BRAZIL

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1. Activities related to the Brazilian Geocentric and Vertical Reference Frames

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In 2018 a considerable effort was carried out by the Brazilian Institute of Geography and Statistics (IBGE) on the re-adjustment of the leveling network based on geopotential numbers. The results provided normal heights to the bench marks (BM) and a close solution to the physical meaning of heights. Temporal analysis of leveling sections from 1945 to 2017, in a total of 74,169 BM, were undertaken. Files were reformatted for processing with GHOST (Geodetic adjustment using Helmert blocking Of Space and Terrestrial data), a software package developed by the Canadian Geodetic Survey. New leveling campaigns supported by GPS for checking inconsistencies were accomplished. The final results have been the update of 69,590 BM information in the data base.

At the same time, IBGE is working on the integration of heights system in the International Height Reference System (IHRS). Six stations of the continuous operating GNSS were already chosen as candidates to the International Height Reference Frame (IHRF). They will be connected by leveling network and gravimetric observations will be undertaken in a radius of 200 km around them, according to Geocentric Reference System for the Americas (SIRGAS) recommendations.

A special attention has been addressed to Geodetic Permanent Tide Gauge Network (RMPG, see Figure 1). A total of five stations along the coast, Arraial do Cabo, Imbituba, Salvador, Fortaleza and Santana, continuously observe the sea level. All stations contribute to the Permanent Service for Mean Sea Level (PSMSL), and consequently to the Global Sea Level Observing System network (GLOSS). Data from tide gauge stations are available in near real time at IBGE ftp server.

Figure 1- Brazilian Network of Tide Gauges for Geodesy – RMPG. In red is the spirit levelling network.

IBGE carried out gravity surveys for the improvement of geoid model in Brazil. In 2018, a total of 3,800 new gravity points were included in the gravity database, taking into account the height values derived from the new adjustment of the leveling network. A big effort has been addressed to gravity surveys in many areas with gravity gaps (Figure 2).

An improved geoid model was released in 2015 (MAPGEO2015), in substitution to previous version MAPGEO2010. It was computed in cooperation between IBGE and EPUSP (Polytechnic School of the University of São Paulo). This product has been based on a 5’ x 5’ grid of geoidal undulations (Figure 3). The main objective is to provide an alternative, based on gravimetric data, to transform the ellipsoidal heights derived from GNSS to a height with physical meaning, referred to an equipotential surface of the gravity field. The area of the model is limited by 6°N and 35°S in latitude and by 75°W and 30°W in longitude. Terrestrial gravity data from 947.953 points in Brazil and neighbor countries, validated with DIVA software, a digital terrain model based on SRTM and the EIGEN-6C4 global geopotential model to degree and order 200, as reference field, were used. The short wavelength component was computed by Fast Fourier Transform, in the so called remove-compute-restore technique. In areas where sufficient data were available, the neural network technique was used to complete the gravity anomaly information. The current model, adopted officially in Brazil (Fig. 3), has a consistency with GPS/BM of 0.17 m. In order to improve the geoid model evaluation, new GPS observations on BM are undertaken every year.

A new version of the geoid/quase-geoid model is under preparation and it will be delivered in 2020.

Figure 2- Status of gravimetric surveys used for MAPGEO2015 geoid model.

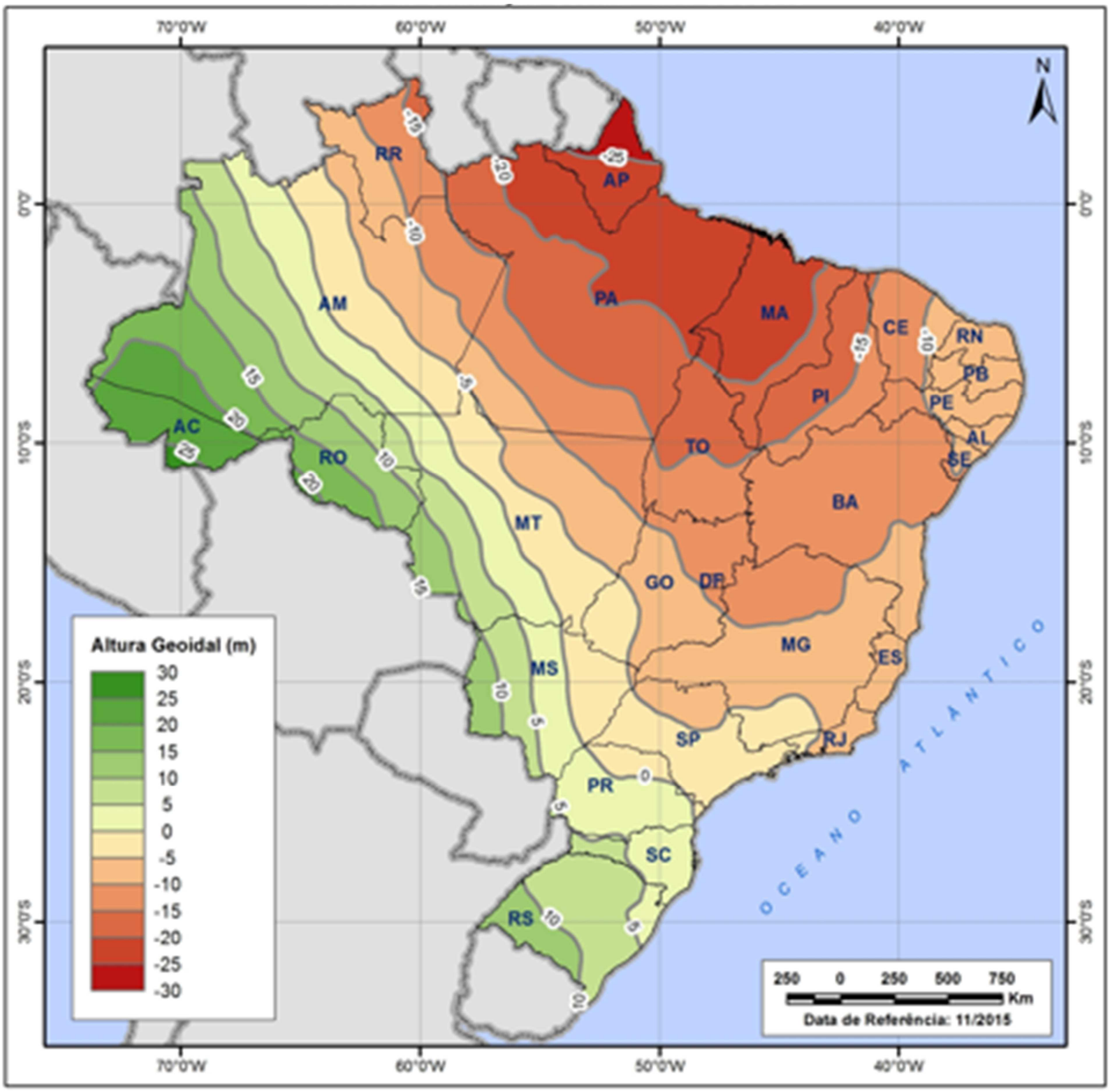

Figure 3- MAPGEO2015 geoid model.

2. Geodetic Reference Frame SIRGAS2000

SIRGAS2000 geodetic reference frame was officially adopted in Brazil on February 25, 2005, following developments carried out in the scope of the multinational SIRGAS initiative (Geocentric Reference System for the Americas – www.sirgas.org) towards the establishment of an accurate, unique, up-to-date and geocentric reference system in the continent, compatible with the most advanced satellite-based radionavigation systems. The SIRGAS2000 frame corresponds to a densification of the International Terrestrial Reference Frame (ITRF - http://www.iers.org/IERS/EN/DataProducts/ITRF/itrf.html?__nnn=true) in the Americas/Brazil; thus being by definition a global geodetic (and geocentric) reference frame.

The adoption of SIRGAS2000 in the country has been promoted by a national project known as National Geospatial Frame-work Project – PIGN (PMRG, http://www.ibge.gov.br/home/geociencias/geodesia/pmrg/default_pmrg.shtm), which was based on the active participation of several institutions in Brazil since 2000, under the leadership of the IBGE.

In this context, the following information/products/tools/services released to users in Brazil have supported the adoption of this new frame, which guarantees the required accuracy for consistently integrating all information layers to the National Spatial Data Infrastructure (www.inde.gov.br):

a) Coordinates of all stations (more than 8,000) belonging to the Brazilian Horizontal and GPS Geodetic Networks referred to SIRGAS2000 at the 2000.4 reference epoch. These coordinates are available through the Geodetic Database (http://www.bdg.ibge.gov.br/appbdg);
b) ProGriD: Coordinates Transformation Program, which transforms coordinates referred to the former reference frames adopted in Brazil (CórregoAlegre, SAD 69 and their realizations) to SIRGAS2000 (http://www.ibge.gov.br/home/geociencias/geodesia/param_transf/default_param_transf.shtm);
c) Geoid Model referred to SIRGAS2000, which converts ellipsoidal heights determined from satellite positioning techniques to the mean sea level. This model is continuously improved by IBGE, in cooperation with EPUSP. The current version is named

MAPGEO2015, (http://www.ibge.gov.br/home/geociencias/geodesia/modelo_geoidal.shtm);

d) IBGE-PPP: IBGE's Precise Point Positioning Online Service (http://www.ibge.gov.br/home/ geociencias/geodesia/ppp/default.shtm), a free service which computes, in post-mission mode, precise coordinates referred to SIRGAS2000 and ITRF2000 based on GNSS data collected by users in Brazil and surrounding regions.

   IBGE-PPP was delivered on April 2009 as a result of a partnership with NRCan/GSD, which has licensed to IBGE its PPP software and precise satellite orbits and clocks, necessary to process GNSS data. The expected positioning accuracy processing data collected by dual frequency receivers using this service is better 10 cm. It has been one of the most used GNSS positioning tools in Brazil, making the connection to SIRGAS2000 easy and straightforward. It has been especially important in applications related to measuring rural properties perimeter, as the standards and specifications edited by the Brazilian Land Reform Institute (INCRA) for this type of application include the use of this service.

Figure 4 presents a histogram with the number of IBGE-PPP jobs processed monthly from April 2009 to 2019. Figure 5 shows the geographic distribution of the stations whose coordinates were computed by this service during this 10-year period. The enormous use of the service can be seen from both figures.

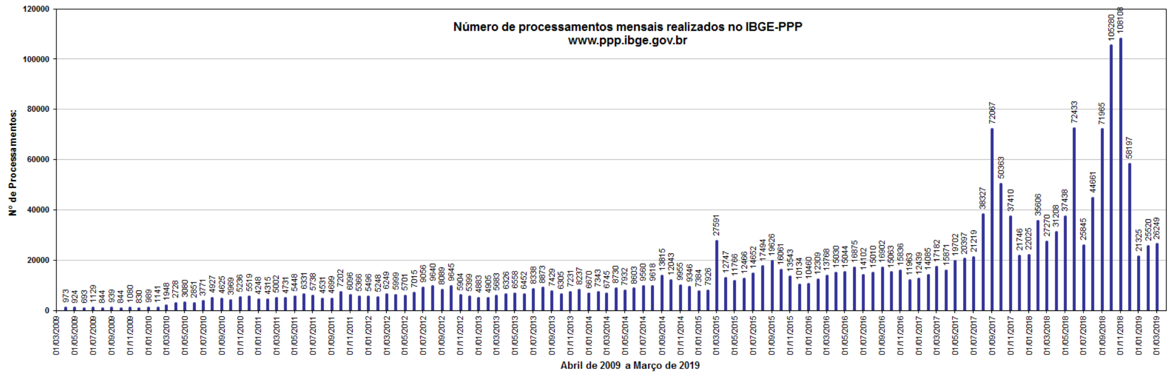

Figure 4- Number of jobs processed monthly by IBGE-PPP.

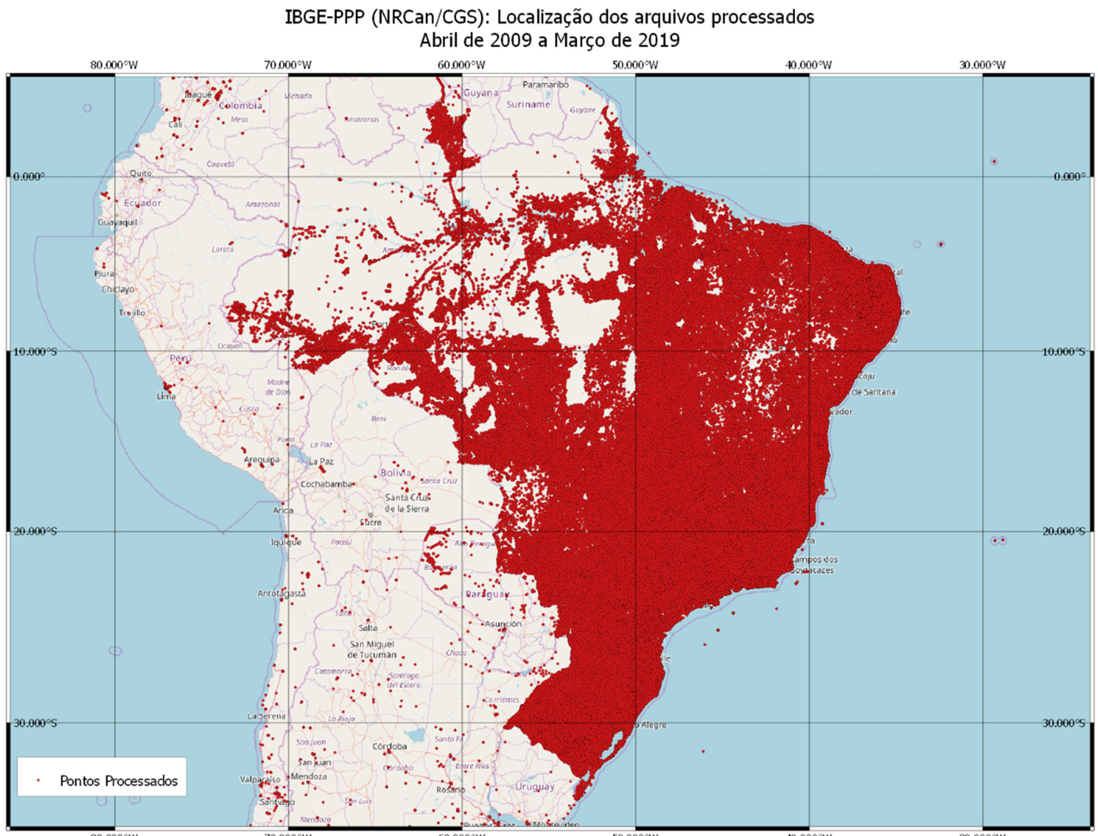

Figure 5 - Geographic distribution of the stations whose coordinates were computed by IBGE-PPP from April 2009 to 2017. Each red dot corresponds to a station.

2.1 RBMC – The most accurate geodetic framework in Brazil

Since December 1996 IBGE, along with several partner institutions in Brazil, has concentrated efforts towards the establishment of the Brazilian Network for Continuous

Monitoring of GNSS (RBMC). The first national continuous operating GNSS network deployed in South America, following standards recommended by the International GNSS Service (IGS). RBMC is the most accurate geodetic framework in the country, making the connection of coordinates to SIRGAS2000 easily in Brazil.

Since 2006, RBMC has gone through an ambitious modernizing and expanding process based on a partnership between IBGE, Brazilian Space Agency (INPE) and INCRA, which largely increased GNSS data availability using different observation rates.

In 2009, the RBMC service was further expanded with the establishment of a real time component, named RBMC-IP, to support kinematic positioning (RTK) and other real time applications. Data corrections are made available using the Network Transport of RTCM via Internet Protocol (NTRIP) by a 'NTRIPcaster' software, which has been released to IBGE by the German Federal Agency for Cartography and Geodesy (BKG) based on a cooperation with the IGS Real Time group (IGS-RT). According to this cooperation, real time data of nine RBMC stations are released to IGS to support computation of precise satellite orbits, among other IGS products.

RBMC is currently (June 2017) composed by 153 GNSS stations, most of them equipped with receivers capable of tracking GPS+GLONASS signals and meteorological devices, allowing the improvement of tropospheric and ionospheric correction models. Out of them, 121 stations operate in real time and the remaining ones in post-mission mode (Figure 6). All RBMC stations belong to SIRGAS continental network, providing the necessary integration of the Brazilian geodetic frame into the continental one.

Among several public institutions that participate in RBMC operations, INCRA, as previously mentioned, has made great contributions, as well as INPE, which uses RBMC data in the Brazilian Space Weather Program (EMBRACE), in the Positioning Integrated System for Geodynamics Studies (SIPEG) and in the Center for Weather Forecasting and Climate Research (CPTEC).

Figure 6 - The Brazilian Network for Continuous Monitoring of GNSS (RBMC). The current status of RBMC stations. Blue dots representing real-time and post-mission stations, whereas black dots (34) represent post-mission stations.

2.2 SIRGAS Analysis Center

As seen in the previous sections, Brazil has actively engaged in the multinational and national cooperation initiatives, which have contributed to the advanced geodetic activities carried out in the country during the last decades. Among these initiatives, SIRGAS one, which has relied on IBGE's participation since its beginning in 1993, should be emphasized. In addition to many roles played along these past 20+ years, IBGE is one of the analysis (i.e., processing and combination) centers since 2008, being responsible for the weekly processing of GNSS data collected by SIRGAS continuous operating network, SIRGAS-CON and for the combination of weekly solutions of nine processing centers, the latter responsibility being shared with the German Geodetic Research Institute (DGFI). SIRGAS-CON stations' coordinates time series feed the computation of station velocities, which are very important for the maintenance of the SIRGAS reference frame and for geodynamics studies of the South American plate. In this perspective, the SIRGAS2000 frame, officially adopted in Brazil can be continuously monitored.

3. Earth Tide Program

Daniel Arana

University of São Paulo, supported by a few organizations, is involved in a project for Earth Tide model for Brazil. The idea was to occupy a sequence of 13 stations along the country, keeping the instrument for one year in each station. To this point, field campaigns were carried out using two gPhones, Micro-g LaCoste, in 7 stations. In 2012 data were collected in the city of São Paulo - SP and Valinhos - SP, next in 2013 and 2014, the collection was carried out in the cities of Presidente Prudente - SP and Cananeia - SP. In 2015, gravimeters were installed in Porto Velho - RO and Manaus - AM. Subsequently one of the gravimeters was installed in Brasília - DF while the other remained one more year in Manaus. At the moment, the campaigns are interrupted, so that the following stations are expected to be observed in the future: Fortaleza - CE, Salvador - BA, Cuiabá - MT, Campo Grande - MS, Curitiba - PR and Santa Maria - RS. Figure 7 shows the distribution of the stations already observed.

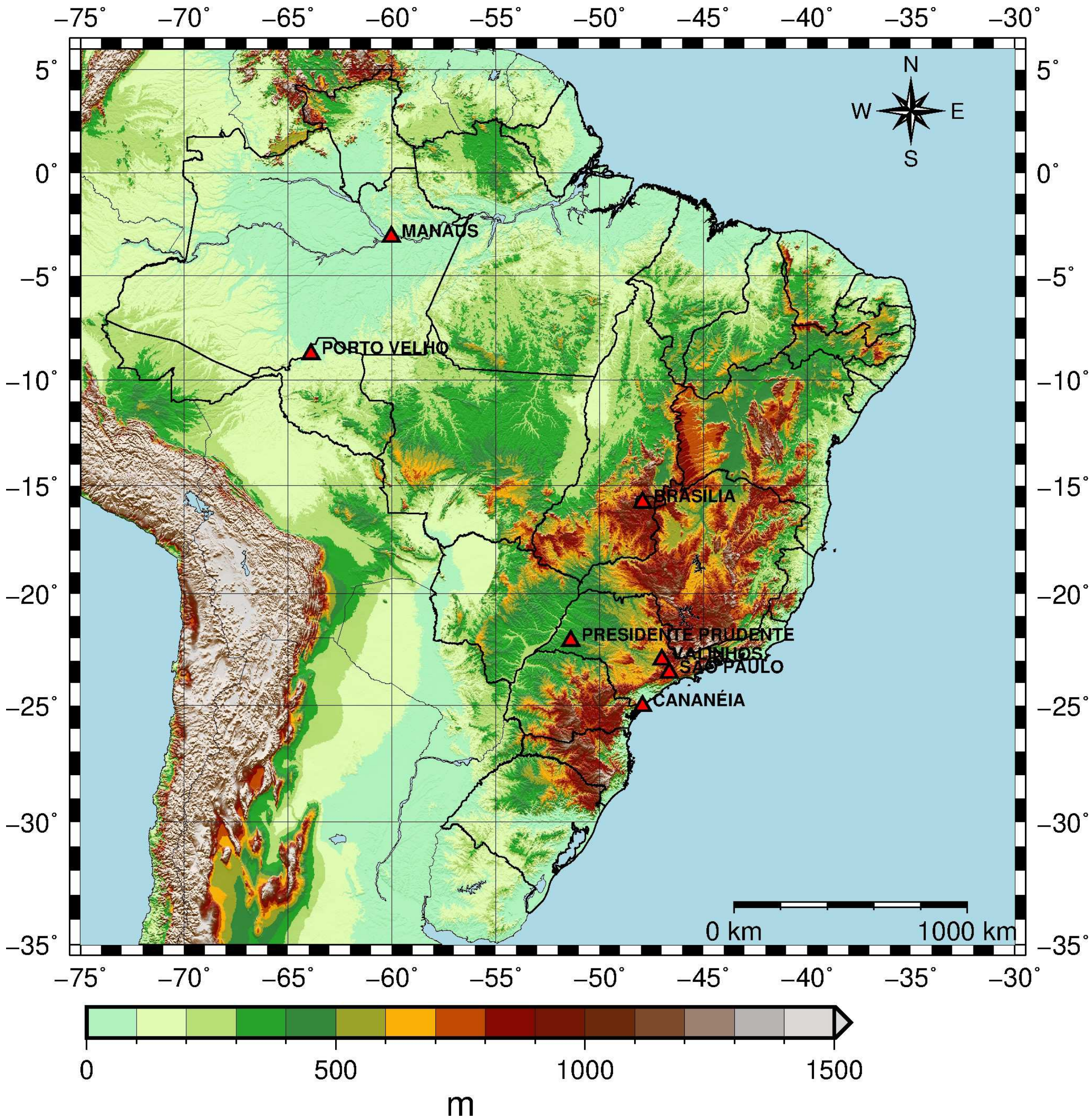

Figure 7 - Distribution of sites observed for Earth tides.

The project has interesting results in Presidente Prudente (PPP)and Cananeia (NEIA) due a careful processing. However, heterogeneity in the data were detected during pre-processing and processing stage. For comparing purposes and conclusive studies it is suggested:

(1) Pre-processing systematization:

a. Software: Tsoft 2.2.15 (at least);
b. Time-resolution: 1 minute;
c. Remove-Restore technique: considering a theoretical elastic Earth tidal model and atmospheric load with -0.3 µGal/mBar;

d. No interpolation for gaps bigger than 12 hours (suggestion); and

e. Low-pass filter: Zero-phase digital filter 6 cpd.

(2) Processing systematization:

a. Software: ETERNA 3.4 V60-B (at least)

b. Catalog for wave constituents: HW95;

c. High-pass filter: N1H60KSP;

d. Estimation of 15 wave constituents (at least): Q_1, O_1, NO_1, P_1, K_1, J_1, OO_1, $2N_2$, N_2, M_2, L_2, S_2, K_2, M_3, M_4.

(3) Analysis of residue observations: It must be considered in-phase and out-phase residuals in each wave constituents;

(4) Identification of components associated with geophysical effects: the use of global models are useful in this process such as: GLDAS (for hydrology); FES2014 or TPX09 (for ocean load); empirical or theoretical admissibility functions (for atmospheric load).

This systematization has brought interesting gains in Presidente Prudente and Cananeia stations. The preliminary results are shown in Table 1 and 2.

Table 1 - Preliminary processing Presidente Prudente.

Wave	**Grav. Factor**	**Grav. Factor SD**	**Phase [º]**	**Phase SD [º]**
Q_1	1.19706	0.00048	-0.014	0.023
O_1	1.17244	0.00010	-0.540	0.005
NO_1	1.18110	0.00131	1.501	0.064
P_1	1.14927	0.00018	-1.254	0.009
K_1	1.14998	0.00007	0.629	0.003
J_1	1.14617	0.00114	-0.097	0.057
OO_1	1.20388	0.00360	-0.937	0.171
$2N_2$	1.17287	0.00061	2.307	0.030
N_2	1.18018	0.00013	1.421	0.006
M_2	1.17428	0.00003	1.217	0.001
L_2	1.17470	0.00095	0.726	0.046
S_2	1.17556	0.00006	1.162	0.003
K_2	1.17344	0.00028	0.890	0.014
M_3	1.08129	0.00136	0.587	0.072
M_4	0.53234	0.07759	-5.594	8.352

Table 2 - Preliminary processing Cananeia

Wave	Grav. Factor	Grav. Factor SD	Phase [º]	Phase SD [º]
Q_1	1.21068	0.00042	-1.540	0.020
O_1	1.16986	0.00008	-1.843	0.004
NO_1	1.14323	0.00128	-0.216	0.064
P_1	1.14792	0.00015	-1.535	0.008
K_1	1.13088	0.00005	-0.555	0.003
J_1	1.17342	0.00100	-0.518	0.049
OO_1	1.18245	0.00283	0.917	0.137
$2N_2$	1.20625	0.00066	4.805	0.031
N_2	1.18951	0.00013	1.891	0.006
M_2	1.16327	0.00003	2.401	0.001
L_2	1.16833	0.00101	5.257	0.050
S_2	1.16896	0.00006	2.741	0.003
K_2	1.15052	0.00026	2.847	0.013
M_3	1.28273	0.00136	-3.137	0.061
M_4	7.92876	0.07891	24.194	0.570

Three major studies are being implemented: a) atmospheric correction: it was proposed an analyzes of different atmospheric corrections in each wave constituents; b) global ocean load consistency: the dispersion and residual components of ocean load models suggests that costal region (<500km) does not shows enough reliability for Earth tidal inelastic studies; and c) application of empirical Earth tide models: since some geophysical effects are not well modeled by global load models, residual components may still be present in absolute gravimetric data. Empirical models are able to better correct these geophysical effects and consequently better define the Zero-Tide System, mainly in coastal and basins region.

4. Absolute gravity network

Iuri Moraes Bjorkstrom
Valéria Cristina Silva

The Institute of Geography and Cartography of the State of São Paulo (IGC) owns an absolute gravitymeter A-10 (Figure 8), with the operation under the responsibility of the EPUSP. The gravitymeter is involved in various activities in São Paulo and in Brazil, out of Argentina, Costa Rica, Ecuador and Venezuela. Figure 9 shows the establishment of new (green point) and reobserved (red points) absolute stations in São Paulo state. From north to south of Brazil a set of absolute stations have also been established (Figure 10). The idea is to maintain a progress in the establishment of absolute gravity networks in Brazil and in Latin America. At the moment the efforts are addressed to the state of Minas Gerais (Figure 11) with stations observed and to be observed.

Figure 8 - Absolute gravity meter A10-32.

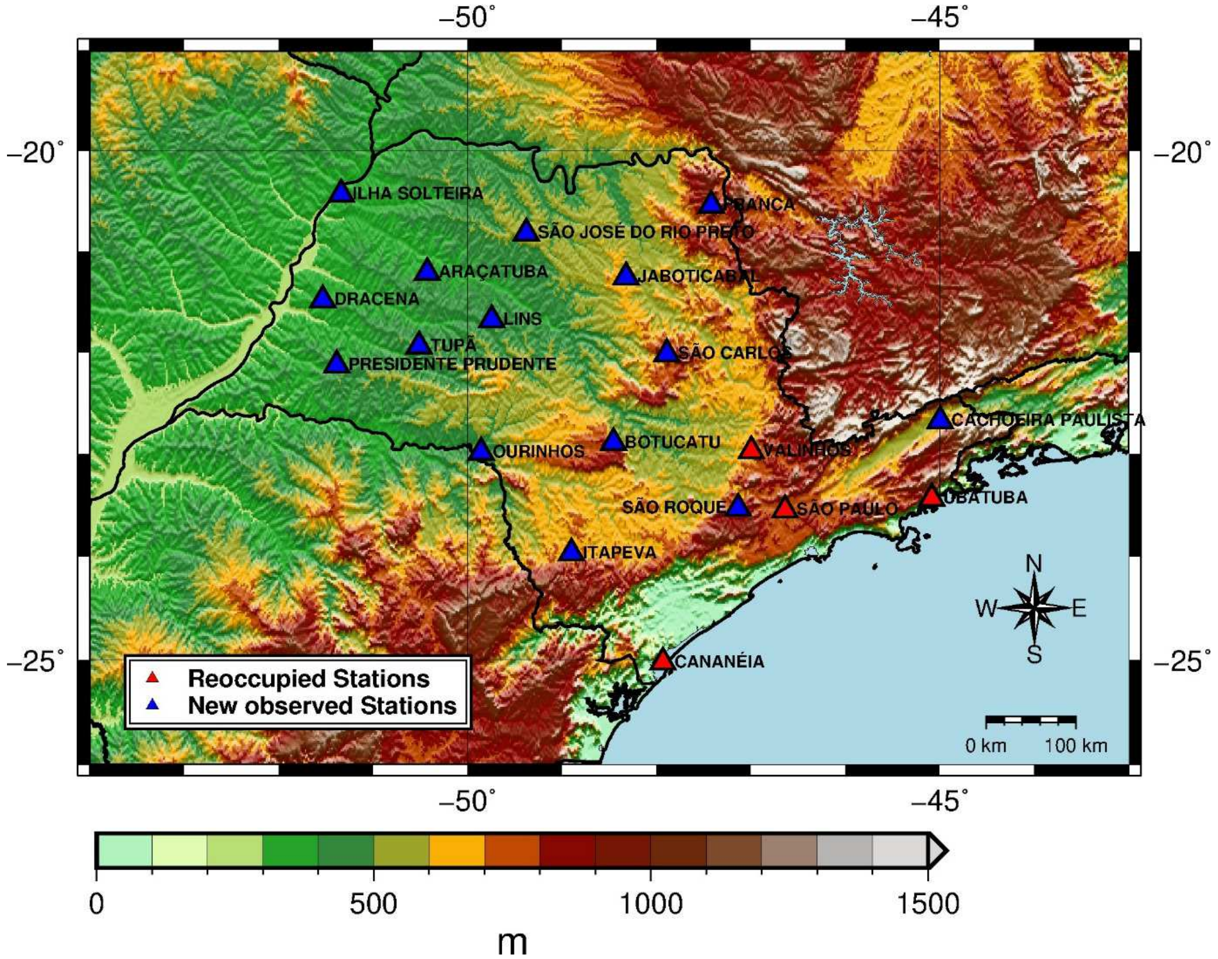

Figure 9 - Absolute gravity stations in São Paulo State.

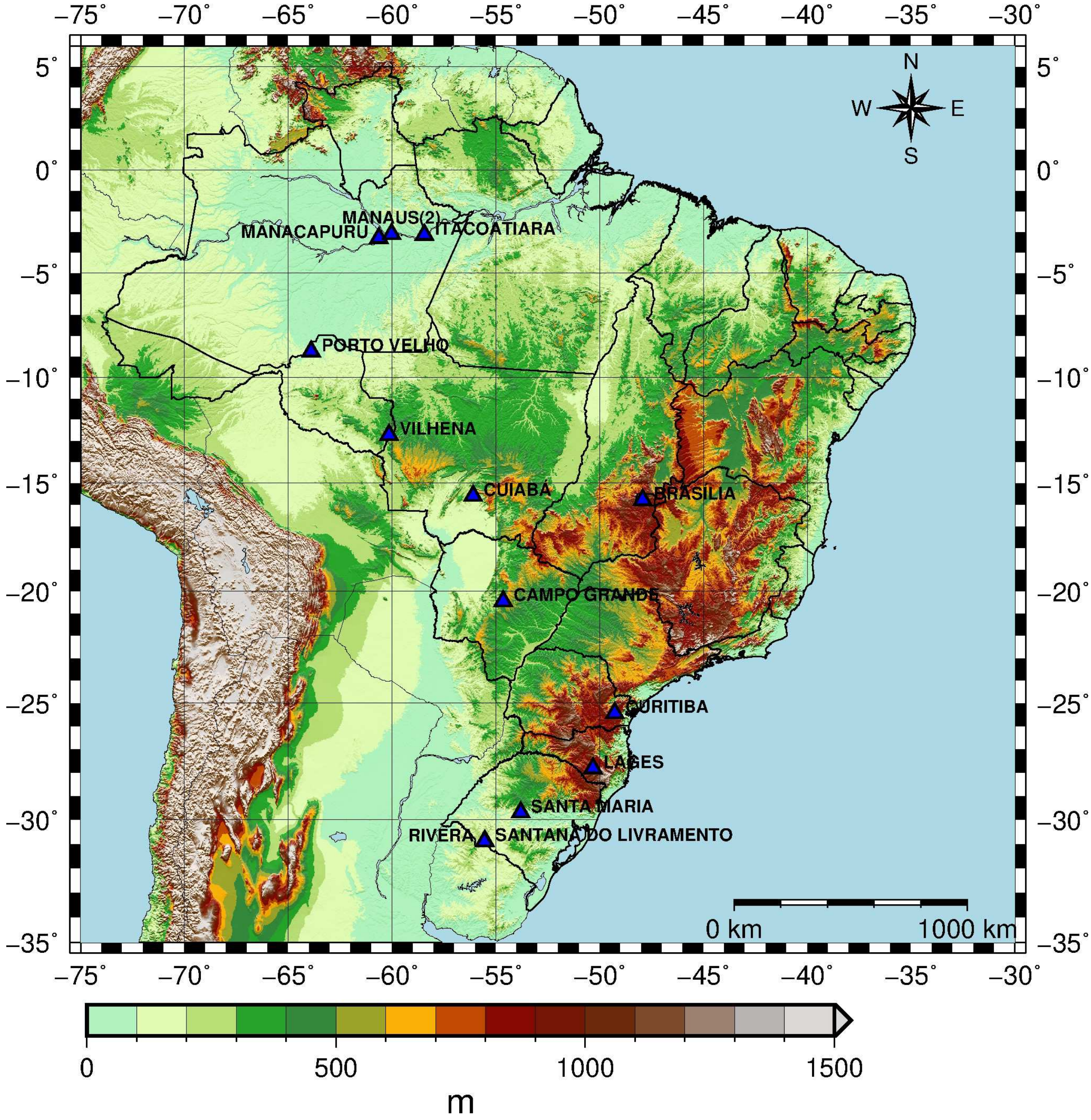

Figure 10 - Absolute gravity stations in Brazil.

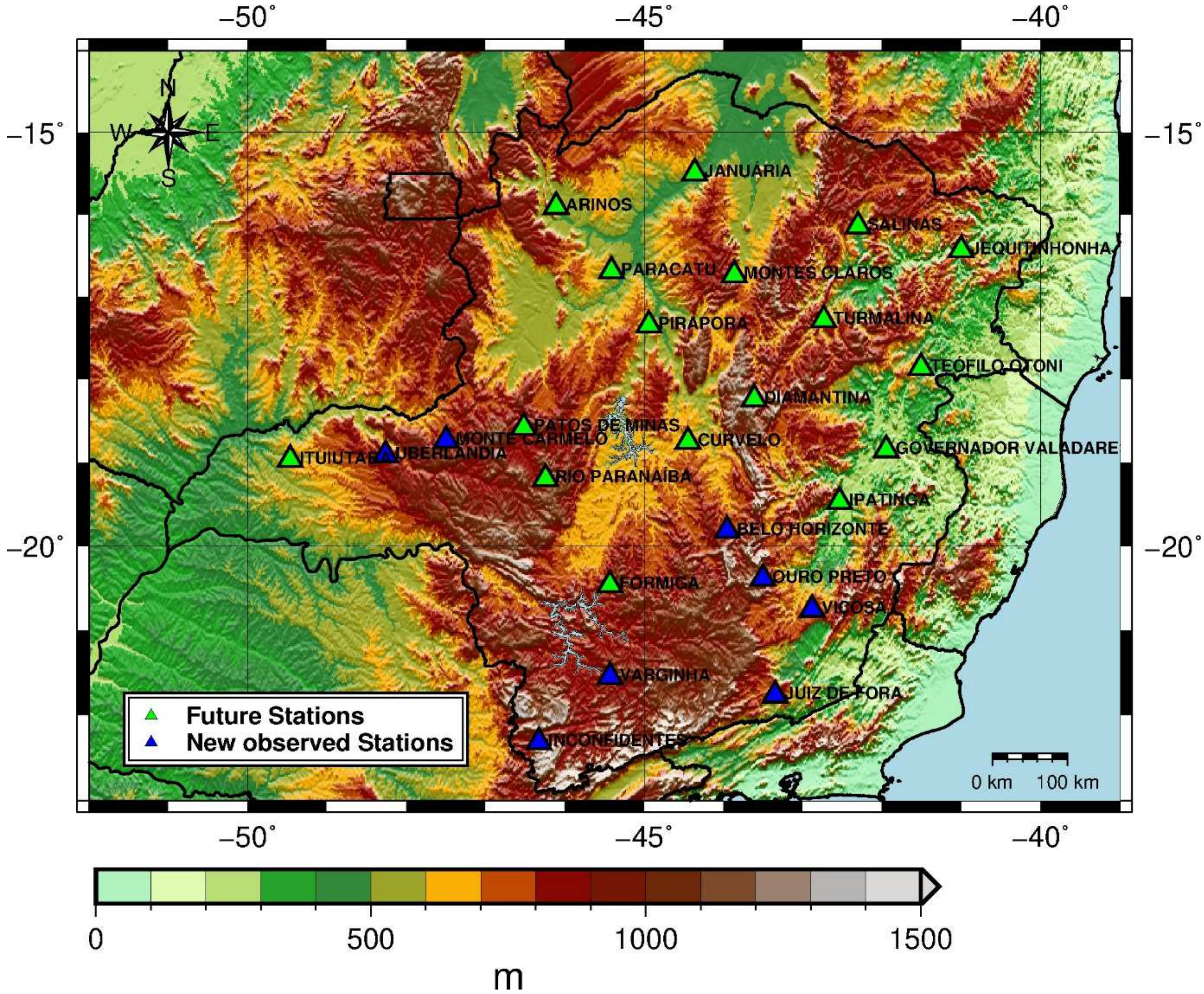

Figure 11 – Absolute gravity nework in Minas Gerais state.

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