Chapter 9

A Filtering Method Developed to Improve GNSS Receiver Data Quality in the CALIBRA Project

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http://dx.doi.org/10.5772/58778

1. Introduction

To study ionospheric scintillation on L-band radio signals, it is nowadays typical to acquire data with GNSS (Global Navigation Satellite System) receivers working at high frequency sampling rate (50-100 Hz) [1]. When dealing with such data, it is common to consider the contribution coming solely from observations at elevation angles, calculated from the receiver to the selected satellite, above an arbitrary threshold, typically 15-30°. Filtering out measurements made at low elevation angles helps keeping a high SNR (Signal to Noise Ratio) and eliminating non-ionospheric related effects, such as multipath [2].

The downside of that well consolidated method is a reduction of the field of view spanned by the GNSS receiver antenna, and, if it is the case, of the whole network. This is not crucial for dense networks or well covered areas, but it can be in the case of not well covered regions, for logistics (e.g. forests, deserts, etc.) and/or environmental reasons (e.g. oceans). The loss of information in many applications could be meaningful.

In this paper, we present a method to filter out spurious data based on an "outliers analysis" able to efficiently remove multipath affected measurements, reducing the data loss from 35-45% to 10-20%. It is based upon the Ground Based Scintillation Climatology (GBSC) ([3], [4]) and the station characterization based upon GBSC [5] is applied to the CIGALA[1]/ CALIBRA[2] network in Brazil. The research shown herein was carried out in the context of the CALIBRA (http://www.calibra-ionosphere.net) project and exploits the CIGALA/CALIBRA network in Brazil, to which the method was applied, enlarging the field of view and, then, improving the capability of inferring the dynamics of the low latitude ionosphere.

2. Data and method

The CALIBRA project builds on the now ended CIGALA (http://cigala.galileoic.org/) project, and exploits a combined network of specialized receivers installed as part of the two projects, the so-called CIGALA/CALIBRA network, which is equipped with Septentrio PolaRxS receivers.

The PolaRxS is a multi-frequency, multi-constellation receiver capable of tracking simultaneously GPS L1CA, L1P, L2C, L2P, L5; GLONASS L1CA, L2CA; GALILEO E1, E5a, E5b, E5AltBoc; COMPASS B1, B2; SBAS L1 [6]. Sampling at 50 Hz, the receiver gives the following main output parameters:

1. σ_Φ phase scintillation index calculated over different time intervals (1, 3, 10, 30, 60 seconds);
2. S_4 amplitude scintillation index calculated over 60 seconds;
3. *TEC* (Total Electron Content) and *ROT* (Rate of TEC change) every 15 seconds,
4. spectral parameters: spectral slope of the phase Power Spectral Density (p) in the 0.1 to 25Hz range and the spectral strength of the phase Power Spectral Density (T) at 1 Hz (60 seconds);
5. Standard Deviation of the Code to Carrier Divergence (*CCSTDDEV* - 60 seconds);
6. *SNR* (60 seconds);
7. *locktime* (60 seconds).

All these quantities (except *TEC* and *ROT*) are calculated for all available signal frequencies transmitted by the satellites and along the slant path connecting receiver and satellite. *TEC* values are obtained by pseudorange measurements only. GPS-*TEC* measurement is based on the L2-P and L1-P pseudoranges; GLONASS-*TEC* is based on the L1-C/A and L2-C/A pseudoranges and Galileo-TEC is based on the L1BC and E5a. *ROT* is computed from the carrier phase measurements only, and hence is much more accurate than *TEC*.

The data used in this analysis was acquired by the CIGALA/CALIBRA network of PolaRxS receivers during the whole year in 2012. Table 1 summarizes all the CIGALA/CALIBRA stations available during the considered period with their corresponding identifier, location and geographic coordinates.

1 CIGALA stands for Concept for Ionospheric-Scintillation Mitigation for Professional GNSS in Latin America.

2 CALIBRA stands for Countering GNSS high Accuracy applications LImitation due to ionospheric disturbance in BRAzil.

http://dx.doi.org/10.5772/58778

Name	Location	Lat (°N)	Lon (°E)
MANA	Manaus	-3.12	-60.01
PALM	Palmas	-10.20	-48.31
POAL	Porto Alegre	-30.07	-51.12
PRU1	Presidente Prudente	-22.12	-51.41
PRU2	Presidente Prudente	-22.12	-51.41
SJCI	São José dos Campos	-23.21	-45.86
SJCU	São José dos Campos	-23.21	-45.96

Table 1. List of the CIGALA/CALIBRA network receivers used in the analysis.

Figure 1 shows the impact of applying a standard 20° elevation cutoff in terms of percentage of data coverage of the network, normalized to the total number of data points (GPS and GLONASS) available in 2012. Figure 1a shows the coverage obtained by applying no threshold on the elevation angle while figure 1b shows that obtained with a threshold of 20°. Both maps and the geomagnetic equator (red line) are projected at a height of 350 km, being representative of the ionospheric F2-layer peak height.

The cutoff reduces significantly the capability of the network in depicting the ionosphere northward of the geomagnetic equator and above the Atlantic Ocean, east of Brazil.

The filtering method based upon the outliers is then described: for each station of the network, the map in azimuth vs. elevation of the standard deviation of the *CCSTDEV* ($\sigma_{CCSTDDEV}$) is produced by using the GBSC technique. The bin size adopted is 5°x5° and observations on both GPS and GLONASS L1 frequency have been considered to maximize the number of observations in each bin. The CCSTDDEV is chosen as it is a good indicator of the multipath activity experienced by the receiver antenna [7] and its standard deviation ($\sigma_{CCSTDDEV}$) identifies the bin in which it experiences a large variability.

As an example, Figure 2a shows the map of $\sigma_{CCSTDDEV}$ obtained for the MANA station in 2012. Each value of $\sigma_{CCSTDDEV}$ is then used to create the corresponding histogram, shown in Figure 2b. The filtering method is based upon the identification of the outliers in such $\sigma_{CCSTDDEV}$ histogram. As stated in the general data analysis theory, most values of a distribution are expected in the inter quartile range (*IQR*) or located between the two hinges. Values lying outside 1.5 times the *IQR* are called "mild outliers" and values outside the boundaries of 3 times the *IQR* are termed "extreme outliers" [8]. The red line in Figure 2b indicates the cutoff for the mild outliers (1.5 *IQR*). The bins corresponding to values of $\sigma_{CCSTDDEV}$ greater than $\langle\sigma_{CCSTDDEV}\rangle$+1.5 *IQR*, i.e. the mild outliers, are filtered out and new analyses can be performed.

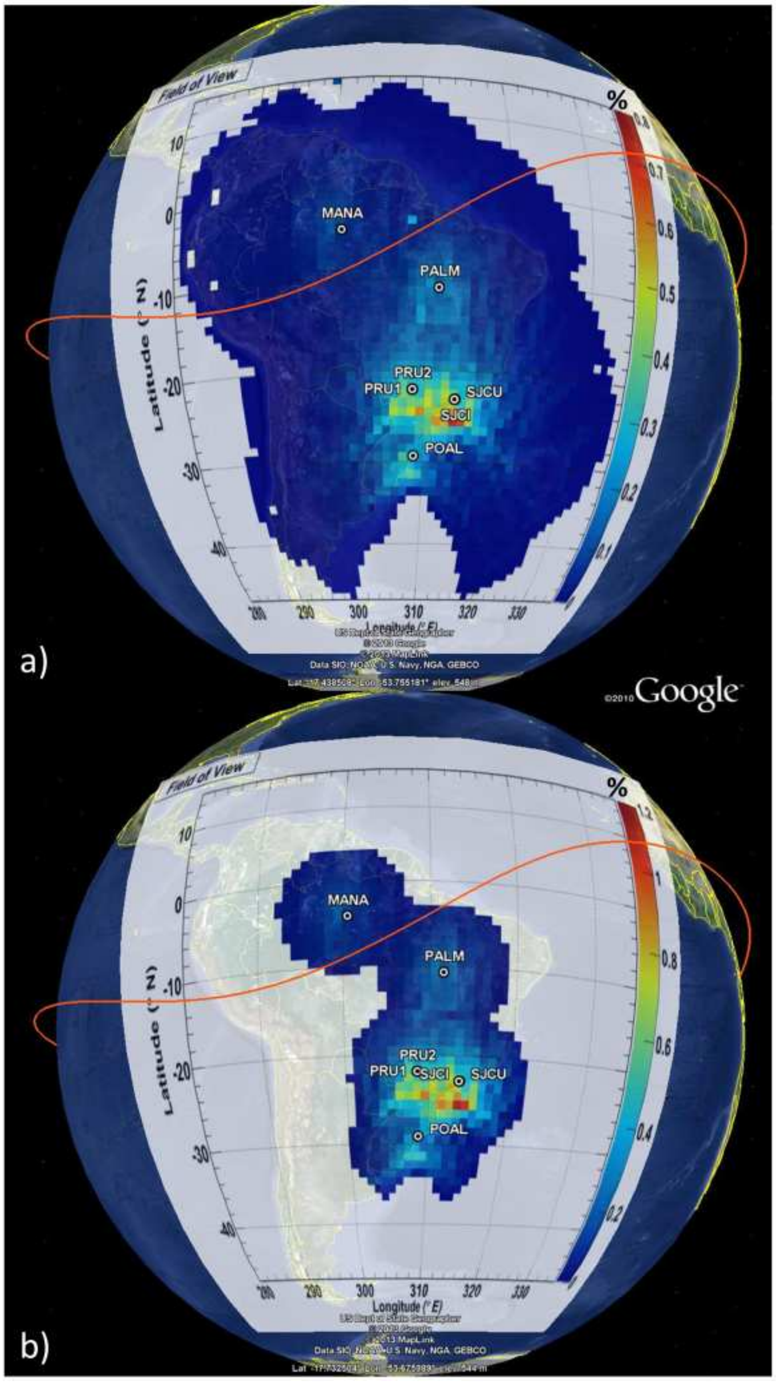

Figure 1. Percentage of data coverage of the CIGALA network considering the full dataset of 2012, obtained applying no threshold on the elevation angle (a) and with a threshold of 20° (b). Both maps and the geomagnetic equator (red line) are projected at 350 km of height.

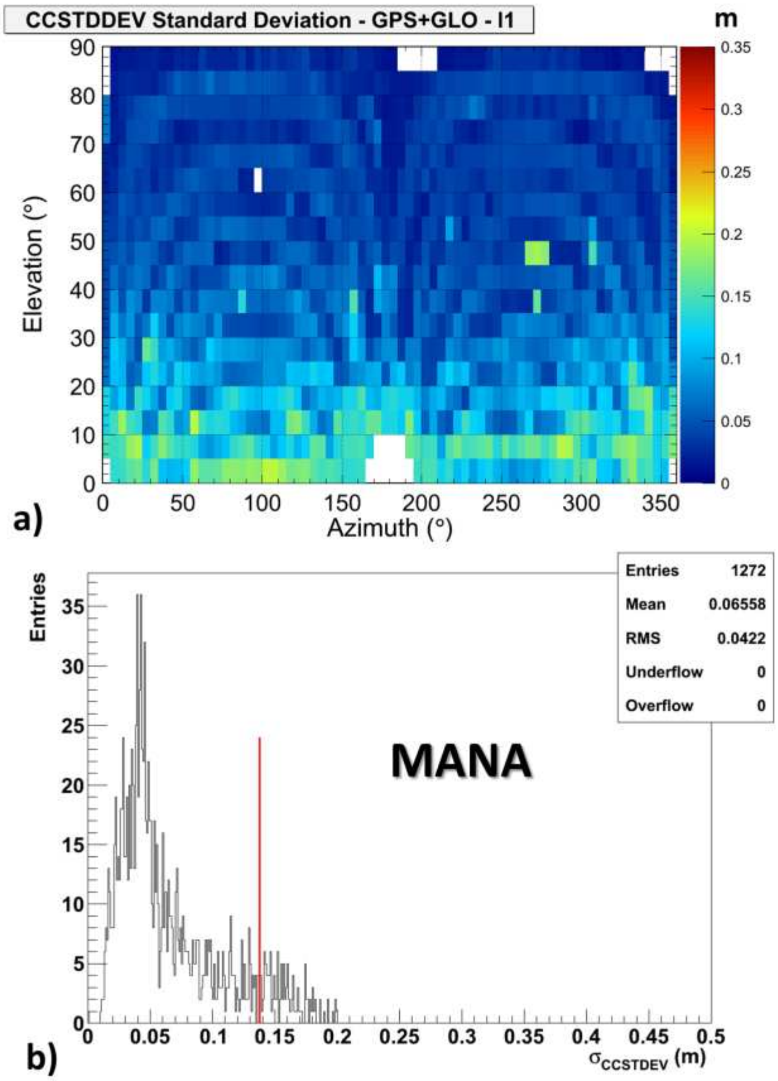

Figure 2. (a) Map of the $\sigma_{CCSTDDEV}$ in *azimuth* vs. *elevation* for MANA (GPS+GLONASS data on L1 frequency) for 2012. (b) Corresponding distribution of the $\sigma_{CCSTDDEV}$. The red line indicates the cut-off for mild outliers.

3. Results

The method is able to remove the contribution mostly from the low elevation angles, as expected, but to keep some "not noisy" bins. By using this technique the number of rejected observations ranges between 12% and 20%, reducing the data loss in comparison to the application of the standard elevation angle cut-off of 15-30°, which ranges between 35 and 45%. Similarly to Figure 1, the percentage of data coverage of the CIGALA/CALIBRA network after the filtering procedure is shown in Figure 3. From this figure and Figure 1(b) it is evident how this filtering allows to cover further ionospheric sectors of interest and to characterize there the pattern of ionospheric variability.

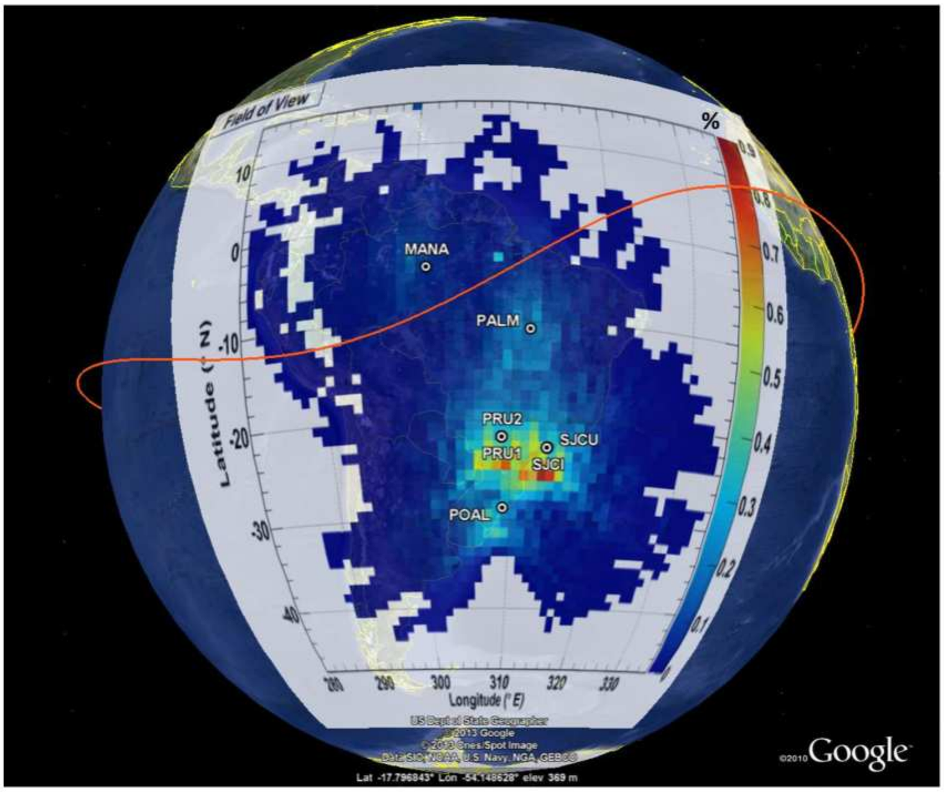

Figure 3. Percentage of data coverage of the CIGALA network receivers considering the full dataset of 2012 after the filtering procedure. The map and the geomagnetic equator (red line) are projected at a height of 350 km.

Figure 4 shows the map of the percentage of occurrence of the amplitude scintillation index S_4 [7] values above 0.25, in geographic coordinates. Such threshold of 0.25 allows the characterization of the areas of the ionosphere in which scintillation affects the GNSS signals in a moderate to strong manner. Only data acquired in the UT range between 22 and 04 UT has been considered, in order to focus on the post sunset hours in which most of the scintillation occurs (see, e.g., [9]). From this map (Figure 4), thanks to the enlargement of the field of view covered by the CIGALA/CALIBRA network introduced by the filtering algorithm, it is possible to see the enhancement of occurrence in correspondence with the northern crest of the Equatorial Ionospheric Anomaly (EIA) [10], mainly covered by the MANA observations. This enhancement is for geographic latitudes greater than 0°N and in a band nearly parallel to the geomagnetic equator (red line), where an occurrence peak of about 6% is reached. On the other hand, the southern crest of the EIA is well covered by the data and its effect in terms of amplitude scintillation occurrence is visible in the band of enhanced scintillation nearly parallel to the geomagnetic equator (red line) and reaching a peak value of about 16%. From these considerations, the most affected regions are those in the latitudinal range between 30°S and 10°N and in correspondence with longitudes between 300°E and 330°E, in particular over São Paulo and Tocantins States (due to the presence of the EIA southern crest) and northward of MANA (due to the presence of the EIA northern crest). The enhancement over POAL is also meaningful and possibly due to the presence of the particle precipitation occurring in the borders of the South Atlantic Magnetic Anomaly (SAMA) [11]. The SAMA is in fact another

http://dx.doi.org/10.5772/58778

source of ionospheric turbulence leading to scintillation, as it disturbs the thermospheric circulation in the atmosphere and alters the rates of production and recombination of the ionized species, mainly under geomagnetic storms [12].

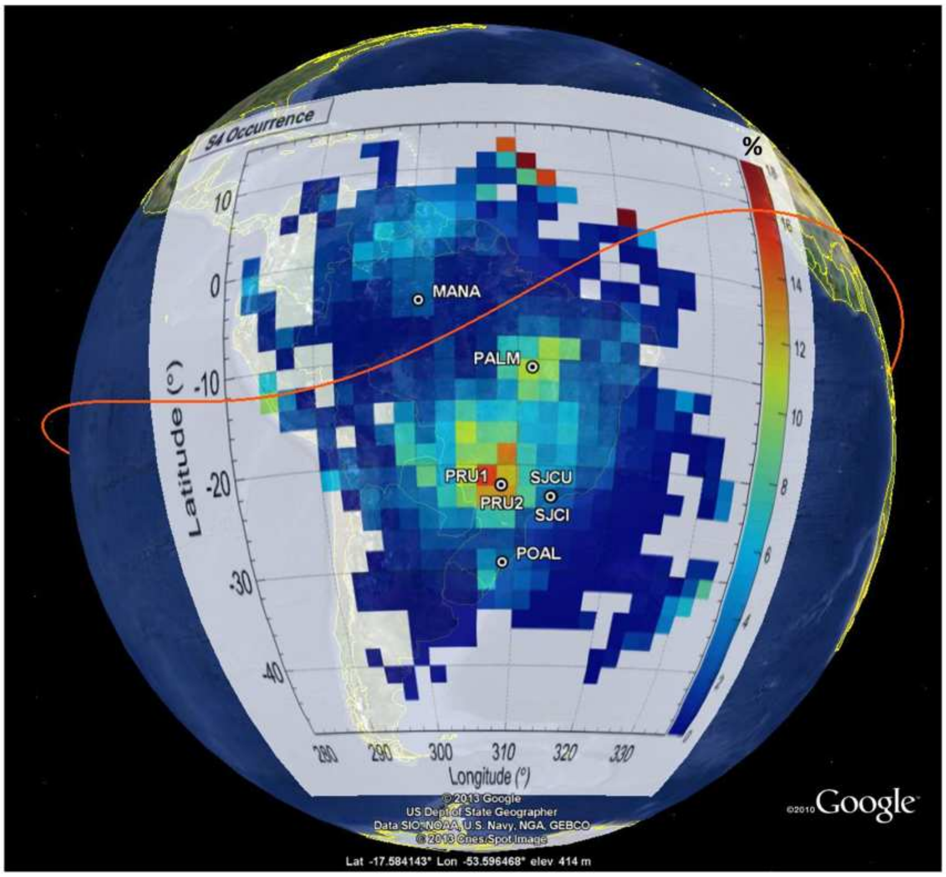

Figure 4. Map of S_4 percentage of occurrence above 0.25 in geographic coordinates (GPS+GLONASS, L1 frequency) in the UT range 22-04 UT.

4. Conclusion

We have shown how the development of a filtering method to remove spurious data based on an analysis of outliers is able to efficiently clean multipath and signal degradation from GNSS data. This approach limits the data loss to 10-20%, while the traditional cut off of 15°-30° on the elevation angle leads to losses of 35-45%. The reduction in data loss, averaged among all the station, is of a factor of about 2.4.

We applied the method to the 2012 data acquired by the CIGALA/CALIBRA network, increasing its capability to depict the ionospheric features. This method optimizes the capability of GNSS networks and helps in planning the installation of additional new receivers aiming to enlarge network coverage.

Acknowledgements

The CIGALA project (http://cigala.galileoic.org/) was funded under the EU Seventh Framework Program, and was carried out in the context of the Galileo FP7 R&D program. The CALIBRA project (http://www.calibra-ionosphere.net) was funded under the EU Seventh Framework Program, and was being carried out in the context of the Transport (including Aeronautics), Support to the European global satellite navigation system (Galileo) and EGNOS program. Both projects are supervised by the GSA.

VR contribution is included in the PhD research project: "Scintillation effects on GNSS: monitoring and data treatment development" carried out at the Nottingham Geospatial Institute of the University of Nottingham. In particular its contribution is in the method concept and algorithm development.

Two monitoring stations were provided by UNESP via FAPESP (Process no. 2006/04008-2). The authors also want to thank the following partner institutions in Brazil: IFTO (Instituto Federal do Tocantins), UFRGS (Universidade Federal do Rio Grande do Sul), INPE (Instituto Nacional de Pesquisas Espaciais), UNIVAP (Universidade do Vale do Paraiba), Petrobras (Petróleo Brasileiro S/A) and UEA/INPA (Universidade do Estado do Amazonas/Instituto Nacional de Pesquisas Ambientais).

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