Spatio-Temporal Analysis of Equatorial Ionospheric Scintillations in the Frame of Absolute GNSS Positioning Algorithms

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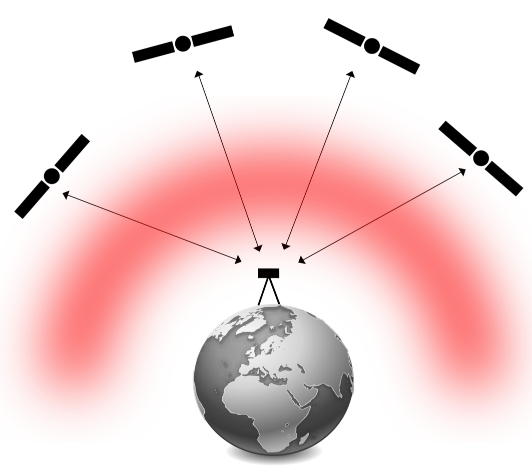
Introduction

Global Navigation Satellite Systems (**GNSS**) allow users to determine their positions anywhere on Earth at any time.

GNSS positioning techniques support many high-precision positioning applications for civil, military, scientific and industrial purposes.

Recent GNSS developements and modernisation offer new powerful possiblities in **Earth Science**.



One of the most important **sources of errors** highly limiting the **accuracy** and **reliability** of high-precision GNSS positioning techniques is the **Ionosphere**.

The **Ionosphere** is a region of the upper atmosphere ionized **by solar radiations**. Among other effects, the Ionosphere is responsible for the **diffraction** of GNSS signals producing **« Ionospheric Scintillations »** and involving **major errors** in positioning algorithms.

Objectives

The global objective of this piece of research is to develop new **strategies** based on the combined use of **Multi-GNSS** in order to improve the **performances** of GNSS positioning during **Ionospheric Scintillations**.

The **Stochastic Model** definition in the frame of absolute positioning applications is frequently reduced to the computation of diagonal (**variances**) elements assuming that non-diagonal elements (**covariances**) are negligible. This assumption could be challenged during Ionospheric Scintillations and the design of a more complete and **advanced stochastic model** could improve positioning performances during such circumstances.

$$\Sigma = \begin{pmatrix} 1 & 0 & .. & 0 \\ 0 & 1 & .. & 0 \\ .. & .. & ... & ... \\ 0 & 0 & ... & 1 \end{pmatrix} \Rightarrow \Sigma = \begin{pmatrix} \sigma_1^2 & 0 & .. & 0 \\ 0 & \sigma_2^2 & .. & 0 \\ .. & .. & ... & ... \\ 0 & 0 & ... & \sigma_n^2 \end{pmatrix} \Rightarrow \Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & .. & \sigma_{1n} \\ \sigma_{21} & \sigma_2^2 & .. & \sigma_{2n} \\ .. & .. & ... & ... \\ \sigma_{n1} & \sigma_{n2} & ... & \sigma_n^2 \end{pmatrix}$$

The combined use of **Multi-GNSS** (GPS, GLONASS, Galileo, etc.) constitutes a powerful tool for **Space Weather** monitoring. Based on a network of **ISMR** (Ionospheric Scintillation Monitoring Receivers) stations in **South America**, we are currently completing a **Spatio-Temporal Analysis** of **Ionospheric Scintillation** data with the aim of measuring and exploiting **spatial** and **temporal correlation** in GNSS positioning **algorithms**.

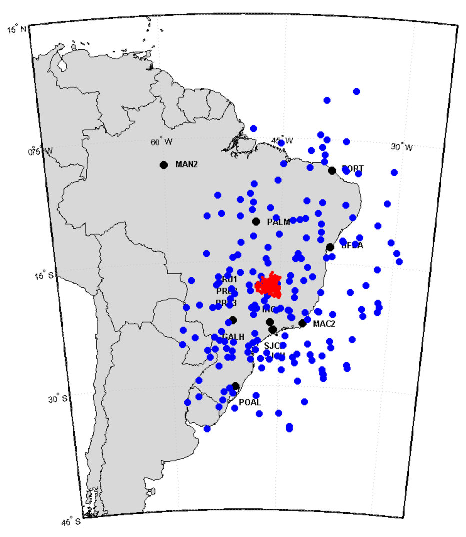
Conclusions

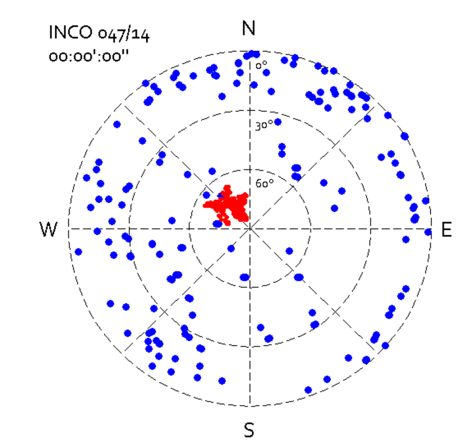
This first part of our **Spatio-Temporal Analysis** highlights the increase of the **positive Global Spatial Autocorrelation** in the ionospheric scintillation data (S4). This result supports the second part of the approach including the following persectives and leading to Spatio-Temporal information for the design of the stochastic model in the frame of absolute GNSS positioning:

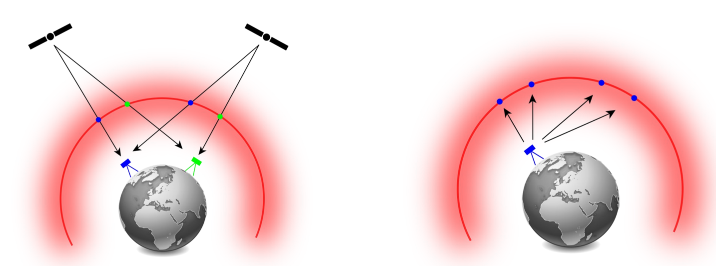
- **Correlograms** for the determination of the scale of spatial structures
- **Local Spatial Autocorrelation** tests — *« Hot Spot Analysis »*
- **Interpolation Model** (spatial covariance function)
- **Time Correlation** detection
- **Spatio-Temporal Information vs Stochastic Model**

ISMR Network

The use of multiple ISMR stations in a delimited area provides denser data set by combining the different Ionospheric Pierce Point from several stations





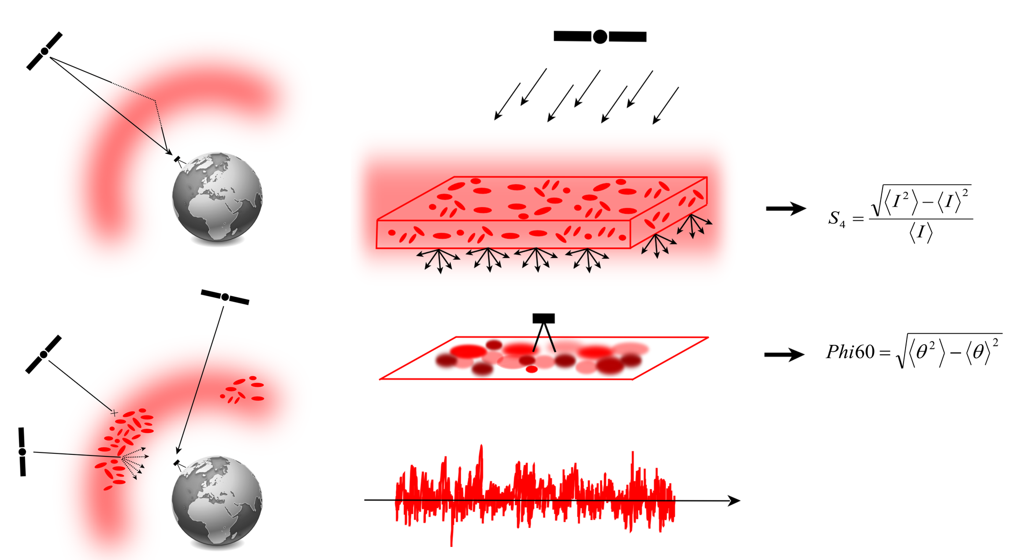


Ionosphere

The **Ionosphere** is a region of the upper atmosphere, from **about 85 to 600 km altitude**. The Ionosphere is a **plasma**, ionized by solar radiations, whose the **free electron density** disturbs the propagation of radio signals.

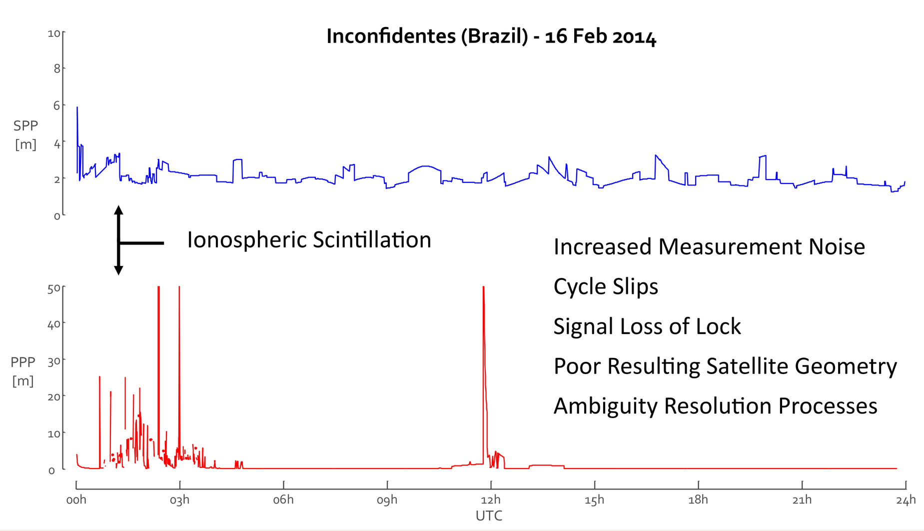
The ionospheric plasma density produces a **refraction** effect on GNSS signals which mainly results in a variation of the signal propagation speed and a **bias** in the measurements achieved by a GNSS receiver.

The ionospheric plasma **inhomogeneities** are responsible for the **diffraction** of the GNSS signals involving rapid fluctuations (**scintillations**) of the **phase** (**Phi60**) and amplitude (**S4**).



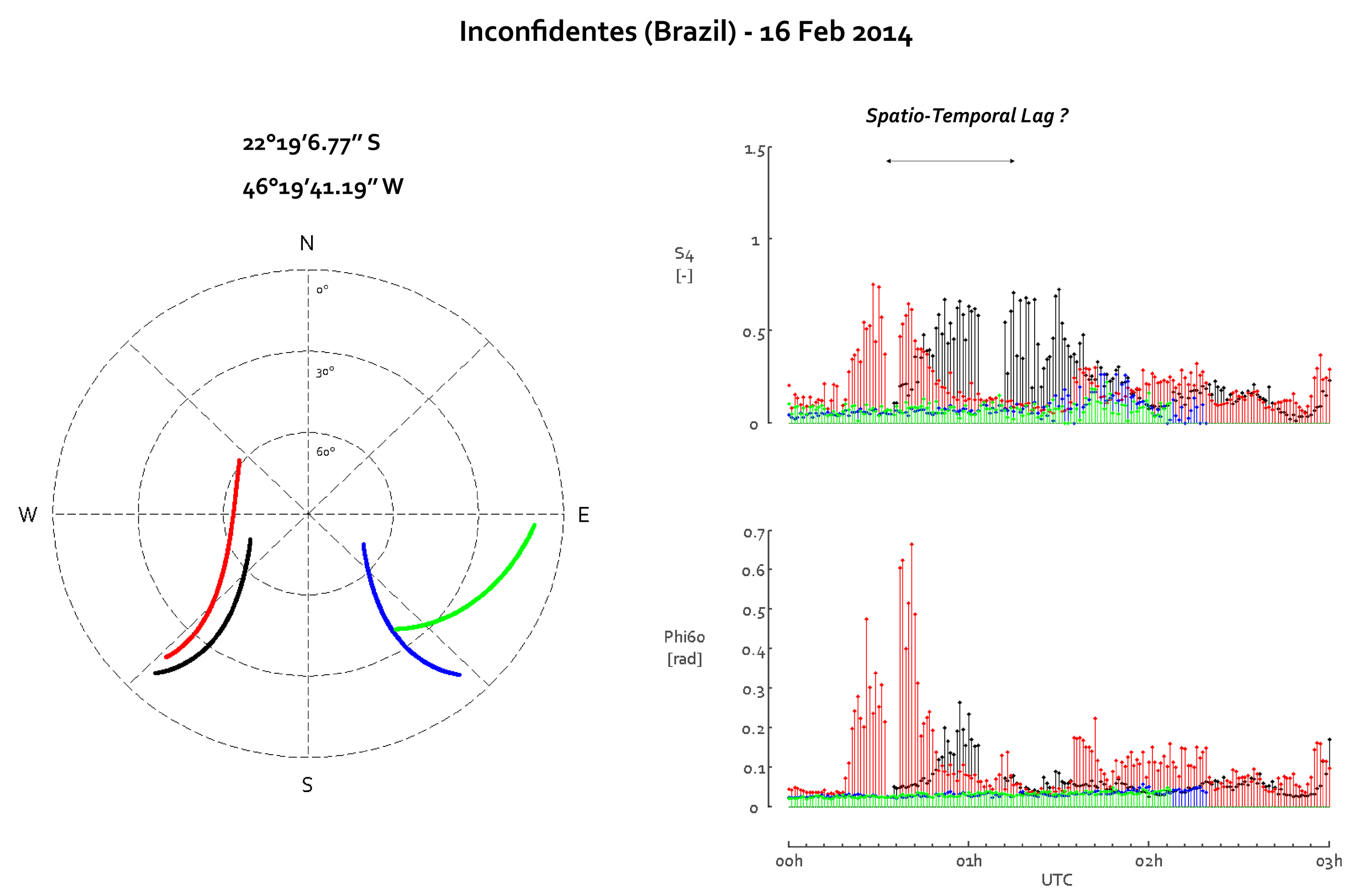
GNSS

Ionospheric Scintillations are highly limiting for absolute GNSS positioning (**SPP/PPP**) due to several **severe impacts**.



Spatio-Temporal Analysis

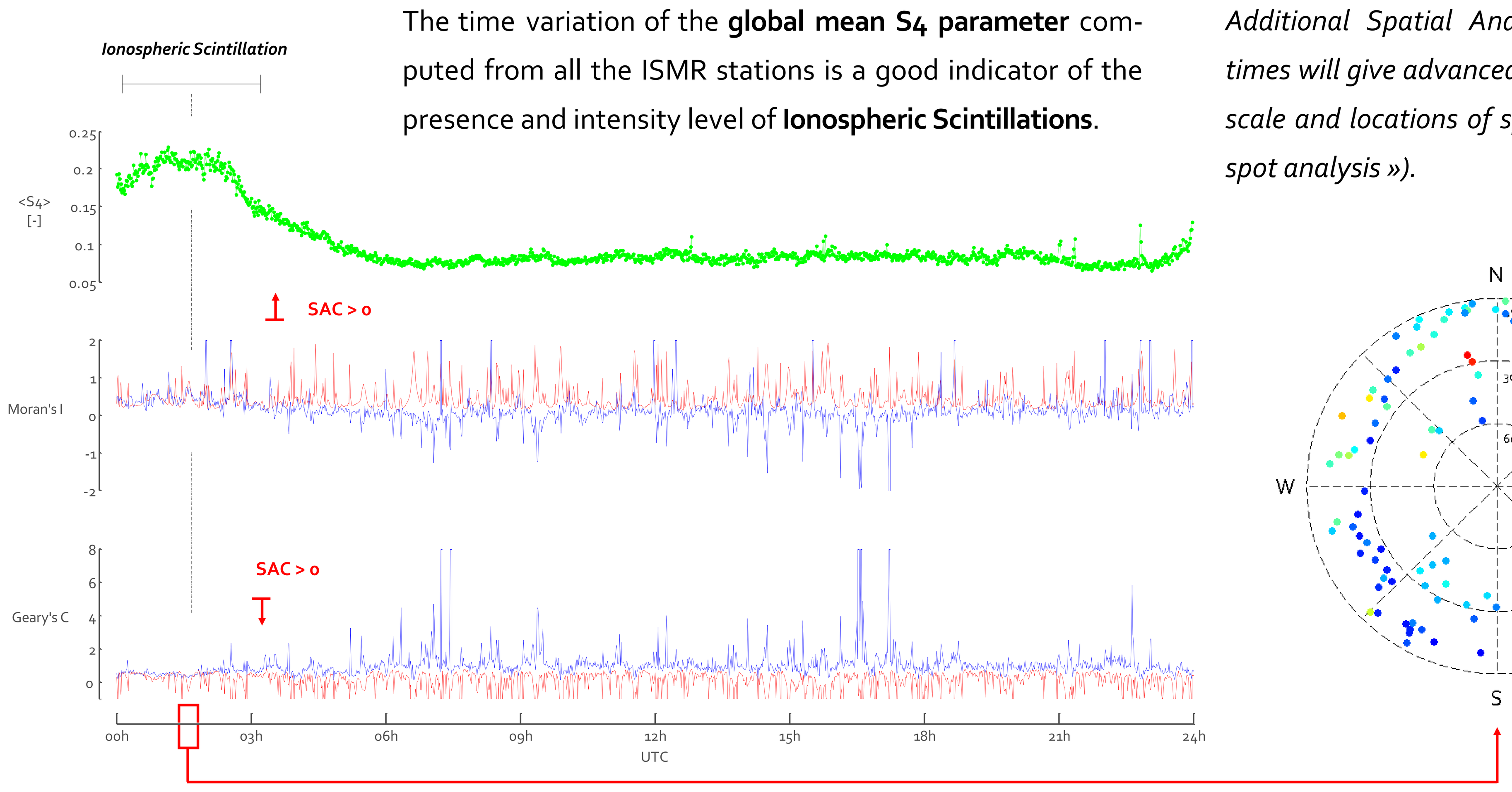
Spatial Autocorrelation



Based on the observation of **S4** and **Phi60** measurements (ISMR), the effects of **ionospheric scintillations** seem to be **colocated** in the same portion(s) of the sky at a given time with eventually a **time lag** due to relative displacements of the ionospheric irregularities and satellites.

Global Spatial Autocorrelation (GSAC) can be detected by satistical hypothesis tests of the well-known **Moran's I** and **Geary's C** indices. During the scintillation event (**00h-03h UTC**), both indices are reaching the limits of their respective confidence intervals indicating the presence of a **significative positive Global Spatial Autocorrelation** in the data during this period.

The time variation of the **global mean S4 parameter** computed from all the ISMR stations is a good indicator of the presence and intensity level of **Ionospheric Scintillations**.



Additional Spatial Analysis tests at specific times will give advanced information about the scale and locations of spatial structures (« hot spot analysis »).