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 developments and modernization offer new powerful possibilities 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 distortion of GNSS signals producing ionospheric scintillations and involving major errors in positioning algorithms.

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 distortion of the GNSS signals involving rapid fluctuations (scintillations) of the phase (ΔΦ) and amplitude (S4).

GNSS

Ionospheric scintillations are highly limiting for absolute GNSS positioning (SPPPPP) due to several severe impacts.

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.

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 perspectives and leading to Spatio-Temporal information for the design of the stochastic model in the frame of absolute GNSS positioning:

- Correlation maps 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

Based on the observation of S4 and phase measurements (ISMR), the effects of ionospheric scintillations seem to be collocated in the same part(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 statistical hypothesis tests of the well-known Moran’s I and Geary’s C indices. During the scintillation event (09h-21h UTC), both indices are reaching the limits of their respective confidence intervals indicating the presence of a significant positive Global Spatial Autocorrelation in the data during this period.

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

Spectral Analysis

Spatial Autocorrelation

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.

ISMR Network

The use of multiple ISMR stations in a dedicated area provides dense data set by combining the different ionospheric Pierce Point from several stations.

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