# Preliminary Results of SIRGAS 2000 Campaign – IBGE Analysis Center

S.M. Alves Costa
Department of Geodesy,
Brazilian Institute of Geography and Statistics- IBGE
Av. Brasil 15671, CEP : 21241-051, Rio de Janeiro, RJ, Brazil
e-mail: soniamaria@ibge.gov.br

E.S. Fonseca Junior
Department of Transportation Engineering
Polytechnic School – University of São Paulo
Caixa Postal 61548, CEP: 05424-970, São Paulo, SP, Brazil
e-mail: edvaldoj@usp.br

J. A. Fazan, J.F.G. Monico, P. O. Camargo
Department of Cartography
São Paulo State University - Faculty of Science and Technology (FCT/UNESP)
Rua Roberto Simonsen 305, CEP 19060-900, Presidente Prudente, SP, Brazil
e-mail: galera@prudente.unesp.br

**Abstract.** This paper reports the present status of SIRGAS 2000 Campaign processing, carried out by the IBGE Analysis Center. Besides IBGE, University of São Paulo (USP) and São Paulo State University (UNESP) are collaborating with some data analysis and processing. While USP has been providing regional ionosphere maps, UNESP is analyzing the quality of data collected during the campaign by different kind of receivers.

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 that will be presented is the processing strategy applied by using the Bernese software, version 4.2. Some preliminary results, together to the local ionosphere maps and the quality of the collected data will also make part of this paper.

**Keywords.** Regional Network, GPS Processing, Ionosphere Maps

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## 1 Introduction

The SIRGAS (South American Geocentric Reference System) is a project that includes all necessary activities for the adoption of a geocentric reference system, compatible with the modern position techniques and standards of precision, particularly the GPS (Global Positioning System). Initially, in 1995 was established a high precision reference network, making possible the integration of all national geodetic networks in South America, to ITRF (International Terrestrial Reference Frame). This first realization of SIRGAS network had a total of 57 stations with coordinates referred to ITRF94 (International Terrestrial reference Frame 94), in other words; SIRGAS was a densification of ITRF94 in South America. During the IAG (International Association of Geodesy) Scientific Meeting in 1997, was pointed out the concern about vertical component and was established the Working Group III (WG III), responsible for definition and establishment of a common vertical system for South America.

In order to carried out the activities of WG III, tide gauges stations of each country where occupied. Additionally, aiming the maintenance of SIRGAS as a reference frame, a new realization was established in 2000. All countries of American continent participated in this campaign. This new was named SIRGAS2000.

The SIRGAS2000 has about 180 stations, distributed in 21 countries. It was carried out from May, $10^{th}$ to $19^{th}$.

At this moment, two institutions, DGFI (Deutsches Geodaetisches Forschungsinstitut) and IBGE (Brazilian Institute of Geography and Statistics) are developing the data collection, organization and processing. This paper reports the status of the activities being developed at IBGE and two others Brazilian universities, UNESP and USP.

IBGE, thought 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. Therefore, it was the chosen software to process SIRGAS2000 observations, making use of version 4.2 and its improvements.

This paper is divided into three main parts. In the first part is described the organization and data preparation. The second part is dedicated to the evaluation of observations in some stations. The third part is detailed the strategy to be followed in the observations processing and additional information.

## 2 Data Organization

Each station was organized with data file of 24 hours period, in RINEX format. The sampling rate for IGS (International GPS Service) and some stations of NGS (National Geodetic Survey) stations was 30 seconds and 15 s for other stations. A total of 184 stations were collected and organized. For details, see Table 1 and Figure 1.

Initially, most of data in receiver format was converted to RINEX format. Some files had to be concatenated in 24 hours period. In a second step some informations, as station and antenna/receiver identifications (according to IGS standard) as well as antenna height were verified.

It was also defined a unique station identification of four digits. It is an important control for the future daily combination of solutions. There are no eccentric stations in SIRGAS2000 campaign.

The second step involved the following tasks:

- Unify the station identification, in order to eliminate the duplicity;
- Check if receiver type, antenna type and antenna height was informed. Request this information from responsible agency when it’s not available.
- Convert receiver and antenna type to IGS standards;
- Reduce antenna height measures from slant to vertical, referred to ARP (Antenna Reference Point).

**Table 1.** Number of countries and stations - SIRGAS2000 campaign.

| Country | Number of Stations |
|---|---|
| Argentina | 20 |
| Bolivia | 9 (6  IGS) |
| Brazil | 21 (11 permanent + 2 IGS) |
| Canada | 13 (12 IGS) |
| Chile | 21 (4 IGS and Hawaii) |
| Colombia | 8 (2 permanent) |
| Ecuador | 7 (2 IGS) |
| English Guyana | 2 |
| French Guyana | 1 ( IGS) |
| Guatemala | 4 |
| Jamaica | 1 ( IGS) |
| Honduras | 1 ( NGS) |
| Mexico | 15 (14 permanent + 1 IGS) |
| Nicaragua | 2 (2 NGS) |
| Paraguay | 1 |
| Peru | 10 ( 1 IGS) |
| Puerto Rico | 1 ( NGS) |
| Trinidad&Tobago | 2 |
| Uruguay | 8 |
| U.S. | 26 (26 NGS / IGS) |
| Venezuela | 11 (1 permanent) |
| **# of countries: 21** | **# of stations: 184** |

## 3 Data Analysis

The preliminary data quality evaluation was performed by the Spatial Geodesy Laboratory (LGE) of the São Paulo State University (UNESP) Presidente Prudente´s campus, using the TEQC (*Translation Edition and Quality Control*) software developed and maintained by UNAVCO (*University NAVSTAR Consortium*). Initially, 23 stations were evaluated allowing to check the receiver data quality. This paper analyze the MP1 (multipath effect in L1) and MP2 (multipath effect in L2), percentage of good observations and the ratio O/slps (O=number of observation slps=number of cycle slips). For multipath evaluation a double frequency receiver is mandatory. Figure 2 and 3, show the minimum, mean and maximum values of MP1 and MP2, adopting the following receiver abbreviations:

TR: Trimble;
ASH: Ashtech;
LE: Leica;
RO: Rogue;
JPL: JPS LEGACY; and
AO: AOA.

Considering that receivers were installed at sites with small or reduced multipath effect, the MP1 and MP2 are good indicators of receiver quality on both frequencies.

From Figure 2, one can see similar performance of the different receiver types, but the JPS-LEGACY at GEOB station presented the worse values. The MP2, from Figure 3, shows Leica, Ashtech and Trimble-4700 with best performance. It may be due to better cryptography manipulation on L2 in these receivers.

For a general analysis, it was calculated the average values of MP1 and MP2 of each receiver set, which are presented at Table 2. These results show the good performance of Leica CRS1000 and SR520 models in both carrier phases. Receivers with a good performance in L1 are Trimble 4700, Trimble 4000SSI and SSE models. At similar quality level are the Rogue SNR 8000ACT and Ashtech UZ-12. For L2 it is observed the better performance of Ashtech and Rogue SNR 8000 –ACT.

**Table 2:** MP1 e MP2 means values for each receiver.

| receiver / model | MP1(m) | MP2 (m) |
|---|---|---|
| **LE-CRS1000** | 0,057 | 0,056 |
| **LE-SR520** | 0,063 | 0,104 |
| **TR-4700** | 0,198 | 0,313 |
| **TR-4000SSE** | 0,245 | 0,596 |

| | | |
|---|---|---|
| **TR-4000SSI** | 0,260 | 0,861 |
| **ASH-ZXII3** | 0,273 | 0,306 |
| **RO-SNR-8000 ACT** | 0,292 | 0,309 |
| **ASH UZ-12** | 0,298 | 0,364 |
| **AO – SNR-12 ACT** | 0,306 | 0,426 |
| **RO-SNR-8000** | 0,331 | 0,936 |
| **TR-4800** | 0,332 | 0,850 |
| **LE-SR299** | 0,495 | 0,465 |
| **JPL-GGD** | 0,675 | 0,717 |

According to ratio of number of real observations and the number of available observations, presented in Figure 4, there are 3 stations with poor performance. The problem of the station occupied with Trimble receiver should be due to local features, because the other Trimble stations did not show any problem.

The indicator O/slps is shown in the Figure 5. This value represents the number of collected observation over mask elevation, divided by the number of cycle slips. Thus, a greater value means less number of cycle slips. The Leica receiver showed again the best performance.

## 4 Further Information for Processing

The informations used to carry out tests to define the best processing strategy were:

(1) Ephemeris : Combined IGS, SP3 files, reference – ITRF97;
(2) Earth Rotation Parameters – ERP: files ERP from IGS combined orbits;
(3) Reference stations coordinates: CODE (files CODXXXX.CRD)
(4) Antenna phase center offset and variation: Informations obtained at IGS. When this information weren't found at IGS, the values from NGS were used.

## 5 Ionosphere Maps

The atmosphere perturbations (ionosphere and troposphere) affect the GPS signal propagation, mainly due to the free charged particles, besides the high solar activity in the last years. With the goal of reducing the ionosphere refraction, CODE (Center for Orbit Determination in Europe) developed the Global Ionosphere Maps (GIMs).

The GIMs are generated on a daily basis in two formats; IONEX - IONosphere Map EXchange Format, IGS format, extension INX and CODE format (accepted by bernese software), extension ION. The TEC is modeled with a spherical harmonic expansion up to degree 12 and order 8 referring to solar-magnetic reference frame. ION file is organized in 12 sets of 149 coefficients (TEC and root mean square), for each 2 hours. The coefficients are derived from GPS observations of 136 IGS stations. In the American continent, about 45 stations contribute with ION maps.

Following CODE recommendations, making use of GIMs in processing without linear combination strategy, two ION maps were tested; one carried out by CODE and other carried out by Department of Transportation Engineering, Polytechnic School – University of São Paulo (EPUSP). The EPUSP maps got the contribution of 16 SIRGAS stations from North America and 15 stations in Central America. Both maps, CODE and EPUSP, have the same input parameters.

## 6 Processing Strategy

The tests developed, aimed to analyze the best strategy to be adopted the final processing. Four strategies were tested:

(1) Ambiguities were not solved, were eliminated in the final daily solution;

(2) Ambiguity resolution with QIF (Quasi Ionosphere Free) strategy and later introduction in the final daily solution;
(3) Ambiguity resolution with QIF strategy and GIMs/CODE. Introduction of solved ambiguities in the final daily solution.
(4) Ambiguity resolution with QIF strategy and EPUSP ION map. Introduction of solved ambiguities in the final daily solution.

Further adopted options and parameters were:

- The strategy forming the single difference phase files was OBS-MAX[1].
- The pre-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).
- Elevation mask of 15° and a sampling rate of 30 seconds and 15 seconds.
- No *a priori* troposphere model.
- The troposphere parameters were estimated in the whole process, even during the ambiguity resolution step (QIF strategy).
- 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.
- Use of elevation-dependent weighting of the observations.
- Estimation of troposphere gradients parameters (one per station), using tilting mapping function.
- One station was chosen to constrain the daily final solution.

[1] Maximum number of observation between two station.

[2] The observation equation difference in phase, allowing to eliminate or minimizing some errors in GPS observations, as the one caused by the ionosphere refraction.

Briefly, the results of tests performed, including 31 North (16 stations) and Central (15 stations) America stations, according the options/strategies mentioned, are presented on Tables 3, 4, 5 and 6. Table 3 and 5 show the number of ambiguities before and after the resolution. About 60% ambiguities were solved with QIF/GIMs strategy, producing better results. It can be seen on Tables 4 and 6, through small baseline RMS.

Adopting EPUSP ION map, more ambiguities were solved, but this was not reflected on the baselines RMS.

**Table 3.** Number of ambiguities before and after resolution considering different processing strategies. Solution of 16 North American stations.

| Strategy | Total number of ambiguities (L3) | Total number ambiguities after resolution (L3) |
|---|---|---|
| Sigma | 833 | 885 |
| QIF (without ionosphere map) | 833 | 433 |
| QIF (with ionosphere map/CODE) | 833 | 356 |
| QIF (with ION EPUSP map) | 833 | 335 |

**Table 4.** RMS in 3 baselines of the final solution for North America.

| Baseline | Lenght (km) | RMS (no ambiguity resolution) (m) | RMS (QIF) (m) | RMS (QIF with ion. map/CODE) (m) | RMS (QIF with ion. EPUSP map) (m) |
|---|---|---|---|---|---|
| SCH2 / CALG | 1841.3 | 0.0007 | 0.0004 | 0.0003 | 0.0004 |
| CNDR / USNO | 1703.7 | 0.0005 | 0.0003 | 0.0003 | 0.0003 |
| AOML / WHIT | 1489.2 | 0.0006 | 0.0004 | 0.0004 | 0.0004 |

**Table 5.** Number of ambiguities before and after the resolution in different processing strategies. Solution of 15 Central American stations.

| Strategy | Total number of ambiguities (L3) | Total number ambiguities after resolution (L3) |
|---|---|---|
| Sigma | 594 | 608 |
| QIF (without ionosphere map) | 594 | 541 |
| QIF (with ionosphere map/CODE) | 594 | 372 |
| QIF (with ION EPUSP map) | 594 | 286 |

**Table 6.** RMS in 3 baselines of the final solution for Central America.

| Baseline | Length (km) | RMS (no ambiguity resolution) (m) | RMS (QIF) (m) | RMS (QIF with ion. map/CODE) (m) | RMS (QIF with ion. map/EPUSP) (m) |
|---|---|---|---|---|---|
| CART / CRO1 | 1432.2 | 0.0011 | 0.0010 | 0.0007 | 0.0007 |
| CART / TEGU | 1331.5 | 0.0010 | 0.0009 | 0.0004 | 0.0005 |
| INEG / TEGU | 1806.2 | 0.0009 | 0.0009 | 0.0005 | 0.0005 |

## 7 Future Works

The processing options developed in this paper had the goal to choose the best strategy for the data processing of SIRGAS2000 GPS campaign. According to the obtained results, will be chosen the QIF strategy, making use of GIMs. More tests will be carried out with data from South America and EPUSP ION map, considering that GIMS/CODE have few stations in this part of continent.

As a consequence of station quantity and Bernese limitations, the final processing should be divided into 9 blocks, comprising 22 stations. Considering that IGS stations have well determinate coordinates and standard deviations, they will be the constrain for blocks on daily solutions. For the final solution, the combination of normal equations of all blocks will be carried out as a "free network" solution and IGS stations will make the link in each block.

## 8 References

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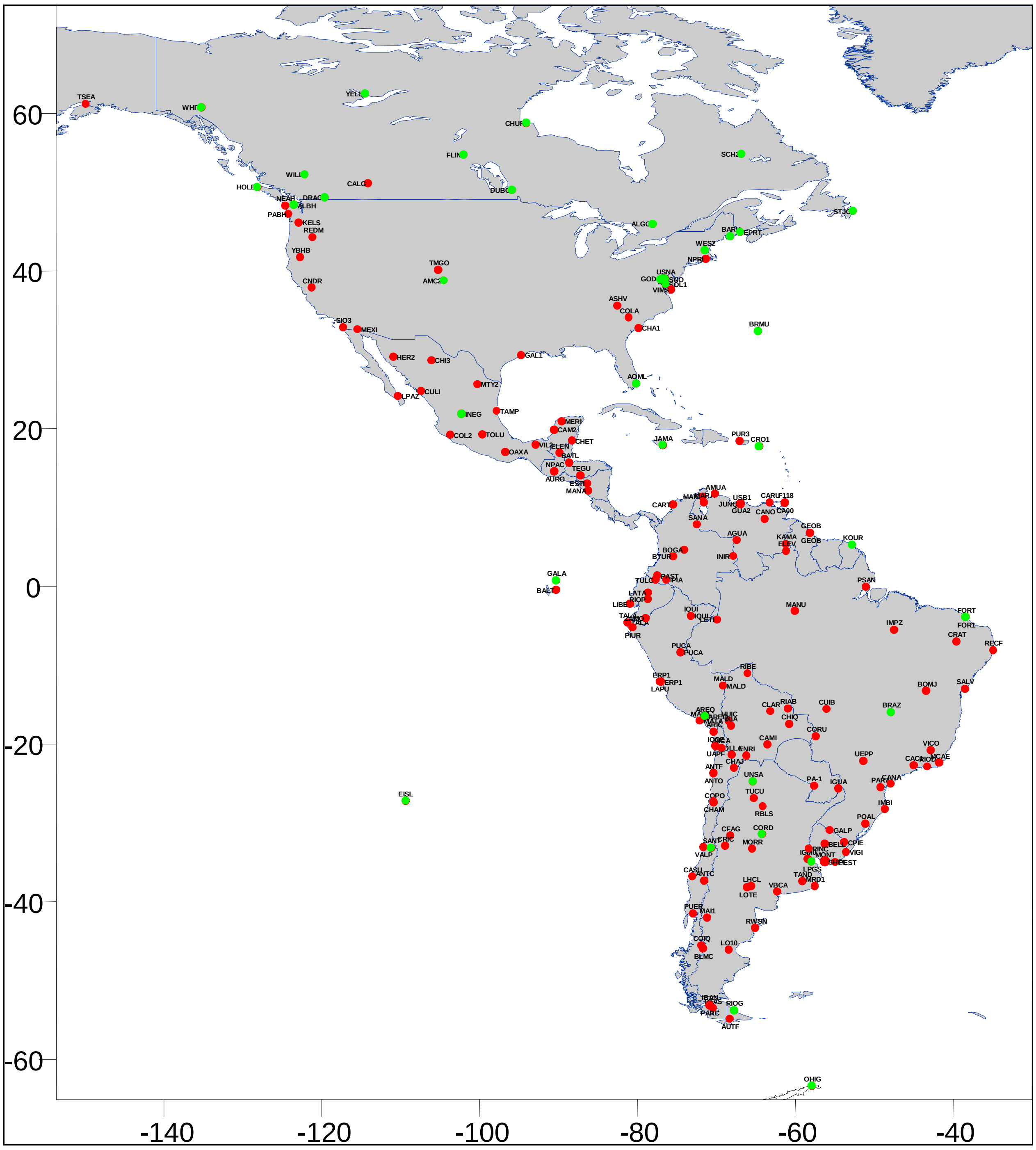


**Fig. 1** Location of sites occupied during the SIRGAS 2000 GPS campaign.

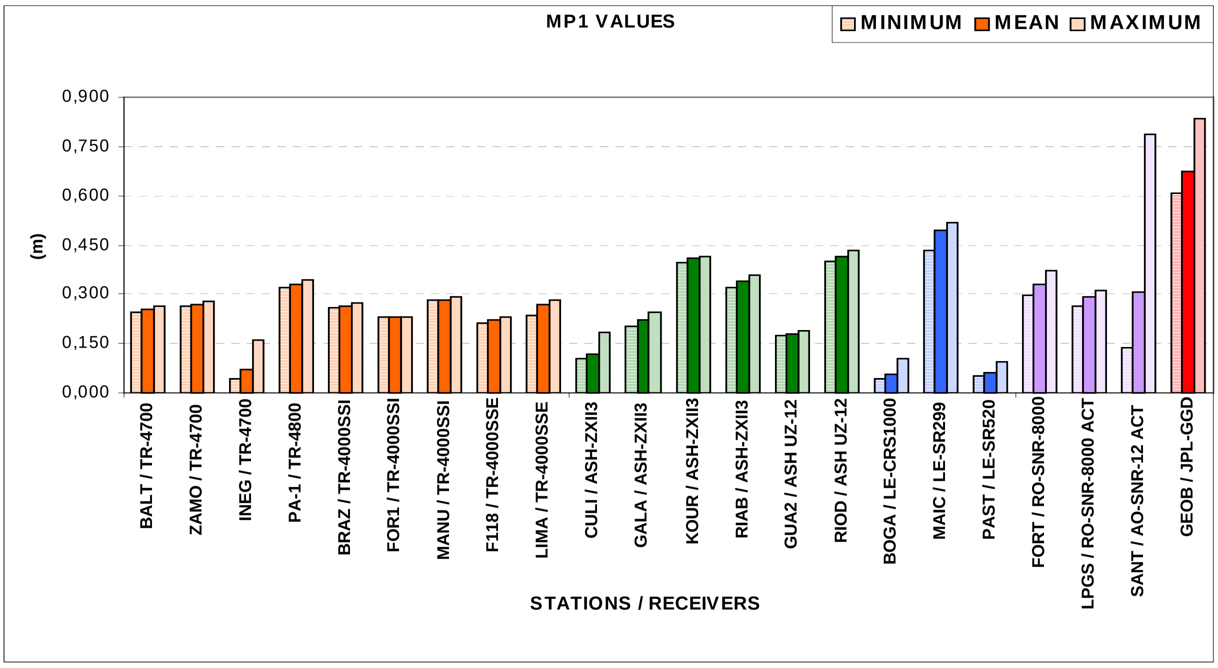


**Fig. 2** multipath analysis on carrier phase L1 (MP1).

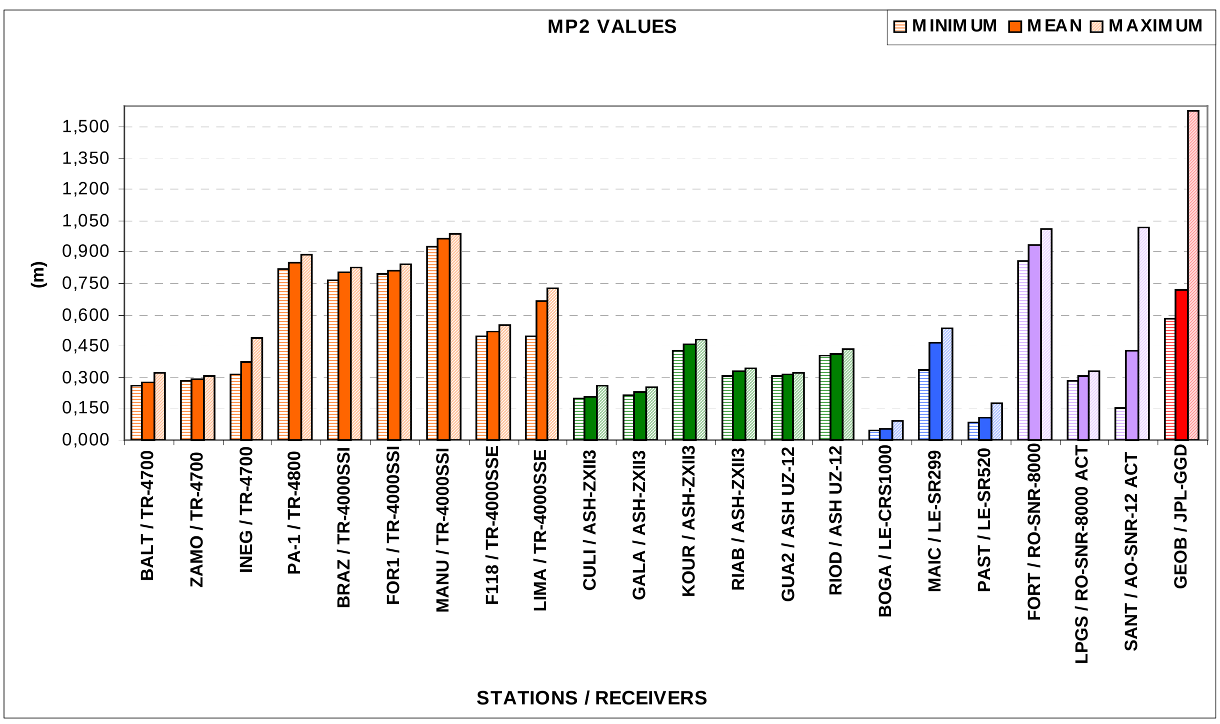


**Fig. 3** multipath analysis on carrier phase L2 (MP2).

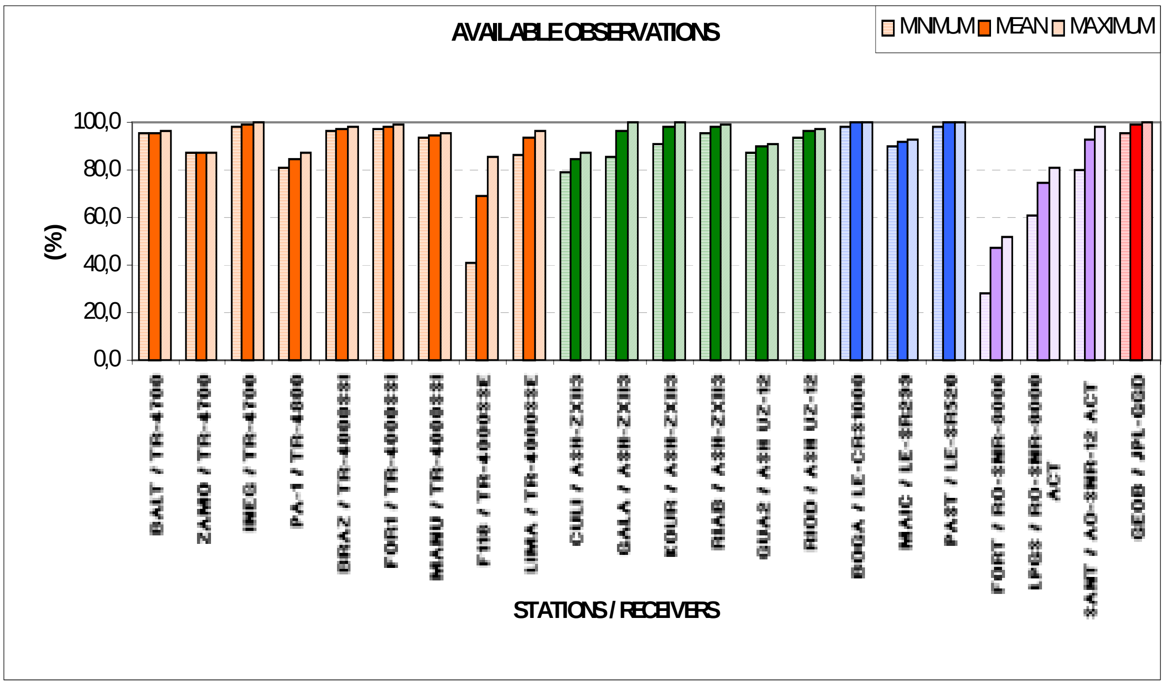


**Fig. 4** percentage of available observations for processing.

**Fig. 5** O/SLPS values.