Brazilian First Order Levelling Network

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Abstract. The establishment of so-called Brazilian Geodetic System´s RAAP (High Precision Altimetric Network) started in 1945, with standard first order spirit levelling procedures. Today, more than 65000 benchmarks cover almost the country, except for the Amazon Region. RAAP heights are referred to Imbituba Datum, defined by MSL(1949-1957), except for the small network in Amapa State, that cannot be connected to Imbituba due to Amazon River. Until 1991, no sistematic gravity surveys over benchmarks were made, so RAAP heights have only normal gravity correction, even though they have been called "orthometric".

Keywords. levelling, reference systems, vertical datum, South America.

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1 Introduction

The establishment of the High Precision Altimetric Network (*RAAP* in Portuguese) of the Brazilian Geodetic System (*SGB*) started in 1945. Ever since, about 65 thousand benchmarks (*RNs*, for “referências de nível) were determined, corresponding to more than 160 thousand kilometers of double run. RAAP’s development can be divided in three periods :

- up to 1969, the areas of larger populational density and economic development were covered (Figure 1, black lines) ;
- from 1970 to 1980, RAAP was extended to the interior of the country and to the most distant points of the Brazilian Territory served by routes, in the states of Acre and Roraima (Figure 1, grey lines) ;
- starting in the 80’s, became reconstituted the lines of RAAP in areas with high destruction level and also in those regions where networks of another institutions existed in the past (Figure 2).

2 Materialization

The stations of RAAP are established along the main Brazilian roads, in average intervals that vary among 3,5 km (before 1985) and 2 km, today.

Two materialization types are being used. The first one is constituted by circular, convex metallic plates, nailed in stable surfaces, as rocky blooming, roadways with appropriate thickness, great engineering structures etc. Along the time the foil model suffered alterations, so much in its dimensions as in the material of its composition and, still, in the signs printed in its surface.

The second model is constituted of a cement mark, with maximum depth of 80 cm below the soil and maximum height of 20 cm above the soil, topped with the same type of metallic foil. That model is used traditionally in the margins of the roads in that don't exist structures for correct sustaining of the foil. Up to 1995, testimony marks were used, constituted by small blocks of cement topped by pin, built to 2m of horizontal distance and 60 cm of depth of the main marks.

It is believed that the fact of not using deep marks – in that the reference point (it plate or pin) it is linked to the rocky substratum through metallic sticks of several depth meters – contributes to the occurrence of chenges in the vertical position of RNs. However, the absence of systematic reobservations of the levelling lines of RAAP doesn't allow a correct quantification and, consequently, an appropriate analysis of the phenomenon.

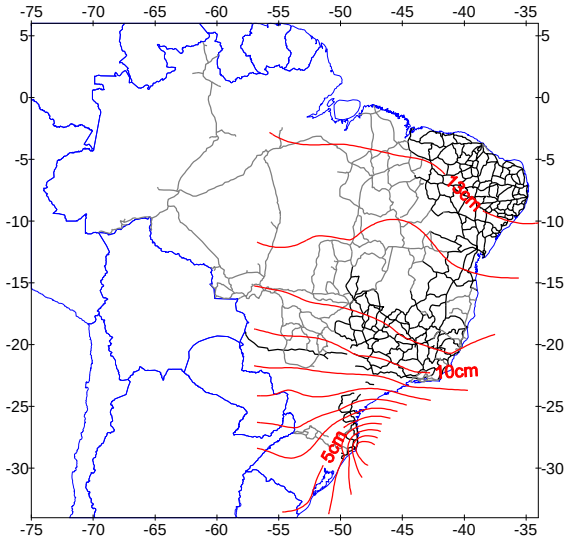

Fig. 1. Spirit levelling starting 1945 up to 1980. Red lines represent standard deviation of heights computed in 1993.

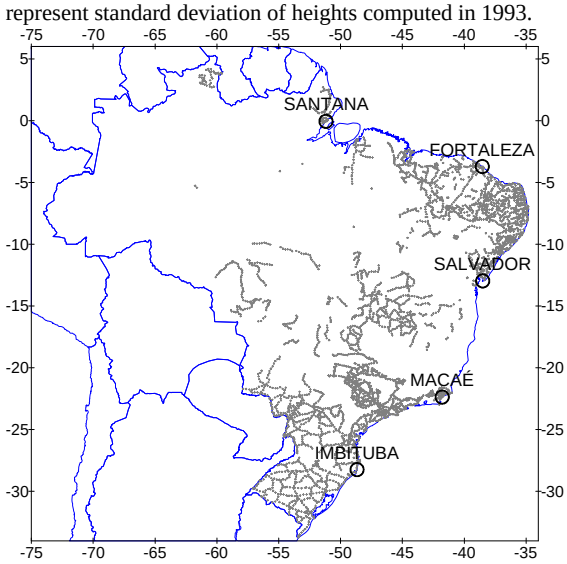

Fig. 2. Spirit levelling since 1980 and “geodetic” tide gauge stations.

3 Observation (spirit levelling)

The spirit levelling was accomplished, in its great majority, with levels Wild N3, rigid tripods and double graduation invar rods, according to the usual procedures for obtaining high precision :

- readings of the rods usually accomplished in the natural sequence of the work (left and right backward, left and right forward), using the same rod in the beginning and the end of a section for the elimination of the index error ;
- observation usually beginning with the first lights of the day, extending up the effects of the increase of temperature begin to harm the horizontalization of bubble level and the accomplishment of the rod readings. Eventually the works were also accomplished in the last hours of the day ;
- length of sights of up to 100 m, being used the limit of 60 m now ;
- backsight and foresight approximately equals, with tolerance of 3 m for the difference among the totals for each section, for minimization of the curvature and refraction effects ;
- not accomplishment of meteorological readings for correction of the related systematic effects ;
- reciprocal runnings usually done in sequence, with its difference attending to the tolerance of 4 mm $\sqrt{}$ km (before 1985) or 3 mm $\sqrt{}$ km, since 1985 ;
- confirmation of the stability of old RNs, for connection of new lines, through the relevelling of at least two existing sections, whose differences among new and old differences should not surpass the same tolerance used for the difference of the double levelling of a section ;

The treatment of observations of spirit levelling, that is, the calculation of the field sheets, is even today accomplished manually. The processing of the lines was accomplished manually until the end of the decade of 80, when the specific computational program entered in effective operation, in personal computers. That program was also used for the criticism of the old lines, whose data were typed along the first years of the decade of 80, as preparation for the first global adjustment of RAAP. In that program it is applied to the levelling data of RAAP the so-called "orthometric correction" regarding normal gravity, the unique correction of systematic effects applied by IBGE.

4 Gravity

According to previous explanation, gravity observations was never used for correction of the levelling data of RAAP. The reason is the absence, until the decade of 90, of that type of observations over RNs of the network, in a systematic way.

Actually, IBGE accomplished extensive gravity surveys in the 60’s. Such surveys concentrated on the area of the horizontal datum, exactly to help on the rigorous redefinition of the horizontal datum at that time, Córrego Alegre.

Only starting from 1991, when the systematic gravity surveys began in IBGE, it was possible to accompany with gravimmetry all the new levelling lines. Before that, several institutions accomplished

gravity observations, but not always on RNs of RAAP. The access to the data also constituted a delicate subject. That situation is being improved with the efforts of the Sub-Commission of IAG for Gravity and Geoid in South America (SCGGSA).

5 Reference

In its first years, RAAP adopted as vertical reference the average of 1 year sea level observations (1919-1920) at the Torres Tide Gauge. At the same time, the US *Inter-American Geodetic Survey* (IAGS) started the systematic observation of sea level at several points of Brazilian coast. This allowed the redefinition of the vertical datum of RAAP, more precisely, with the annual averages between 1949 and 1957, at Imbituba Harbour (Figure 2).

Two characteristics of Imbituba Datum must be highlighted :

- its location, in extreme south of the country, leads greater differences (up to 25cm) regarding local mean sea levels at north coast. Besides, in distant regions the error propagation of the levelling also reaches high values (13cm in the north coast, according Figure 1) ;
- the network cluster in Amapa State is referred to a local datum (Santana, Figure 2), due to the impossibility of crossing Amazon River with levelling in that region.

In the present days, the Department of Geodesy of IBGE is establishing the Geodetic Permanent Tide Gauge Network (RMPG), whose stations are uniformely distributed along Brazilian coast (Figure 2). The objective of RMPG is monitorate, precisely, the differences between the vertical datum of RAAP and the regional mean sea levels. Station MACAE is working since 1994. Station IMBITUBA will be instaled and will start normal operation in 2001, while other stations should operate starting 2002. All of these stations are tied to GPS stations, occupied in the SIRGAS 2000 GPS Campaign.

6 Adjustment

Between 1945 and 1975, eight manual adjustments of the observations of RAAP were accomplished. Only first three involved all the available observations in every moment. Starting from the fourth adjustment, it was used a procedure consisting of fixing the existing altitudes, partitioning the network in blocks that successively connected to the previous ones.

In the end of the decade of 70, it was started the preparation of the first automated adjustment. All levelling summaries were typed, and the respective lines, criticized. However, it still was not possible to accomplish an unique adjustment with all the lines of the network, what took to a new blocking. Such a blocking, however, it was not done in the same way that the previous one, being made through the establishment of an initial net of macro-loops, avoiding the occurrence of excessive distortions. The differences between the results of that global adjustment, finished in 1993, and the ones from the manual adjustments can be appreciated in the Figure 3. It can be observed that, in areas in that there was RNs of the manual adjustments, the differences stay in the order of 25cm. In that regions that there were no RNs of the manual adjustments, the differences reach more than 80cm.

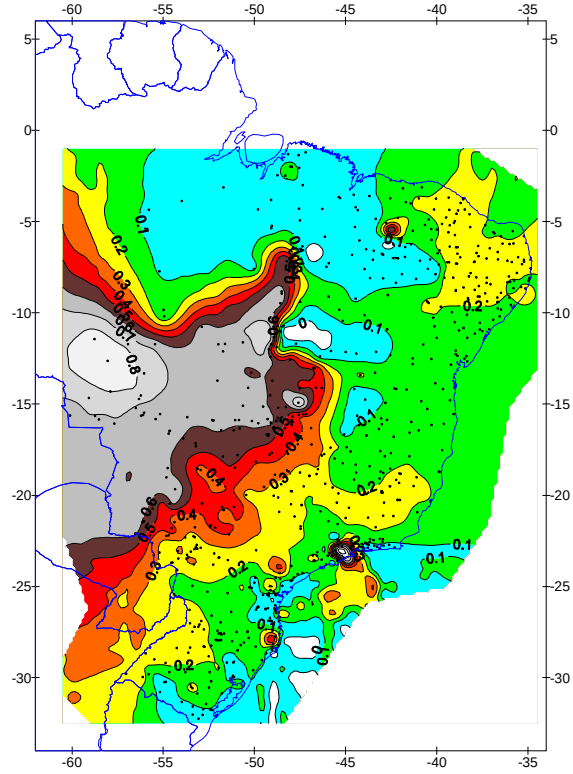

Fig. 3. Differences between heights from manual adjustments and from the first global adjustment (1993).