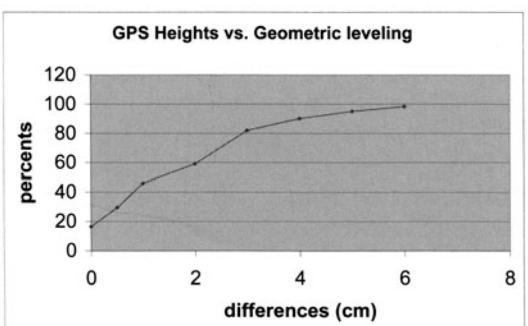

Fig. 1 GPS heights vs. geometric leveling.

5 Regional and National Geoid Modeling

5.1 Goals

At the end of 1994, the CNUGGI Geodesy Subcommittee created the "Geoid Modeling" Working Group, with the following goals:

- Interact with the South America Geoid Subcommittee and Working Group III from the SIRGAS Project.
- Gather all basic gravity information in the country, adjusted by the one coming from the IGM, the one coming from different Universities, together with the relative gravity maps from Fiscal Oil Fields (YPF).
- Add new gravity measurements to the previously existing data.
- Have ellipsoidal height values at the leveling points (certain N).
- Define the method criteria for a correct integration of gravity anomalies.
- Use and generate software.
- Interact with well known researchers from other countries.
- Develop human resources, based on seminars, postgraduate courses, and round tables about the subject.
- Participate at national and international scientific events.
- Contribute to the global geoid model for South America, and obtain the one for the Argentine Republic.

Since 1997, the Military Geographic Institute, the National Rosario University and different groups belonging to La Plata National University, have been working together under the coordination of this Working Group in order to execute the stated goals.

At the end of 2000, the same Subcommittee created the Geopotential Origin Working Group.

5.2 Realization up to the present

5.2.1 Data bases

The IGM data, which was used to generate the preliminary geoid models for the Argentine Republic at 20'x20' and 30'x30', was depurated.

There was a non stop continuity as regards gravity surveys at areas where there was no information, or where it was necessary to densify the existing one. This goal is being coordinately fulfilled through contributions from several institutions and individuals, as listed in the sequel.

- The Military Geographic Institute, mainly at the Patagonian south and at the provinces of Corrientes and Misiones
- The Rosario Physics Institute (IFIR) belonging to Rosario National University (UNR): provinces of San Luis, San Juan, Córdoba, Mendoza and Santa Fe
- The Gravity Department, Astronomic and Geophysics Sciences, La Plata National University (UNLP): half northern part of Buenos Aires province, provinces of Chubut, Mendoza and Tierra del Fuego. At the last one, the gravity network (with GPS support) over the geodetic network points was established; during 1998, and supervised by the last university, teachers from Morón University surveyed the northern part of Buenos Aires province.
- The gravity database handed over by Dr. J. Goetze (Germany) belonging to the argentine northeast area was added
- The ETOPO5 Terrain Digital Models and the 3'x3' one produced by the University of Leeds were also added to the existing ones
- Dr. D. Blitzkow, from the Polytechnic belonging to San Pablo University, Brazil (EPUSP) handed over: the "frame" for calculating the argentine geoid, the OSU91, JGM2 EGM96 Geopotential Models, used for processing 30'x 30' and 20'x20' argentine preliminary models and Sandwell satellite altimetry model

5.2.2 International action

Visits to the University of Leeds and the Polytechnic School al the University of San Pablo took place. In addition, the second international school for the determination and use of the geoid and the South America geoid model calculation workshop have been attended.

5.2.3 Human resources training

The following events took place:
Workshops
Postgraduate Seminars
Postgraduate Courses
Postgraduate Apprenticeships
Scholarship Tutoring
Thesis
Doctorates
Round Tables about Geoid
Production of Scientific Research

6 Determination of Crust Vertical Movements, Evaluation of Sea Technology, Variations of the Mean Sea Level and its Influence on the Zero of the Argentine Height System

As in most countries in the world, the argentine vertical reference system zero is defined to coincide with the mean sea level, assuming it is placed very near the geoid. The zero was established in 1924 by using the Mar del Plata mareograph (φ= -38.0, λ= -57.5). Afterwards, about 1949, the origin of the leveling network was moved to Tandil (φ= -37.4 λ= -59.1) where more stable geological conditions were found.

At present we know that the ocean mean level moves apart from the geoid and does not keep unchanged through time.

The analysis of long data series of several argentine mareographs show information ranging from increases of about four millimeters per year up to decreases of the same amount. These differences cannot be explained by means of the recently mentioned elements and could perhaps be owing to local recent crustal movements.

Since 1998, the La Plata National University and the Deutsches Geodätisches Forschungsinstitut carry on a cooperation project with the objective to determine vertical crustal movements along several points of the argentine sea shore, the evaluation of sea surface topography and variations of mean sea level in the area and to establish its influence on the argentine height system zero (Drewes et al., 1999; Kaniuth et al., 1999).

In order to perform the research, two new permanent GPS stations have been established, one in Bahia Blanca (φ= -62.3, λ= -62.3), operated by National South University, and another one in Rawson (φ= -43.3, λ= -65.1), operated by the Province of Santa Cruz Cadastre and Territory Information Directorate. The observations of these two stations are routinely processed by the Regional Network Associated Analysis Center SIRGAS (Seemüller and Drewes, 2000) and by the DGFI which contribute, together with the Buenos Aires, La Plata and Tierra del Fuego ones to realize ITRF along the Argentine coast.

Up to now, four GPS campaigns have taken place, seven days duration each one, where the receivers were placed at Mar del Plata, Puerto Belgrano (φ= -38.7, λ= -62.3) and Puerto Madryn (φ= -42.8, λ= -59.1) mareographs, and at Tandil Normal Reference Altimetric Point which sets the argentine vertical system zero.

The observations related to these campaigns are being processed by means of *Bernese* software (Rothacher and Mervart, 1996) and it is expected, in a short term, to have the first evaluation of local vertical movements in the mareographs area (Natali et al., 2002).

In a short term it is expected to: 1) establish a new permanent station, perhaps at Puerto Deseado, in order to improve the coverage in the continent south, 2) continue GPS measurement field campaigns at the different mareographs, 3) process observations emphasizing on vertical component analysis, and 4) add satellite altimetry information in order to study sea surface topography.

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