Results of SIRGAS 2000 GPS Network by IBGE Analysis Center

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Abstract. This paper reports the results of SIRGAS 2000 GPS network processing, carried out by the IBGE Analysis Center. Besides IBGE, University of São Paulo (USP) is collaborating with some data analysis and processing.
In this paper will be presented the organization of the information collected (tracking files and forms) and the data edition carried out. Another important information is the processing strategy applied by using the Bernese software, version 4.2 and its improvements.
Analysis of final results regarding station performance and velocities based on SIRGAS95 and SIRGAS2000 results will be presented.

Keywords. Regional Network, GPS Processing, Adjustment

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1 Introduction

Besides DGFI (Deutsches Geodaetisches Forschungsinstitut), IBGE (Brazilian Institute of Geography and Statistics) has taken part as global data base and evaluation of the second realization of SIRGAS2000 GPS network.

IBGE, through Department of Geodesy, is responsible for the establishment and maintenance of Brazilian Geodetic System (SGB). Since 1997, Bernese software has been used to process GPS observations.

The objectives of SIRGAS2000, the new realization of SIRGAS reference network were:

- Maintenance of SIRGAS reference frame, through the computation of station velocities;
- Perform WG III activities, occupying tide gauge stations in each country, in order to define a unique height reference system and connecting the classical national leveling networks.

The selection criteria of stations for this campaign aimed to occupy:

- Tide gauges, which define a vertical datum of the classical leveling networks in each country. Other tide gauges, mainly in countries with long extension of coast, involving in this case the variations of sea level regarding geographical variations.
- Stations of classical leveling networks at the borders between neighboring countries.
- Stations participating of SIRGAS95 network. This repetition of observations serves to compute site velocities.

The SIRGAS2000 has about 180 stations, distributed in 21 countries and carried out from May 10th to 19th, 2000.

The Bernese software, version 4.2, was used to process GPS data and combine daily results.

This paper is divided into three main parts: the first one is dedicated to describe the organization and data preparation; the second one is dedicated to the strategy followed by data processing and the origin of additional information, for example: antenna phase center variation and offsets, precise ephemeris and ionosphere maps; and the final one is dedicated to the combination of daily solutions, analyzing final results and velocities computations.

2 Data Organization

The two institutions involved with processing were responsible for collecting, checking, organizing and exchanging the GPS data files by ftp. Almost 21 institutions, responsible for cartography and geodesy in each American country sent data, allowing for the project success.

The data in each station are organized in 24 hours period. Initially, most of data in receiver format was converted to RINEX format at 15 (42% of stations) and 30 (58% of stations) seconds sampling rate. A total of 184 stations, were collected and organized, as seen in Table 1. The next step was the checkup of the RINEX header, concerning station name, receiver and antenna type (according to IGS standards) and antenna height with all observation forms.

Briefly, the main tasks involved for data collecting and organization were:

- Unify the station names (identification). Two of them had their identification changed in order to eliminate the duplicity (ELEV/Venezuela and MANU/Brazil);
- Check if receiver/antenna type and antenna height were informed. Request this information from responsible agency when it's not available.
- Convert receiver and antenna identification to IGS standards;
- Reduce antenna height measures from slant to vertical, referred to ARP (Antenna Reference Point).

In order to connect SIRGAS network to the ITRF (IERS - International Earth Rotation Service - Terrestrial Reference Frame) the conventional coordinates of the IGS sites given in the ITRF97, were reduced to SIRGAS2000 epoch, 2000.4, using ITRF97 velocities (table 2), and used as a-priori reference coordinates.

Other important a-priori information, used in this processing, are the combined IGS orbits, reference ITRF97 and Earth Rotation Parameters (ERP) associated with them.

The information about antennae phase center offset and variation was obtained at IGS. When this information weren't found at IGS, the values from NGS were used.

Table 2. A-priori reference coordinates in ITRF97 epoch 2000.4.

ID	X (m)	Y (m)	Z (m)
ALBH	-2341332.9184	-3539049.5241	4745791.3364
AREQ	1942826.7761	-5804070.2607	-1796893.9553
AOML	982296.7844	-5664607.2372	2752614.4583
BRAZ	4115014.0713	-4550641.5286	-1741444.0500
CRO1	2607771.2034	-5488076.7738	1932767.7077
FORT	4985386.6380	-3954998.5999	-428426.4690
KOUR	3839591.4256	-5059567.5591	579956.9507
LPGS	2780102.9733	-4437418.8745	- 3629404.5797
OHIG	1525872.5558	-2432481.3132	-5676146.1343
RIOG	1429907.7422	-3495354.7660	-5122698.6828
SANT	1769693.4188	-5044574.1703	-3468321.0477
WES2	1492233.3307	-4458089.4897	4296045.9977
AMC2	-1248596.1271	-4819428.2166	3976505.9928
INEG	-1260435.7168	-5788547.6374	2360340.2842
JAMA	1388059.8223	-5909149.0459	1951963.8104
UNSA	2412830.3916	-5271936.6876	-2652209.1011
CORD	2345503.8657	-4910842.7962	-3316365.4236

3 Network configuration and blocks division

Considering the great number of stations and computer/program limitations, SIRGAS2000 network was divided for processing. The criteria adopted to divide the whole network was by latitude zones. The quantity of blocks was chosen in terms of processing time and memory space supported by computers. About two IGS stations in each block were chosen to make the link between blocks; consequently these stations are repeated in adjacent blocks. In table 3 is presented the latitude limits used for block definition. Figure 1, also shows SIRGAS2000 network configuration and blocks division and Table 1 presents the stations/country included in each block (about 22 stations in each one), as well as link stations in shadow (same as IGS stations presented on Table 2).

Table 3. Latitude zones of SIRGAS2000 processing blocks.

Block	Latitude Limits
SIRGASN	61° N to 45° N
SIRGASN1	45° N to 25° N
SIRGASN2	25° N to 10° N
SIRGASC	10° N to 00°
SIRGASS	10° N to 15° N
SIRGASS1	00° to 20° S
SIRGASS2	15° S to 35° S
SIRGASS3	20° S to 35° S
SIRGASS4	35° S to 62° S

4 Processing Strategy

In order to choose the best strategy for data processing, three alternatives were studied:

1. Ambiguities are not solved, being eliminated in the final daily solutions;
2. Resolution of the ambiguities using QIF (Quasi Ionosphere Free) strategy and introduction of them in the final daily solution;
3. Resolution of the ambiguities using QIF strategy and GIMs (Global Ionosphere Maps) from CODE (Center for Orbit Determination in Europe) and introduction of them in the final daily solution.

The final strategy chosen for processing was the ambiguity resolution with QIF strategy and GIMs/CODE, because more than 42 % ambiguities were solved producing better results.

The following options and parameters adopted were common for the three strategies:

- Combined IGS ephemeris and ERPs (Earth Rotation Parameters) were used to produce the daily solutions. Regarding combined ephemeris orientation, the 10 observation days were processed in 24 hours period, from 0 to 24 hours UTC (Universal Time Coordinate) approximately.
- The strategy forming the single difference phase files was OBS-MAX[1].
- The pre-processing and processing step was made in session mode, detecting and correcting the cycle slips in the ion-free[2] L3 frequency combination (linear combination of L1/L2).
- The ambiguities were solved for each baseline separately on ambiguity resolution step.
- During the data processing, the double phase differences were modeled in L3, using an elevation mask of 10° and a sampling rate of 30 seconds.
- The elevation-dependent weighting is applied using function cos(z)**2
- No *a priori* troposphere model was used.
- The troposphere parameters were estimated in all steps of parameter estimation. The corrections of the troposphere delay at zenith for each station were estimated every 2 hours, having 12 daily correction numbers. Neill mapping function was adopted to compute corrections.
- Estimation of troposphere gradient parameters, using tilting mapping function (one parameter per station).
- Final daily solutions were processed as "free network", no constrains were applied.

5 Combination of solutions

For the combination of daily solutions, the 10-days solution blocks, were combined as "free network solution". The same procedure was used for block combination. The reference frame for SIRGAS2000 network will be defined in the next meeting of SIRGAS project. All troposphere parameters were eliminated in block combination, aiming to reduce the great number of parameters in solution. Considering that results of ITRF2000 are already available and has been improved when compared with former ITRF versions, there is a strong tendency to adopt ITRF2000 as new reference frame for the SIRGAS2000 realization.

The program used to develop combination of solutions was ADDNEQ2, which belongs to Bernese software. The coordinates of eleven IGS stations (CRO1, KOUR, FORT ALBH, WES2, BRAZ, AREQ, LPGS, SANT, OHIG, and RIOG) presented in Table 1 were included on final block combination as a priori coordinates.

8 Results

A total of 181 stations had coordinates computed. Processing problems occurred in three stations (ELEN, BATL and ANTO), and they were excluded from results. The stations with less than 5 days of results are: AURO (2 days), CHAJ (3 days), JUNQ (3 days), LOTE (4 days), NPAC (1 day) and RIOP (3 days).

The elimination of SA code degradation could be checked in SIRGAS2000 GPS campaign. The RMS of 24 hours data for code processing was between 1 to 3 meters in the great number of stations, with exception of day 136 where all stations reported RMS between 5 to 6 meters. Stations in English Guyana, GEOD and TTWR, occupied with JAVAD receivers had RMS about 10 meters in code observations. The fact was verified in CASU (Chile) station, occupied with JAVAD receiver, but RMS was about 8 meters.

[1] Maximum number of observation between two stations.
[2] Eliminates the first order effects of the ionosphere.

Two informations were checked in the final block results. The first one was the quantity of solved ambiguities in each block and other one, was the number of observations eliminated after the residual outlier step. It could be verified that more than 50% of ambiguities were solve in blocks between latitudes 61° N to 10° N and 35° S to 62° S. The same way could be noted that less than 10% of observations are eliminated in blocks between latitudes 61° N to 45° N and 35° S to 62° S.

One of the procedure to estimate the accuracy of results, is the comparison of the station coordinates from reference IGS stations from free network solution with ITRF realization of combined ephemeris, in this case ITRF97. The standard deviation of transformation was 10 mm and the standard deviation per component derived from residuals were north= 6.2 mm, east= 6.2 mm and up= 13.4 mm.

In order to check the consistency of daily solutions, the standard deviations per component in each station was checked, using coordinates repeatability and normal equations (giving a more realistic accuracy of the coordinates). These numbers represent the daily solution accuracy of station GPS coordinates. The stations, which have up component RMS higher than 20 mm are: EISL, ENRI, IPIA, TALA, TAND, OAXA and RIOP.

9 Velocities estimation

The station velocity estimation was computed using coordinates results of SIRGAS95 network and preliminary results of SIRGAS2000 from IBGE analysis center. Time interval between two SIRGAS GPS campaigns, was 4.9 years and the program to compute them was developed at IBGE. Considering that SIRGAS95 solution, was constrained in ITRF94, at epoch 1995.4, the SIRGAS2000 solution adopted here to compute coordinates was tied (applying very high weights) in the ITRF97 at epoch 2000.4, through the coordinates of eleven fiducial stations as mentioned in section 7 of this paper. No transformation parameters were used to convert ITRF94 (SIRGAS95) coordinates to ITRF97.

In Table 4 are listed the velocities estimated only in stations present in SIRGAS campaigns and ITRF2000, in order to check velocity results. It was decided to use ITRF2000 velocity results instead of ITRF1997, because ITRF2000 has more stations in South America and it has a more precise solution. As can be seen, the velocities have a reasonable agreement with ITRF2000.

10 Conclusions

The SIRGAS2000 GPS campaign was processed in a free network and in a constrained mode (for velocity estimation), in 181 stations comprising the whole American continent.

The final coordinates of SIRGAS2000 network are not available until this moment because SIRGAS analysis centers and Scientific Committee did not discuss results.

Table 4. Velocities estimated by SIRGAS GPS networks and ITRF2000 velocities.

Station	ITR 2000 Vx (mm/y)	ITRF 2000 Vy (mm/y)	ITRF 2000 Vz (mm/y)	SIRGAS Vx (mm/y)	SIRGAS Vy (mm/y)	SIRGAS Vz (mm/y)
MANU	-.0039	.0055	.0143	-.0065	.0026	.0072
IMPZ	-.0252	.0180	.0194	-.0088	.0022	.0093
VICO	-.0009	-.0075	.0123	-.0043	-.0040	.0096
BOMJ	-.0033	-.0063	.0140	-.0056	-.0021	.0096
UEPP	.0014	-.0080	.0116	-.0008	-.0031	.0085
PARA	.0049	-.0085	.0090	.0011	-.0034	.0079
BRAZ	.0005	-.0063	.0115	-.0062	-.0030	.0089
CUIB	.0009	-.0066	.0113	-.0009	-.0035	.0083
FORT	-.0013	-.0044	.0121	-.0056	-.0030	.0095
LPGS	.0025	-.0072	.0087	-.0008	-.0061	.0057
RIOG	.0079	-.0102	.0028	.0042	-.0075	.0045
EISL	.0638	-.0190	-.0068	.0635	-.0223	-.0136
SANT	.0221	-.0059	.0111	.0212	-.0038	.0072
AREQ	.0118	-.0010	.0137	.0104	-.0015	.0085
MARA	.0141	.0023	.0080	.0083	.0124	.0057
KOUR	-.0027	-.0039	.0122	-.0045	-.0055	.0075
OHIG	.0193	-.0037	-.0039	.0186	-.0028	-.0062

11 References

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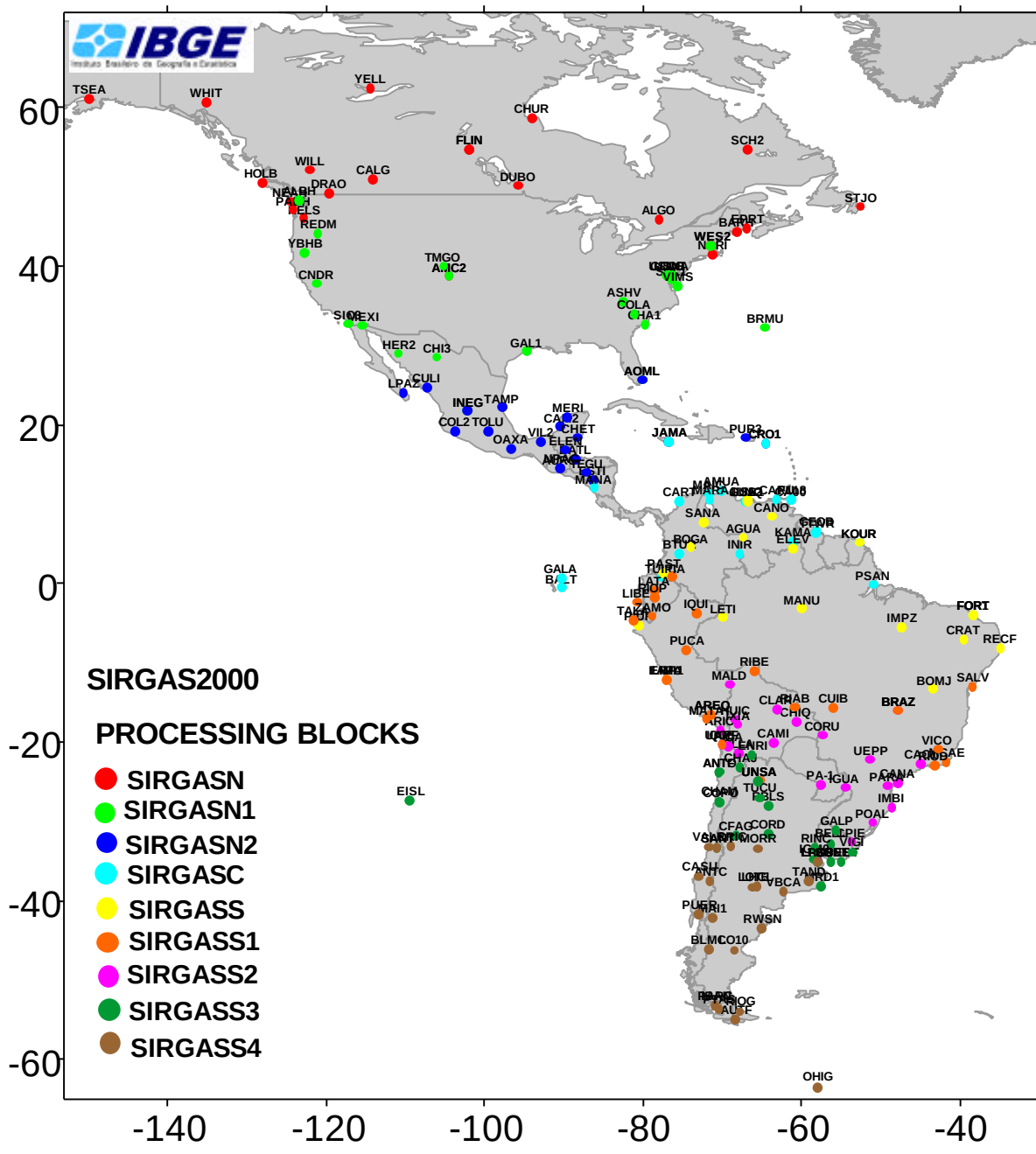

Fig. 1 Station locations of the SIRGAS 2000 GPS network.

Table 1. List of stations in each processing block.

	SIRGASN	SIRGASN1	SIRGASN2	SIRGASC	SIRGASS	SIRGASS1	SIRGASS2	SIRGASS3	SIRGASS4
1	TSEA / US	WES2 / US	AOML / US	JAMA / JA	FORT / BR	BRAZ / BR	BRAZ / BR	UNSA / AR	LPGS / AR
2	WHIT / CA	AMC2 / US	INEG / MX	CRO1 / US	GALA / EQ	AREQ / PE	UNSA / AR	LPGS / AR	SANT / CH
3	YELL / CA	ALBH / US	MTY2 / MX	MANA / NI	KOUR / GF	IPIA / CO	IXIA / BO	CHAJ / CH	VALP / CH
4	CHUR / CA	REDM / US	CULI / MX	CART / CO	AGUA / VE	LATA / EQ	MALD / EQ	ENRI / BO	MORR / AR
5	FLIN / CA	YBHB / US	LPAZ / MX	MARA / VE	CANO / VE	RIOP / EQ	CLAR / BO	ANTO / CH	CRIC / AR
6	DUBO / CA	CNDR / US	COL2 / MX	MAIC / CO	ELEV / VE	IQUI / PE	CHIQ / BO	ANTF / CH	LHCL / AR
7	ALGO / CA	TMGO / US	TAMP / MX	AMUA / VE	GUA2 / VE	LIBE / EQ	CORU / BR	TUCU / AR	TAND / AR
8	SCH2 / CA	USNA / US	TOLU / MX	BALT / EQ	SANA / VE	TALA / PE	UEPP / BR	RBLS / AR	VBCA / AR
9	STJO / CA	USNO / US	OAXA / MX	CARU / VE	USB1 / VE	ZAMO / EQ	CAC1 / BR	CHAM / CH	RWSN / AR
10	EPRT / US	GODE / US	VIL2 / MX	F118 / TR	BOGA/CO	PUCA / PE	CANA / BR	COPO / CH	LOTE / AR
11	BARH / US	SOL1 / US	CAM2 / MX	CA00 / TR	PAST / CO	LAPU / PE	PARA / BR	CFAG / AR	CASU / CH
12	CALG / CA	VIMS / US	MERI / MX	GEOB / GI	LETI / CO	ERP1 / PE	IGUA / AR	CORD / AR	ANTC / CH
13	WILL / CA	ASHV / US	PUR3 / US	TTWR / GI	MANU / BR	MATA / PE	PA-1 / PA	GALP / UR	PUER / CH
14	DRAO / CA	COLA / US	JAMA / JA	PSAN / BR	FOR1 / BR	UAPF / CH	IMBI / BR	BELL / UR	MAI1 / AR
15	HOLB / CA	CHA1 / US	CRO1 / US	FORT / BR	IMPZ / BR	UNSA / AR	POAL / BR	RINC / UR	L10B / AR
16	WES2 / US	BRMU / UK	CHET / MX	BTUR / CO	CRAT / BR	SALV / BR	CPIE / UR	VIGI / UR	BLMC / CH
17	AMC2 / US	AOML / US	ELEN / GM	TULC / EQ	RECF / BR	CUIB / BR	LPGS / AR	MONT / UR	COYQ / CH
18	ALBH / US	GAL1 / US	BATL / GM	GALA / EQ	BOMJ / BR	RIAB / BO	HUIC / BO	PEST / UR	PARC / CH
19	NEAH / US	INEG / MX	AURO / GM	KAMA / VE	BRAZ / BR	RIBE / BO	PICA / CH	SHEE / UR	PTAS / CH
20	PABH / US	SIO3 / US	NPAC / GM	INIR / CO	LIMA / PE	VICO / BR	CAMI / BO	IGM0 / AR	IBAN / CH
21	KELS / US	MEXI / MX	TEGU / HO	KOUR / GF	PIUR / PE	MCAE / BR	ARIC / CH	SANT / CH	RIOG / AR
22	NPRI / US	HER2 / MX	ESTI / NI	JUNQ / VE	AREQ / PE	RIOD / BR	IQQE / CH	MRD1 / AR	AUTF/AR
23		CHI3 / MX					OLLA / BO	EISL / CH	OHIG/AN

BR = Brazil
PA = Paraguay
US = United States
VE = Venezuela
EQ = Equator
CA = Canada
GI = English Guyana
GM = Guatemala
JA = Jamaica
UK = United Kingdom

UR= Uruguay
CH = Chile
CO = Colombia
PE = Peru
MX = Mexico
GF = French Guyana
TR = Trinidad&Tobago
HO = Honduras
NI = Nicaragua
AN = Antartida