SIGNAL SCINTILLATIONS IN THE LOW LATITUDES AND HIGH LATITUDES REGIONS

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ABSTRACT

The **PR**ediction of **I**onospheric **S**cintillation (**PRIS**) project that we present in this paper includes a measurement campaign of signal scintillations of satellite to earth links due to the propagation through ionosphere and the improvement and the development of models for estimating and forecasting the scintillations activity.

1. INTRODUCTION

This paper deals with the problem of signal scintillations due to propagation through ionosphere in the low latitudes and high latitudes regions. A measurement campaign is on going in several locations in these regions in South America, Africa and Asia for the low latitudes and in Northern Europe for the high latitudes in the frame of an ESA / ESTEC contract.

This measurement campaign started for some of the receivers in 2005. All the receivers will be deployed for the summer 2006. The experiment will last one and a half year, unfortunately in a period of low solar activity. However we expect to collect enough data to derive the scintillations parameters. In addition we have some data corresponding to high solar activity at low latitudes which will be used for comparisons.

Models including for scintillations forecasting will be developed concurrently.

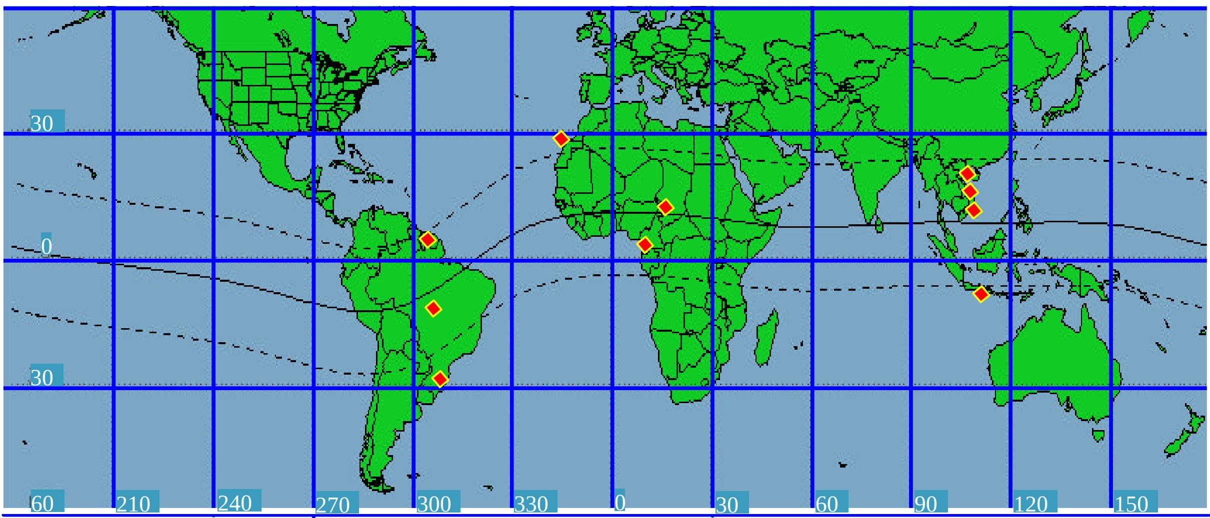

Figure 1 : Receivers locations in the low latitudes regions

NB : The station located in Kiruna (Sweden) doesn't appear on this map

2. DEPLOYMENT OF SCINTILLATION RECEIVERS

One scintillation receiver is installed in the high latitudes and eight are installed in the low latitudes region. Four of them are practically at the same longitude: Three in Vietnam and one in Indonesia allowing calculating correlation distances in the medium. Two receivers are installed in central Africa (Douala and N'Djamena), practically at the same longitude and the last one is in Cayenne (French Guyana). One receiver is finally installed in the Canary Islands i.e. at the upper limit of the region susceptible to be affected by scintillations. In addition some Brazilian data has kindly been made available to us by INPE, Brazil.

For some of the receivers, we have an internet connection, in particular in Cayenne, the Canary Islands and Kiruna. Algorithms have been developed in order to have all the data collection recorded automatically. Alert messages are forwarded to a control / command station on occasion for the receivers using an internet connection. For the other receivers we store the data in situ. These data are then sent to Europe on a monthly basis.

The antennas have been installed in a clear environment. However a dedicated processing has been implemented in order to remove the multipaths effects prior to the analysis of the signals received.

3. OPERATION OF THE SCINTILLATION RECEIVERS AND THE DEDICATED MEASUREMENT EQUIPMENT

To collect and archive the data coming from the different receivers situated at various locations around the world, a measurement network has been established. Since the receivers are operated in either off-line mode or on-line mode, we have distinguished between receivers which are foreseen to be part of a dedicated network and receivers which operate under stand alone conditions.

The EVNet consists in a set of sensor stations, a Central Processing and Control Facility, external processing centres, and customer sites. Intentionally, the sensor stations are located at various world-wide locations. The archived GNSS data and environmental data (if any) are uploaded to the central ftp server on a daily basis.

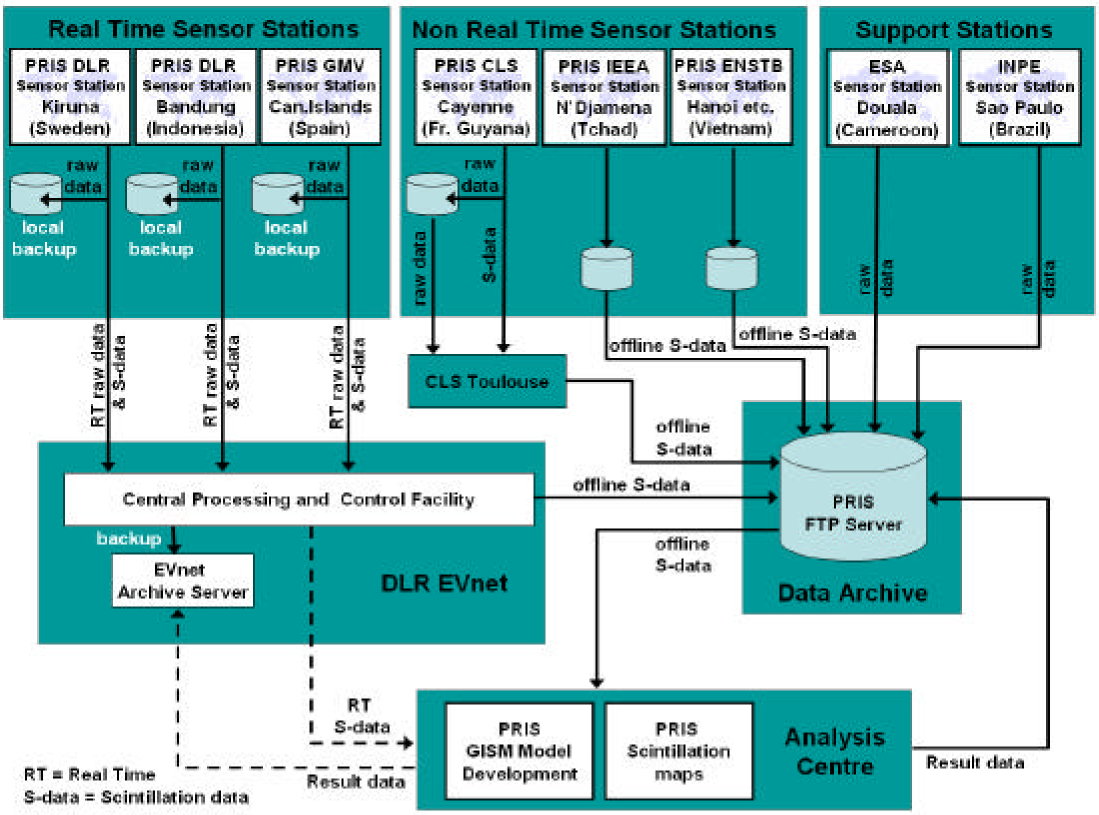

Figure 2 : Functionnal architecture of the PRIS data collection and processing center

Each sensor station is equipped with GNSS receivers and environmental sensors like meteorological sensors, for instance. Meteorological sensors might useful for discrimination of amplitude effects caused by troposphere from those caused by ionospheric scintillations. These sensors are connected to a PC which runs the EVNet sensor station operating software to control the sensors and to receive, pre-process, and distribute the measurement data. Sensors can be connected via serial lines, and/or Ethernet (TCP/IP).

CPCF

The Central Processing and Control Facility (CPCF) acts as the heart of the EVNet. It receives all real-time data streams from the sensor stations and distributes them to internal and external clients (customers). The sensor stations can be operated via remote control from the CPCF, completely. The CPCF contains a user database which is the central authority for any kind of access to the EVNet. Access to real-time data streams can be controlled on a per-sensor level.

To automatically store all real-time data streams and higher level products, the CPCF possesses a data archive component. This archive comes with an API which provides a mean to take advantage of EVNet system libraries to implement numerical processors according to the EVNet database specifications. Additionally, the data archive provides a web-front-end which allows to download archived data via a standard web browser by browsing the archive contents on the basis of certain meta information associated with the actual data, e.g. the type of a sensor and/or the time period the measurement was made. The matching data is displayed on the web page and can then be downloaded selectively. All communication between distributed components of the EVNet, namely between sensor stations and the CPCF, and between the CPCF and external customers is transmitted via the Internet.

4. PROCESSING OF DATA

The following raw GPS data at a frequency of 50 Hz are stored on a local PC:

- L1 and L2 carrier phase
- L1 and L2 code measurements
- L1 and L2 C/No
- L1 and L2 intensity

These raw data are stored in hourly files for a period of 1 week, and after that the oldest files are replaced by the new files following a circular buffer.

This stored high-rate raw data are not transmitted to the Central Processing Facility, but they are available during 1 week and retrieved from the Central Processing Facility only for specific periods (e.g. once strong scintillations are detected, when a specific feature needs to be deeper analysed, etc) .

The high-rate raw data are converted into 1s-hourly or 30s-daily observation and navigation RINEX files. In order to reduce the needed storage room, the RINEX file are compressed using Hatanaka method. Those files are transmitted daily to the Central Processing Facility.

A software has been developed for the computation of the scintillation parameters. It consists in a script/commands file that executes other command files or programs (written in C or Fortran). This script is prepared to restart automatically in case of loss and subsequent restoration of electrical power.

the pre-process includes the following tasks:

- **Measurements validation**. The purpose of the measurements validation sub-module is to detect abnormal tracking measurements analysing their expected range and temporal evolution.
- **Cycle-slip detection and repair**. The purpose of the cycle slip detection and repair sub-module is to detect the cycle slips in the carrier phase measurements and to repair them when possible. The number of detected cycle-slips per epoch and satellite will be account for, as well as the number of unrepaired cycle-slips.
- **Ionospheric combination**. The purpose of the ionospheric combination sub-module is to construct the ionospheric combination (L2-L1) or geometry free linear combination.

The pre-processed data is used to compute the following “scintillation parameters”:

- **S4 index**. This index is traditionally used to monitor the amplitude scintillation.
- **Standard deviation s_{f}.** This parameter is used to monitor the phase scintillation.

These two parameters are calculated on 1 minute-long samples.

Additionally the following scintillations indicators are computed:

From the raw data files:

- Fades duration vs fades levels. The correlation of the fade scintillations to the frequency and the correlation time depending on the level of fluctuations are calculated.
- Probability of fades vs S4
- Spectrum parameters (intensity & phase) : 3 parameters are derived : the low frequency value, the cutoff frequency and the slope.

From the processed data files:

- L2 signal losses. Most of the GPS receivers experience problems in keeping the L2 signal during ionospheric scintillations.
- The correlation between s4 and sigma phi and the correlation versus frequency.
- The dependency on the season and on the local time and on the geophysical parameters : solar spot number & magnetic activity (specially at high matitudes).
- Correlation distances and geographical extent. The extent of the scintillation region will be established. The installation of receivers at different latitudes but at the same longitude will help for this calculation.
- The dependency on latitude
- The number of cycle slips. Another effect of ionospheric scintillations in the increase in the number of detected cycle slips.
- TEC rate of change. Ionospheric disturbances, scintillations in particular, can be detected by monitoring the TEC temporal variations. That TEC variations can be measured with temporal differences of the L2-L1 phase data combination.
- C/No ratio. The signal to noise ratio provide information on the amplitude of the scintillations.
- C/No before Loss of Lock. The probability of loss of lock on one or more satellites is also calculated. It depends on S4 and on the C/N0 ratio which is related to the elevation angle

Other ancillary data provided are:

- Time
- GPS satellite PRN
- Elevation
- Azimuth
- Latitude of the sub-ionospheric pierce point
- Longitude of the sub-ionospheric pierce point

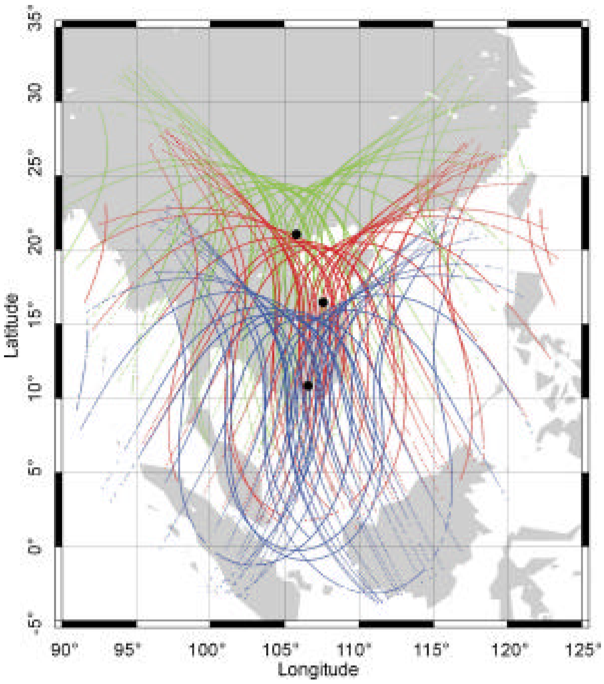

Figure 3 : receivers deployment in Vietnam. The scintillation region extent will be calculated using simultaneous observations.

5. MODELLING AND FORECASTING IONOSPHERIC SCINTILLATIONS

The GISM model will benefit from the data analysis performed in the frame of this activity. The medium parameters used in the model will be upgraded.

The forecasting procedure takes into account the actual ionospheric conditions and predicted geophysical conditions such as solar flux and geomagnetic activity. Thus, the existing scintillation model GISM has to be checked with respect to the main driving parameters. Besides the geophysical conditions (solar activity level, latitude, local time etc.) the internal state of the ionosphere plays a significant role.

The complex nature, structure and dynamics of the ionosphere require also complex information on the ionization state, particularly under perturbed conditions. This may be provided by calibrated ground TEC observations at selected sites or regions and/or by space based TEC and electron density measurements.

The development of the empirical model requires studying the relationships between large scale ionospheric conditions and scintillation activity. Statistical studies will provide information on the possible correlation. Significant correlations between large scale phenomena (e.g. strong horizontal gradients) and scintillation activity should be helpful for the prediction of scintillation effects.

The achievable accuracy and the reliability of the scintillation forecast model may still be constrained by the insufficient knowledge and limited availability of observations. However, the forecast model that shall be developed is expected to optimize the use of all available data characterizing the ionosphere and thus, to provide forecast information for the GNSS user that have not been available so far. In addition, the experience gained during this project, will be helpful to improve the forecast technique.

6. DATA DRIVEN SCINTILLATION MAPS

In the same manner as TEC maps are required for correcting propagation errors in Wide Area Augmentation Systems (WAAS, e.g. within EGNOS) users must be informed by delivering scintillation maps for estimating the perturbation degree of usable radio links to the GNSS satellites. Ionospheric irregularities and corresponding scintillations may strongly depend on the location. The generation of nowcast and forecast maps of radio scintillations for L frequency band is an important task within this project.

The main idea to generate the scintillation maps follows the reconstruction principle of TEC maps produced in DLR successfully since 1995 (Jakowski, 1998). Here the observed TEC data are assimilated into a regional TEC model in a way that the map provides measured values near measuring points and model values at regions far away from measurements. By applying this concept, the measured link related scintillation data will be assimilated into the scintillation model GISM during each epoch. The weighting of measurements can be defined by a single assimilation parameter.

7. CONCLUSION

The receivers deployment which has been realized allows obtaining a global earth coverage and we expect that the results that will obtained will be much helpful. For each part of the world we have chosen locations such that several receivers can be used simultaneously in order to retrieve the scintillations characteristics allowing in particular estimating the extent and the correlation properties of the medium.

Not mentioned in the document but also of significant interest is the fact that signal from GEO satellites can be received with several receivers allowing performing complementary analysis. In theses cases, the links are only affected by the motion of the ionosphere.

A new feature and service that we intend to deliver is the forecasting of scintillations. This will be implemented using an assimilation technique using both a model and the measurements data.

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