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CIGALA: A FP7 INNOVATIVE ACTIVITY TO TACKLE THE THREAT OF IONOSPHERIC SCINTILLATION TO GNSS OPERATIONS IN LATIN AMERICA

CIGALA: Uma Atividade Inovadora do Programa Europeu Quadro 7 para Atacar a Ameaça da Cintilação Ionosférica nas Operações GNSS na América Latina

João Francisco Galera Monico[1]; Giorgiana De Franceschi[2]; Bruno Bougard[3]; Marcio Aquino[4] & Marc Soley[5]

[1]Universidade Estadual Paulista – UNESP
Faculdade de Ciências e Tecnologia – FCT, Departamento de Cartografia
Rua Roberto Simonsen, 305, Presidente Prudente, SP, Brazil
galera@fct.unesp.br

[2]Istituto Nazionale di Geofisica e Vulcanologia – INGV
Upper Atmosphere Physics
Vigna Murata 605, 00143 Rome, Italy
defranceschi@ingv.it

[3]Septentrio N. V. – SSN
Greenhill Campus
Interleuvenlaan 15G, 3001 Leuven, Belgium
Bruno.Bougard@septentrio.com

[4]University of Nottingham – UON
NGI - Nottingham Geospatial Institute
University Park, Nottingham, NG7 2RD, United Kingdom
marcio.aquino@nottingham.ac.uk

[5] Pildo Consulting, SL
Parc Tecnològic de Barcelona Nord Office
A216-A220, 08042 Barcelona, Spain
marc.sole@pildo.com

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ABSTRACT

Drifting ionospheric electron density irregularities may lead to the scintillation of transionospheric radio waves, as in the case of signals broadcast from artificial satellites. Scintillations can not only degrade signal quality but also cause receiver loss of lock on GNSS satellites, therefore posing a major threat to GNSS based applications demanding high levels of accuracy, availability and integrity. The problem is particularly acute in Latin America and will be further amplified with the next solar maximum, expected to occur in the 2012-2014 time frame. The CIGALA (Concept for Ionospheric Scintillation Mitigation for Professional GNSS in Latin America) project, led by Septentrio N.V. and co-funded by the European GNSS Supervisory Authority (GSA) through the European 7th Framework Program, will tackle this problem. The aim of the CIGALA project is to develop ionospheric scintillation mitigation countermeasures to be implemented in Septentrio's professional multi-frequency multi-constellation GNSS receivers, to be tested in Latin America. The project will leverage research and development activities coordinated between European and Brazilian experts and will involve a wide scale ionospheric measurement and test campaigns that will be conducted in Brazil with the support of several local academic and industrial partners. The overall strategy adopted and the current status of the project is presented and preliminary results discussed.

Key words: Low Latitude Ionosphere, Ionospheric Scintillation, Mitigation Techniques, GNSS.

RESUMO

Irregularidades na densidade de elétrons na atmosfera podem proporcionar cintilação nas ondas de rádio, tal como nos casos dos sinais transmitidos pelos satélites artificiais, como os do GNSS. Cintilação não somente degrada a qualidade do sinal, mas também faz o receptor perder sintonia com os sinais GNSS e desta forma, ameaçar as aplicações GNSS que demandam alta acurácia, disponibilidade e integridade. O problema é particularmente importante na América Latina e irá se ampliar no próximo ciclo solar máximo, que deve ocorrer entre 2012-2014. O projeto CIGALA (Concept for Ionospheric Scintillation Mitigation for Professional GNSS in Latin America) liderado pela empresa Septentrio N.V. e financiado pela GSA (Autoridade Européia Supervisora do GNSS) via o Programa Europeu Quadro 7 irá atacar o problema. O objetivo do projeto CIGALA é desenvolver métodos de mitigação da cintilação ionosférica para ser implementados nos receptores GNSS de multi freqüência da Septentrio, que serão testados na América Latina. Isto envolverá pesquisas e desenvolvimentos que serão coordenados entre profissionais europeus e brasileiros e abrangerá medições de parâmetros da ionosfera em larga escala, bem como campanhas testes a serem realizadas no Brasil com o suporte de parceiros acadêmicos e industriais. A estratégia a ser adotada e o estado da arte do projeto serão apresentados com resultados preliminares sendo apresentados e discutidos.

Palavras- chave: Ionosfera de Baixa Latitude, Cintilação Ionosférica, Técnicas de Mitigação, GNSS.

1. INTRODUCTION

The Earth's ionospheric environment represents the largest contributor to the GNSS error budget. Ionospheric scintillation, a phenomenon that relates to fluctuations in the phase and amplitude of the signals from GNSS satellites when they cross regions of electron density irregularities in the ionosphere (KINTNER *et al.*, 2001), can impose serious degradation on GNSS system functionality, including integrity, accuracy and availability.

To characterize these fluctuations two indexes are internationally adopted: the amplitude scintillation index, S_4, which is the standard deviation of the received power normalized by its mean value, and the phase scintillation index, $\acute{o}_{\ddot{o}}$, which is the standard deviation of the detrended carrier phase.

The two geographic areas most affected by scintillations are the auroral zones and the equatorial regions (AARONS, *1982*). The low latitudes show a characteristic feature of the plasma density, known as the equatorial anomaly (EA) (KELLEY, 1989), for which a plasma density enhancement is produced and seen as crests on either side of the magnetic equator. It is a region in which the electron density is considerably high and inhomogeneous, producing ionospheric irregularities structures causing scintillations. In the Brazilian longitudinal sector, the ionospheric F region irregularities present peculiarities due to several local physical conditions, such as the high magnetic declination angle that characterizes this region (ABDU *et al.*, 1981; BATISTA *et. al*, 1986). The separation between the magnetic and the geographic equators and the presence of the EA, associated with large background electron densities and large horizontal gradients of electron density due to the equatorial anomaly crests, also produce important peculiarities in the irregularity distributions [DE PAULA *et al.*, 2007].

Under disturbed conditions the global ionospheric scintillation scenario, due to irregularities formation/inhibition and dynamics, can be particularly complex as recently highlighted during the April 2006 storm over Vietnam (ALFONSI *et al.,* 2010) and over Brazil by *Muella et al.* (2010) in relation to the Halloween storm occurred the 29-30 October 2003. During this event, space weather maps, produced by the Ionospheric Data Assimilation Three Dimensional (IDA3D), demonstrated the dramatic poleward motion of the equatorial anomaly peaks (GARNER *et al.*, 2006). BASU *et al.* (2005) observed a large storm enhanced density (SED) plume over the continental US extending into Canada in a SE to NW direction between 20:00 and 20:15 UT on 30 October, possibly observed later simultaneously with scintillation events over Svalbard by Mitchell *et al.* (2005), by Stolle *et al.* (2006) and by De Franceschi *et al.* (2008) over the North polar ionosphere.

Considering the increasing relevance of satellite technologies to modern society, knowledge and monitoring of such events are essential, so that warnings and forecast information can be made available to end users and system designers of GNSS (such as GPS, GLONASS and the forthcoming Galileo) to guarantee the necessary levels of accuracy, integrity and availability of high accuracy and safety-of-life applications. Especially when faced with severe geospatial perturbations, mitigation tools to minimize destructive effects on satellite signals (loss of lock, degradation of accuracy and poorer satellite availability) are also needed.

In this context, the challenge of the CIGALA project is to understand the causes of ionospheric disturbances and model their effects in order to develop novel countermeasure techniques to be implemented in professional multi-frequency GNSS receivers, providing a timely competitive advantage in the Latin American market. To achieve the objectives, the CIGALA consortium brings together Europe's leading industry and research institutions in the area of GNSS and, in particular, leading players in the field of analysis, understanding and mitigation of the effect of the ionosphere on GNSS systems. The Consortium Partners are: Septentrio Satellite Navigation N.V. (SSN), Pildo Consulting S.L. (PLD), University of Nottingham (UON), Istituto Nazionale di Geofisica e Vulcanologia (INGV), Universidade Estadual Paulista Julio de Mesquita Filho (UNESP) Presidente Prudente, Consultgel (CGS) and PETROBRAS. Together they represent a vertically integrated consortium, with knowledge stretching from basic research (conducted by UON, INGV, UNESP, SRC, UNG) to the design and marketing of products (SSN). The consortium is strengthened by Pildo's and CGS's broad competencies in GNSS, especially in the specific Latin America context. Moreover it owns a powerful bridge with local partners in Brazil with the participation of UNESP and CSG.

The CIGALA project started on February 15th, 2010 and will end on February 14st, 2012. The overall strategy of the work-plan is based on three tightly interacting work packages (WP) that operate with focus on i)Research and Modeling (WP200), ii) Measurements and Model Validation (WP300), and iii) GNSS Application (WP400). WP200 starting from archive data, will carry out ionospheric scintillation simulation and will continue with data collected in WP300 to incrementally develop an ionospheric scintillation and tracking error model that will be further verified in WP300 and used in WP400. In particular WP300 relies on SSN world-leading multi-frequency multi-constellation GNSS products and expertise as well as on the infrastructure of the local partners in Brazil.

The current status of CIGALA is described in Sections 2 and 3. Section 2 deals with the state-of- the-art of models capable of predicting signal propagation and tracking perturbations related to the ionospheric scintillation that are at the base of developing mitigation tools. Section 3 presents the current stage of the field measurement campaigns in Brazil based on the deployment of multi-frequency Galileo-capable receivers, aimed to collect data for supporting model development as well for testing the newly developed countermeasures against scintillation. Concluding remarks, result of market needs and local end user requirements are presented in Section 4.

2. SCINTILLATION AND TRACKING MODELS

Ionospheric scintillation may affect GNSS receivers in several ways. When the scintillation activity is low to moderate, the signals experience increased noise levels which may degrade positioning accuracy. This is more evident in applications that require high accuracy such as surveying, geodesy, construction, etc. In case of scintillation activity from moderate to high, the signals experience large disturbances and the receivers may find very difficult to maintain signal track. An important aspect is the performance of phase locked loops (PLL), which characterize the ability of a given GNSS receiver to use the information embedded onto the received signals with the best possible accuracy.

In the presence of low to moderate scintillation activity, the PLL measures the phase of received signals with an increased error in comparison to when scintillation is absent. The PLL still tracks the GNSS signals, but the resulting position estimate will have a lower accuracy, introducing serious problems to a range of high precision applications (CERVERA *et al.*, 1998; CONKER *et al.*, 2003; HUMPHREYS *et al.*, 2005).

In the presence of moderate to high scintillation activity, the PLL may suddenly lose the phase lock of a GNSS satellite that is in view of the receiver. This is known as cycle slip and the mean time between cycles slips depend on the intensity of the scintillation activity. If this is very intense, the PLL may never recover the phase lock after a long succession of cycle slips. In such a case, the receiver cannot use the signal of that particular satellite and the number of satellites being tracked reduces, leading to a poorer tracking geometry. As strong scintillation events may affect the signals of several satellites simultaneously and the number of satellites may well go under the nominal number of 4, particularly during high solar conditions at low latitudes (MORRISSEY *et al.*, 2004; KNIGHT *and* FINN, 1998; GROVES *et al.*, 2000).

Several efforts have been attempted in order to model the effects of ionospheric scintillation on PLL performance. Usually, the PLL performance is evaluated on the basis of the phase error variance, which is found to increase in presence of ionospheric scintillation (CONKER *et al.*, 2003). A key limitation in such an approach is the assumption of PLL linearity, while during severe scintillation events the PLL is not expected to work in a linear regime. Very recently, the PLL performance has been evaluated also in terms of two additional parameters: the mean time between cycle slips and the mean time between data bit errors (HUMPHREYS *et al.*, 2008). This approach seemed to be very promising for its ability to assess the PLL performance in its linear and non-linear regimes as well as for understanding how cycle slips and data bit errors occur, as they both introduce a threat to the overall receiver performance. A deeper analysis of the features relative to the GPS unit used by Humphreys *et al.* (2008) has revealed that their studies were indeed using correlated samples. As such, their analysis is de facto limited within the linear regime, despite the claims.

The simulation of scintillation effects on the signals (to be input to software PLL models) can be also accomplished either by using analytical models (FREMOW *and* RINO, 1983; AARONS *et al.,* 1980, AARONS, 1985; IYER *et al.,* 2006), climatological models such as the WideBandMODel (SECAN *et al.*, 1995) and in-situ-data based models (BASU *et al.,* 1976; 1981; 1988; WERNIK *at al.*, 2007). Based on a review of available scintillation models delivered in the frame of CIGALA (AQUINO *et al.*, 2010), it seems that the most adequate models within the context of CIGALA are the WBMOD (SECAN *et al.*, 1995) and WAM (WERNIK *et al.*, 2007) models. Such models rely on physical principles driving the propagation of radio waves through plasma density irregularities as well as to the modeling of those irregularities in the ionosphere according to specific helio-geophysical conditions. Both models take into account the strong scintillation by assuming the Rice distribution of the power fluctuations for which the amplitude scintillation index S_4 becomes:

$$S_4^{\,2} \approx 1\text{-}\exp(\text{-}S_{4w}^{\,2}) \qquad (1)$$

where S_{4w} is the scintillation index derived from the weak scintillation model (SECAN *et al.,* 1995). Moreover, the two models are very user friendly, making their use both simple and appropriate for our and other studies. In particular the WAM model appears to be a especially good candidate, as it can be easily updated and fine tuned with low latitudes in situ data, recently collected such as those from the Communication/Navigation Outage Forecasting System (C/NOFS) (DE LA BEAUJARDIÉRE *et al.*, 2004), or taken from historical archive, such as the Dynamics Explorer 2 plasma density measurements (HANSON *et al.*, 1981). WAM will also output critical spectral parameters such as the spectral strength (T) and slope (p) which are needed for the error analysis and the tracking models.

In addition to these, another approach to model scintillation that is particularly relevant to the CIGALA project is the generation of actual scintillation time histories that can be implemented for instance in a GNSS signal hardware simulator, which could in turn be connected to a GNSS receiver to assess the effects on receiver tracking. One such model is the so called Cornell Scintillation Model (CSM), which is a statistical model that creates scintillation perturbations on signal amplitude and phase based on the Nakagami-m distribution, thus enabling the generation of such time histories (HUMPHREYS *et al.,* 2008).

There are also ongoing studies on the mitigation of scintillation effects on GNSS applications, which consider the variance of the output error of both the receiver PLL and DLL (Delay Locked Loop), under the premise that these variances better express the quality of, respectively, the phase and code range measurements used to calculate position (AQUINO *et al.*, 2009). The capability of incorporating phase and amplitude scintillation effects into the variance of these tracking errors, via the models of Conker *et al.* (2003), allows the application of appropriated weights (based on the inverse of these variances) to measurements from different satellites. This proposed mitigation technique gives the least squares stochastic model used by the receiver for position computation a more realistic representation, in particular in a scintillation scenario, where the ionospheric irregularities affect each satellite differently. Improvement of 17% to 38% in the height error was achieved when the technique was applied to relative positioning based on GPS C1 and P2 pseudoranges for baselines ranging from 1km to 750km, at high latitudes in Northern Europe. A mitigated solution based on pseudorange and carrier phase measurements was implemented and compared with the non-mitigated solution, for a baseline of ~125km between the INGV stations in Longyearbean (~78°N;~16°E) and Ny Alesund (~79°N; 12°E). During a period of occurrence of high phase scintillation it was observed that problems related to carrier phase ambiguity resolution affecting positioning accuracy (height in particular) were reduced by the use of the proposed mitigated solution (AQUINO *et al.*, 2009).

From the above considerations, given in details in Aquino *et al.* (2010), and focusing on the main scope of the CIGALA project, that is the development (and potentially the operation) of an improved scintillation robust receiver, two possible strategies will be followed for moderate and strong scintillation scenarios.

In the case of moderate scintillation a possible solution lies on the implementation of a suitable software-based error modeling strategy in order to minimize the scintillation effects, so that the relative degradation in each of the satellites being tracked is taken into account. This presumes that the relative levels of scintillation affecting the different satellites can be modeled or measured. Therefore such a strategy will be based on the use of both real data and modeled scenarios. The use of real data collected during CIGALA's lifetime will allow for the fine tuning of the proposed strategy through validation of the algorithms actually used by the prototype receiver to calculate position. On the other hand, the use of scenarios generated by scintillation models of choice will allow the introduction and assessment of the potential geographic distribution of the irregularities causing the corresponding (moderate) scintillation levels. This will allow the refinement of the strategy, taking into account the scintillations climatology, i.e. the contribution of the different satellites (and corresponding link geometries) being tracked simultaneously. The modeled scenarios will be translated into actual signal effects with the aid of a hardware signal simulator, possibly in conjunction with the Cornell Scintillation Model (CSM).

In the second case, the GNSS signals from one or more satellites are totally lost, due to the inability of the tracking loops to maintain lock on the received signals. This may be caused by a critical decrease of the signal-to-noise ratio and/or by a critical increase in the signal dynamics. A possible strategy would be to elaborate advanced (hardware) tracking solutions, in order to reduce the probability of loss of lock and to increase the mean time between consecutive losses of lock. Such an exercise will be based on the analysis of both real data and modeled scenarios. The use of real data collected during CIGALA's lifetime will allow the analysis of the response of the tracking loops implemented into the prototype receiver when it is subject to severe ionospheric scintillation events. This is mandatory in order to design suitable advanced tracking loops. The use of modeled scenarios, as produced by scintillation models of choice, will allow the consideration of the climatology of scintillations, i.e. the different levels of ionospheric scintillation under realistic adverse space weather conditions in the Latin American region. The modeled scenarios will be characterized by a range of scintillation levels, given both by scintillation indices and by spectral parameters, which are expected to be the inputs to the tracking models to be developed. Also here a role is foreseen for the hardware signal simulator, in the same manner as with the first case. The tracking solutions will then need to be evaluated and tested against different conditions likely to occur in Latin America (and overall at low latitudes). The expectation is that this will be an iterative process, involving test/validation using the prototype receiver, which will finally lead to an optimal and final solution.

A preliminary investigation was carried out to assess the correlation between different scintillation levels and receiver signal tracking performance. However, the unavailability of real worst case scintillation data from the low latitude regions prompted the use of the CSM to generate the scintillation time histories. These scintillation time histories are then loaded onto the simulation scenario in the Spirent simulator. The receiver tracking performance is evaluated by determining the tracking jitter (variance of the tracking error at the output of the receiver PLL) using the model suggested in Conker *et al.* (2003). For the L1-C/A PLL, the model is limited to S_4(L1) < 0.707 and for the semicodeless PLL, the model is limited to S_4< 0.687. Above these S_4 limits, the receiver is considered to have lost lock.

Data from station Manaus (**MANA**, 3.1° S, 60° W, dip latitude=6.4° N), a location close to the trough of EA in Latin America, were analysed in the five hour long simulations starting at 18:00 local time (LT) and ending at 23:00 LT on 20 October 2000. In these simulations, different levels of scintillation, as represented by the CSM scintillation parameters S_4 and τ_0 (τ_0 is the channel decorrelation time of the autocorrelation function) were applied. Further, in order to emulate a worst case environment, simulations have been carried out where all the line-of-sight signal links are modified for the scintillation effects. Figure 1 shows the scintillation indexes, S_4 and ó$_{ö}$ and the L1 lock time recorded by the receiver for GPS PRN 1 during the simulations. From figure 1, it is clear that there is a gradual increase in S_4 (middle panel) from 0.3 to 1 and then a decrease. However, once moderate level of scintillations (S_4>0.5) are reached, a loss of lock occurs on L1 (bottom panel of figure 1). Re-acquisition of the signal is difficult throughout the moderate-strong scintillation levels and it is only possible when the scintillation level gets weaker (S_4< 0.6) after which the lock time on L1 starts to increase. Also, during the time when loss of lock occurs, the s_f (top panel of figure 1) is significantly outside the reasonable threshold of 1-2 rad and is shown as gaps in the figure.

Figure 2 shows the tracking jitter variance for the GPS L1C/A estimated using Conker *et al.* (2003) for a third order PLL with 15 Hz bandwidth. The gaps in the figure correspond to the time when a loss of lock occurred on L1 and hence the estimation of the tracking jitter variance was not possible. It is observed from figure 2 that there is an increase in the tracking jitter variance with an increase in scintillation levels. Further analysis is underway to estimate the exact functional relationship between the jitter variance and scintillation.

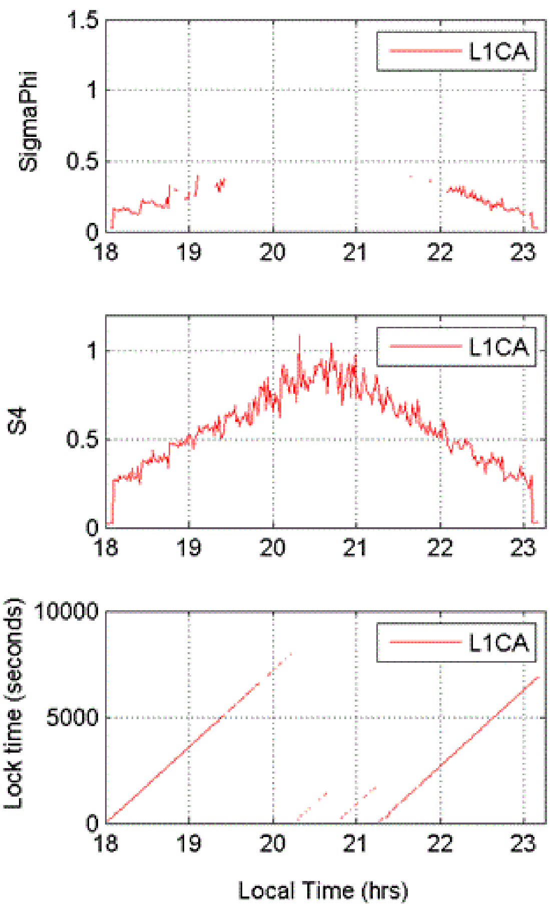

Fig. 1: The scintillation indices, S_4 and ó$_{ö}$, and the lock time on L1 as recorded by the receiver for GPS PRN 1.

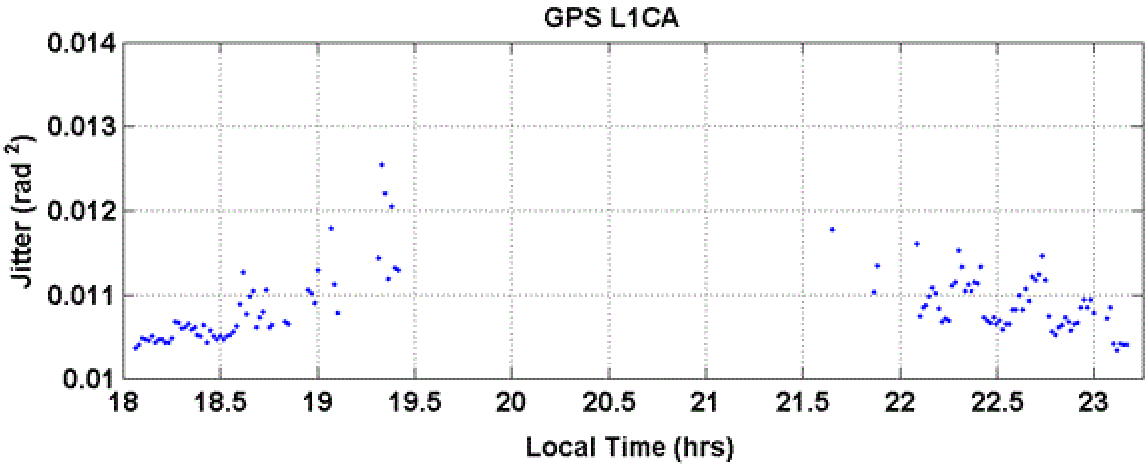

Fig. 2 - Tracking jitter variance for GPS L1-C/A estimated using *Conker et al.* (2003).

3. MEASUREMENTS CAMPAIGN IN BRAZIL

The CIGALA measurement activity is concentrated during the early phase up towards the peak of the next solar maximum. Under such conditions it is crucial to undertake a campaign of measurements on the ionospheric plasma over Latin America. In particular, the campaign will collect high sampling rate measurements to produce the phase and amplitude of the GNSS signals (GLONASS, GPS, GALILEO) received over the area of interest, covering as much as possible the equatorial region. Figure 3 shows the distribution of the CIGALA stations in Brazil. They are deployed at Manaus AM, Palmas TO, Presidente Prudente and São José dos Campos SP, Macaé RJ and Porto Alegre RS. Two stations will be deployed at Presidente Prudente and São José dos Campos.

The sites selection was based on the proximity to the crest of the ionospheric EA, roughly corresponding to the area between 20°S and 40°S geographical latitude. Each measurement station is composed of a multi-frequency GNSS receiver specifically adapted for scintillation analysis (at least 50Hz measurement logging rate, very high clock stability, high tracking robustness). In order to decide among the several possible sites, the selection was based on several scientific and operational criteria, addressed to suit the demands of the project in an optimal way. The locations selected are listed in Table 1. The measurement activity will also include episodic campaigns to address other GNSS applications in Brazil for geodesy, surveying, land management and precision farming. Therefore, it will involve positioning in the context of RTK (Real Time Kinematics) and DGPS (Differential GPS) networks, requiring a set of GNSS base stations.

The CIGALA Scintillation Monitoring Stations are constituted by the new Septentrio PolaRxS receivers, which have been specifically designed for ionospheric monitoring and space weather application. They incorporate an ultra low noise OCXO frequency reference and a state-of-the-art GNSS engine to support multi-frequency ionospheric monitoring using all satellites in view. In the past, ionospheric monitoring using GNSS signals has essentially been limited to the L1CA signal from the GPS satellites, simply because that was the only unclassified signal available to the civilian community. In the recent years, the GNSS constellations have undergone significant changes. GPS satellites transmit civil signals on L2 and L5, GLONASS satellites transmit civil signals on L1 and L2, and GIOVE satellites add civil signals in the L1, E5a

Fig. 3 - Distribution of CIGALA stations in Brazil

and E5b bands. A major difference between CIGALA and past monitoring campaigns is that all these new signals will be monitored. The purpose is to maximize the number of scintillation events that will be collected. On the one hand, monitoring all satellites in view increases the probability to observe an event, and on the other hand, the signal structure used by the new GNSS signals decreases the probability of losing lock during scintillation events. Especially the presence of a "pilot" tone in the new GNSS modulations is expected to bring a significant advantage.

In addition to S_4, $ó_{ö}$ and TEC (Total Electron Content) parameters, the PolaRxS also logs the spectral slope and strength, and the scintillation indexes on all frequency bands. The indices are stored in hourly files in the form of comma-delimited ASCII records. The raw binary data (the high-rate carrier phase and signal intensity) are archived as well to allow detailed post-processing analysis of scintillation events.

The data collected during CIGALA project will be complemented by historical past measurements in order to provide meaningful statistics of the amplitude and phase equatorial scintillations. A preliminary analysis on available historical data has been recently applied by adapting the so-called Ground Based Scintillation Climatology (GBSC) to the region of interest. GBSC relies on the scintillation indices, $ó_{ö}$ and S_4 respectively, and it was originally developed for high latitude receivers, to investigate the physical process involved in the ionospheric scintillation, to contribute with the mitigation algorithms and as a first step towards the forecasting of Space Weather related events with GNSS receivers [*Spogli et al.*, 2009; *Spogli et al.*, 2010]. Historical GPS data here used come from a SCINTMON receiver located in Presidente Prudente (PP - Brazil, 22.12ºS, 51.41ºW), managed by the Instituto Nacional de Pesquisas Espaciais (INPE), which has the ownership of the data. Data coming from such location are very interesting: Presidente Prudente is one of the selected sites for the deployment of the CIGALA multi-constellation receiver, due to his proximity to the Southern crest of the EA. The SCINTMON receiver was originally developed by the Cornell University since 1995. The S_4 data analyzed refers to year 2009, from Jan 1st to Oct 31st, with a significant data gap between Jun 29th and Jul 25th, under low solar activity conditions. The receiver was set to acquire data only during the time range 2100 UT to 0900 UT, corresponding to 1800 LT to 0600 LT. This has been chosen to focus the pre-reversal enhancement of scintillation activity due to the spread of the F layer in the equatorial ionosphere just after the sunset. Figure 4 shows the map of the percentage of occurrence of S_4 for the investigated period in a Geographic Latitude vs. Longitude, 1°x1° grid, by selecting S_4>0.25 (moderate/strong scintillation characterization). Three scintillating areas are highlighted: the first one, more evidenced, is located in the range (-20°;-15°) latitude and (-57°;-53°) longitude corresponding to the southern crest of the EA, where post-sunset scintillation is more likely to occur. The other two structures are located around 27°S-46°W and 22°S-52°W. They are probably signatures of the South Atlantic Magnetic Anomaly (ABDU *et al.*, 2005), still under investigation.

All data collected in the CIGALA campaign will be made available for the data analysis as input for the development of new algorithms and models to firstly reproduce and secondly mitigate the ionospheric scintillation effects. This data collection will also constitute a project legacy for the international scientific community and for the GNSS receiver designers and signals users. A data repository has been designed to fulfill the optimum usage of the data collected. The infrastructure architecture is schematized in Figure 5. The data tree of the FTP (file transfer protocol), is structured in levels (LVL). In particular the LVL-3 will contain three subfolders:

· Parameters directory, containing data files with one minute sampling rate. The files store observational information, such as: $S_{4,}$ $ó_{ö}$, STEC (Slant Total Electron Content), SNR (Signal to Noise Ratio), PRN, elevation, azimuth, TOW (Time Of the Week), code and phase range.

· Raw data directory, containing the raw data files at 50 Hz sampling rate.

· Rinex format data at 1 second interval.

The test phase starts with the validation through available historical data collected over the region, in particular over Brazil, under similar helio-geophysical conditions, i.e. during past solar maxima. During that phase the analysis is addressed also to develop tools to ingest measurements in different formats and/or different sampling rates, and to evaluate and attempt to correct possible multipath effects on the

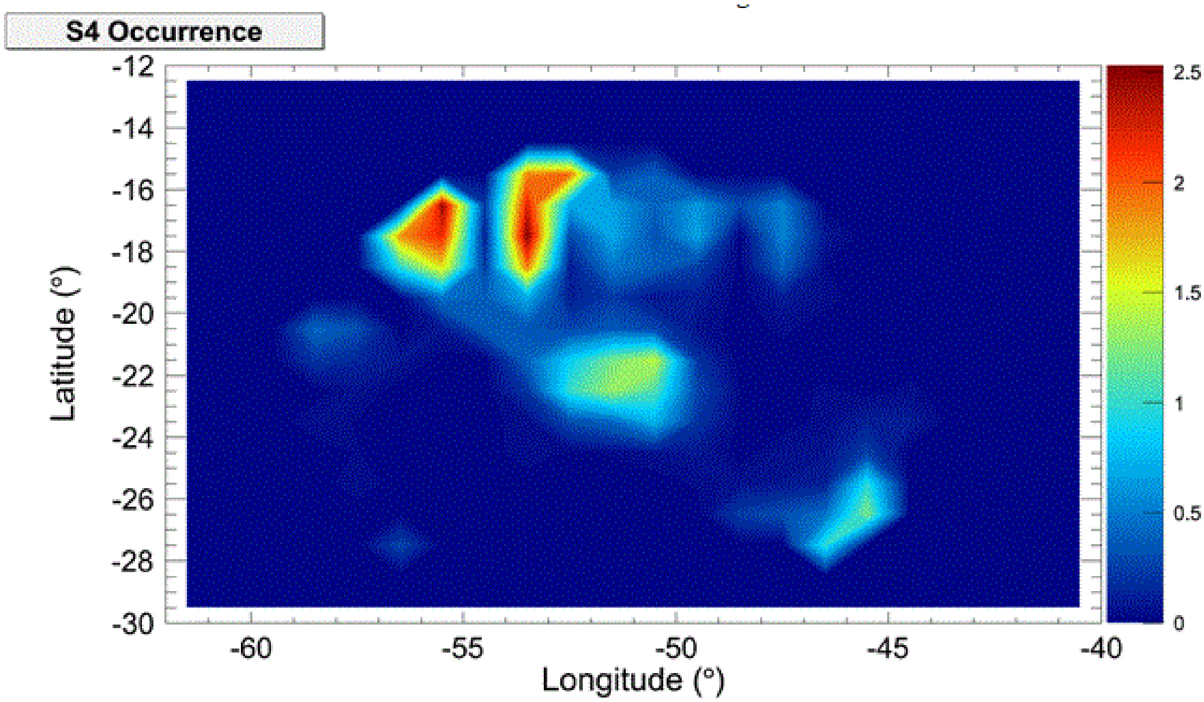

Fig. 4 - Map of the percentage of occurrence of S_4>0.25 in a longitude vs. latitude grid.

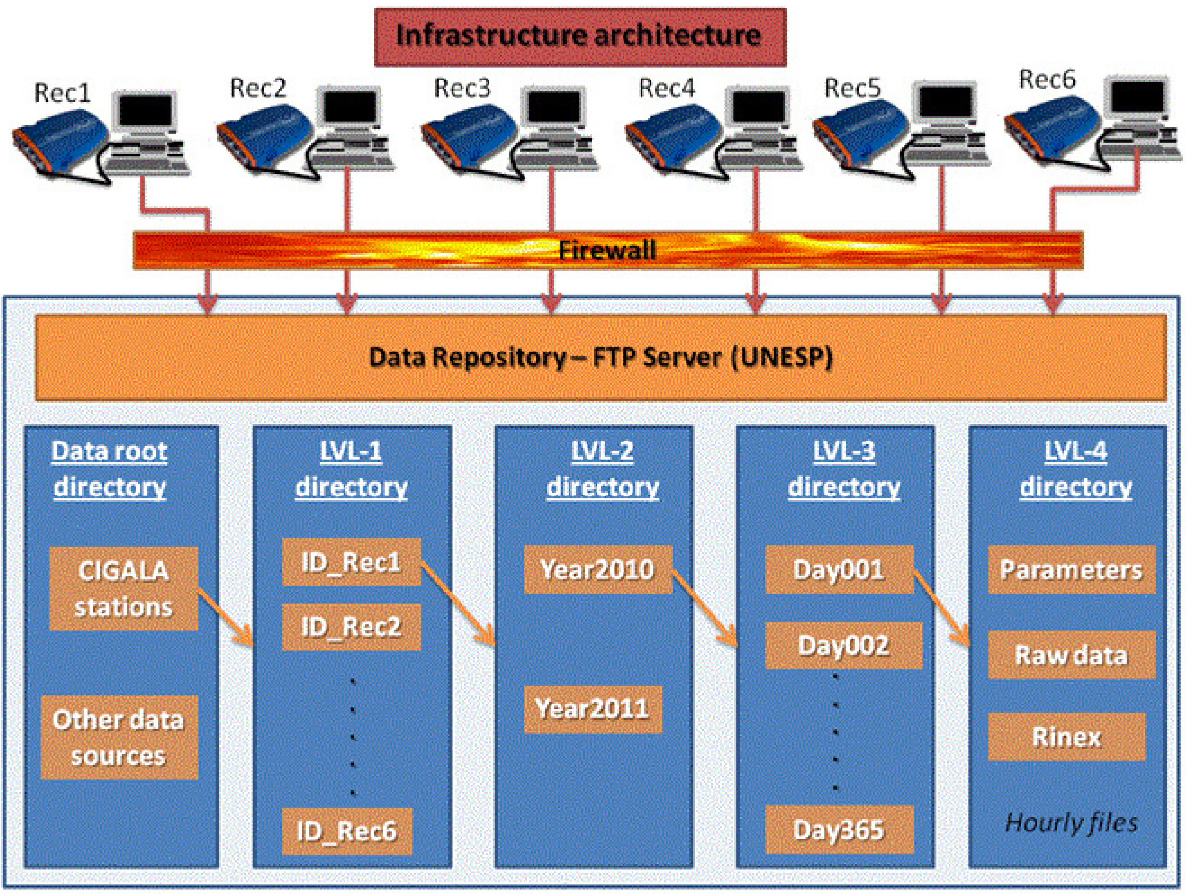

Fig. 5 - A sketch of the Infrastructure architecture designed for the data repository of CIGALA project.

measurements. In a second phase the work will be addressed to the analysis of the raw data collected during the campaign to derive the necessary parameters, including scintillation spectral parameters and indices. Both phases will be instrumental to provide the necessary information on the climatology of the equatorial perturbations on GNSS signals. Both phases will provide the necessary inputs to develop the countermeasure tools.

In order to provide a first insight about the identification of scintillation occurrence in the context of the CIGALA project, Figure 6 shows S_4 and ó$_{ö}$ for Presidente Prudente station, just few days after starting collecting data at February 2011. Although low level of scintillation is expected during this time, one can observe that moderate level of scintillation could be detected. S4 and ó$_{ö}$ larger than 0.25 and 0.30 respectively are expected to be due to the occurrence of scintillation. Once more data become available, several other spots of scintillation will probably be detected and the mitigation approach will be applied and assessed.

4. CONCLUDING REMARKS

Ionospheric scintillation events are most severe at high and equatorial latitudes, in particular at solar maximum conditions, and the whole of Latin America, Brazil in particular, is severely affected by scintillation occurrence. CIGALA will study the phenomenon up to and during the critical period 2010-2012, which coincides with the ongoing deployment of GALILEO, with the main goal to reduce the 'ionospheric threats' posed by scintillations to many and varied GNSS based systems. In particular the project aims to address the high levels of accuracy, integrity and availability demand looking at the considerable market opportunity it represents.

The disruption and consequential cost to society of a severe ionospheric event leading to scintillation occurrence has been assessed from several reports arising as the one about the 'Halloween' storms of Oct/Nov 2003, when one of the most intense solar flares on record took place (WEAVER *et al.*, 2004): high resolution land surveying was delayed by several companies, airborne and marine survey operations were postponed, drilling operations were cancelled and deep water drill ships resorted to backup systems.

The CIGALA project aims at tackling a fundamental threat pending on the accuracy, integrity and availability of GNSS applications in general, and GALILEO and EGNOS related services in particular. This is crucial in Brazil, where ionospheric scintillation has a significant impact on high accuracy positioning GNSS applications. In this context, the GNSS-based applications benefited by the CIGALA outcome are easily identified and given in detail by *Bougard et al.* (2010):

- Off shore positioning / tracking;
- Precision Agriculture;
- Geodesy and mapping.

The CIGALA project exploits an excellent opportunity to make a positive impact in this area, engaging and attracting the interest of a large community around potential solutions to an otherwise unresolved problem.

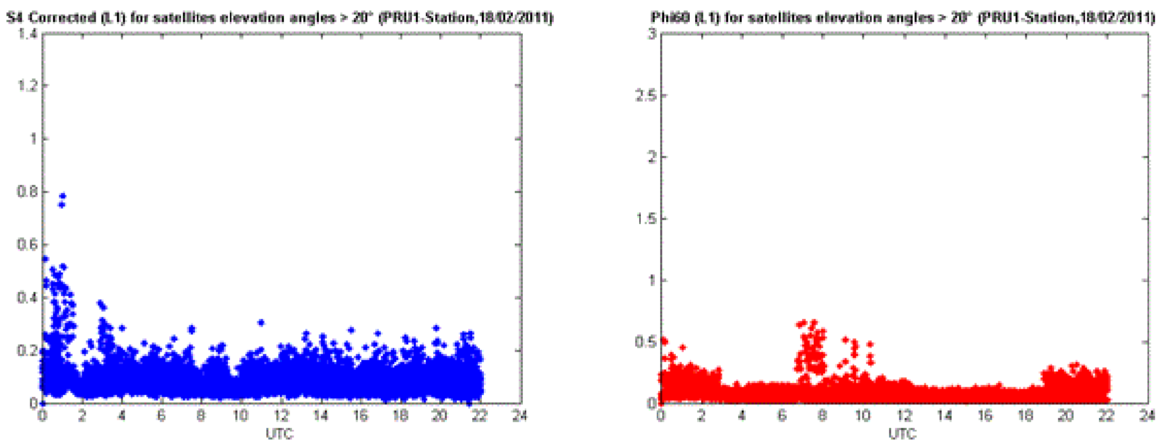

Fig. 6 - S4 and ó$_{ö}$ for station Presidente Prudente SP on Feb 2011.

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