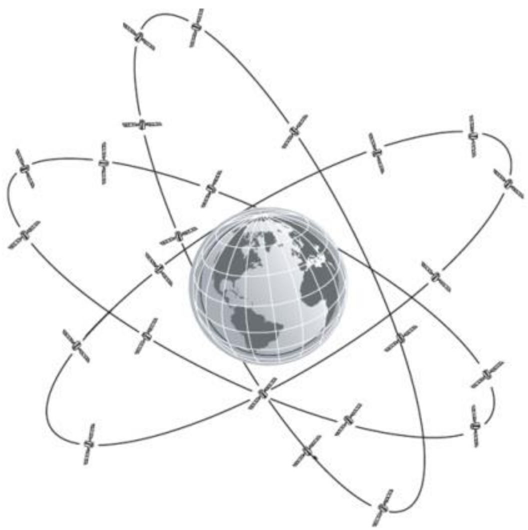
Spatio-Temporal Analysis of Equatorial Ionospheric Scintillations in the Frame of Absolute GNSS Positioning Algorithms



Matthieu Lonchay[1,2]

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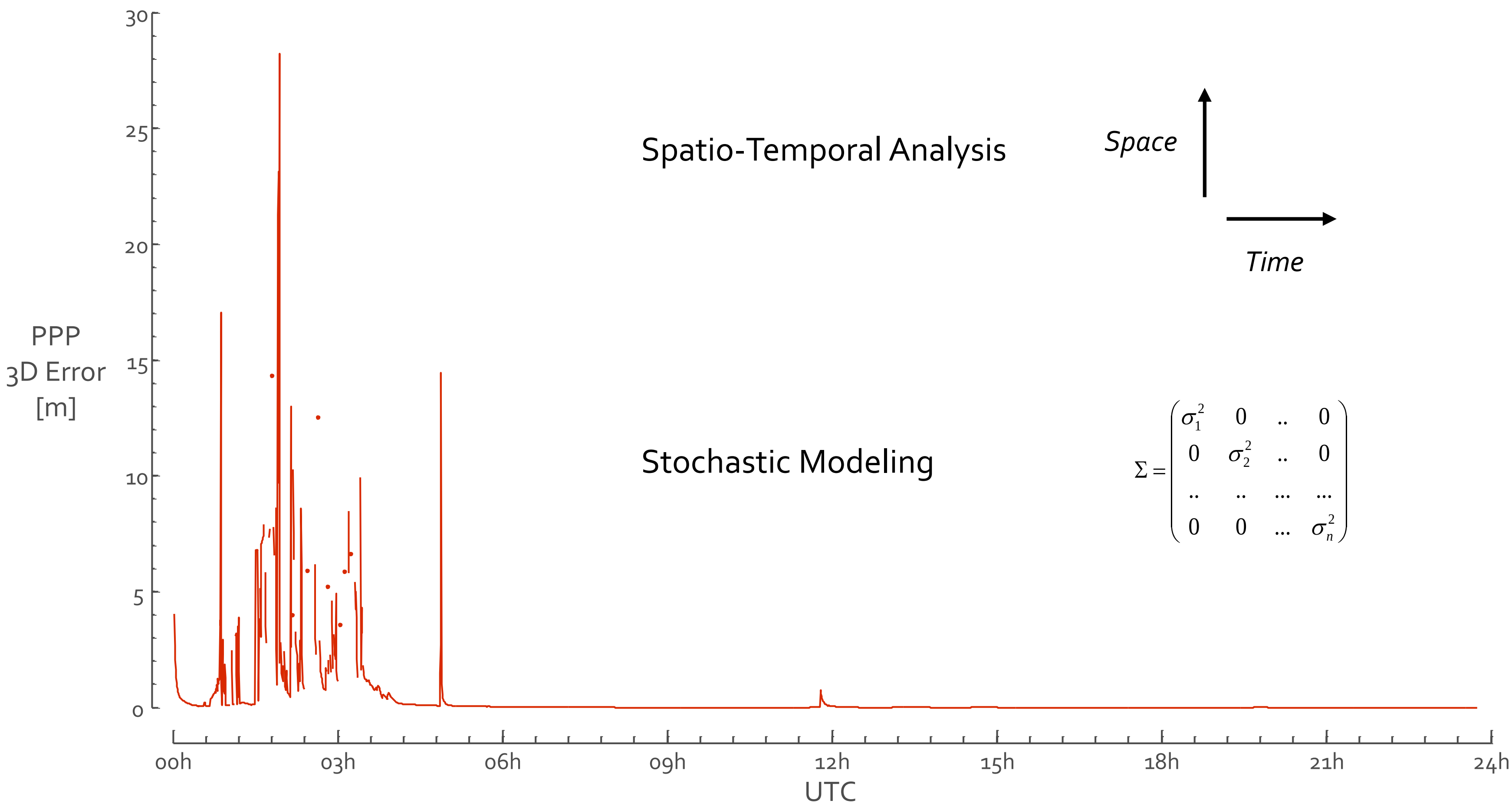
Spatio-Temporal characteristics of Ionospheric Scintillations may be exploited to build a more effective Stochastic Model



$$\Sigma = \begin{pmatrix} \sigma_1^2 & 0 & .. & 0 \\ 0 & \sigma_2^2 & .. & 0 \\ .. & .. & ... & ... \\ 0 & 0 & ... & \sigma_n^2 \end{pmatrix}$$

Introduction

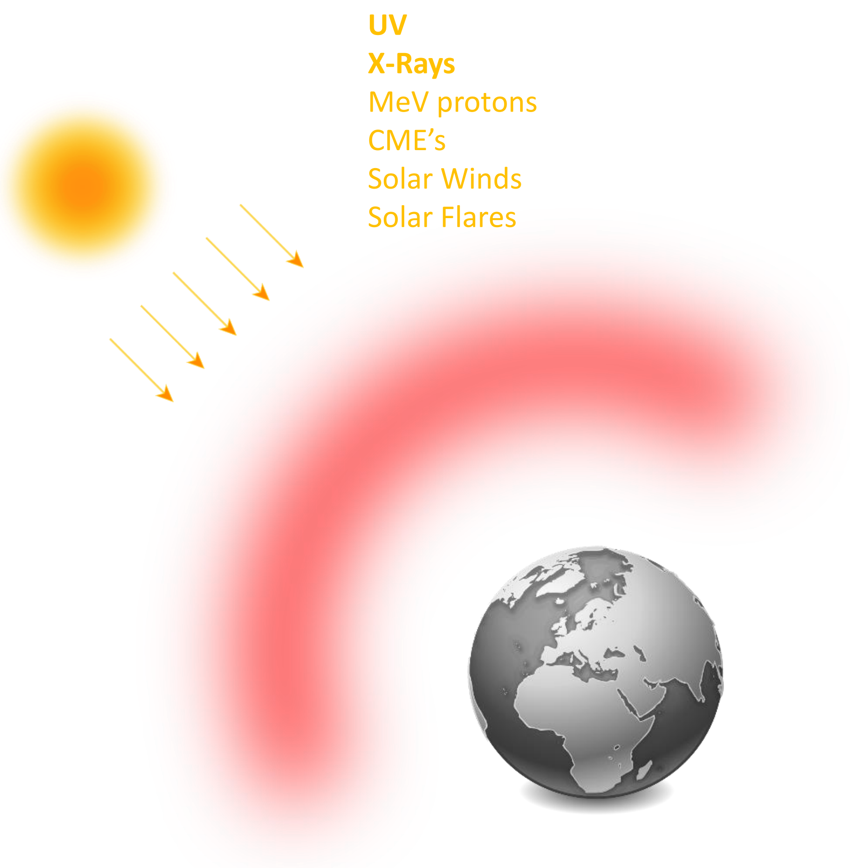
Ionosphere

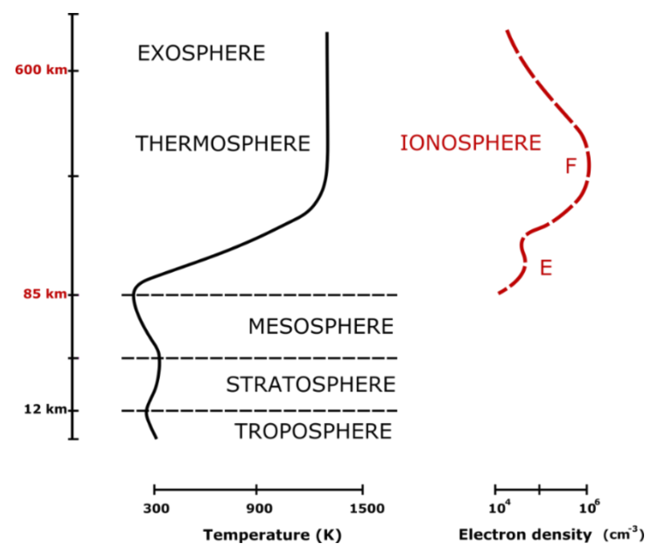
Positioning

Analysis

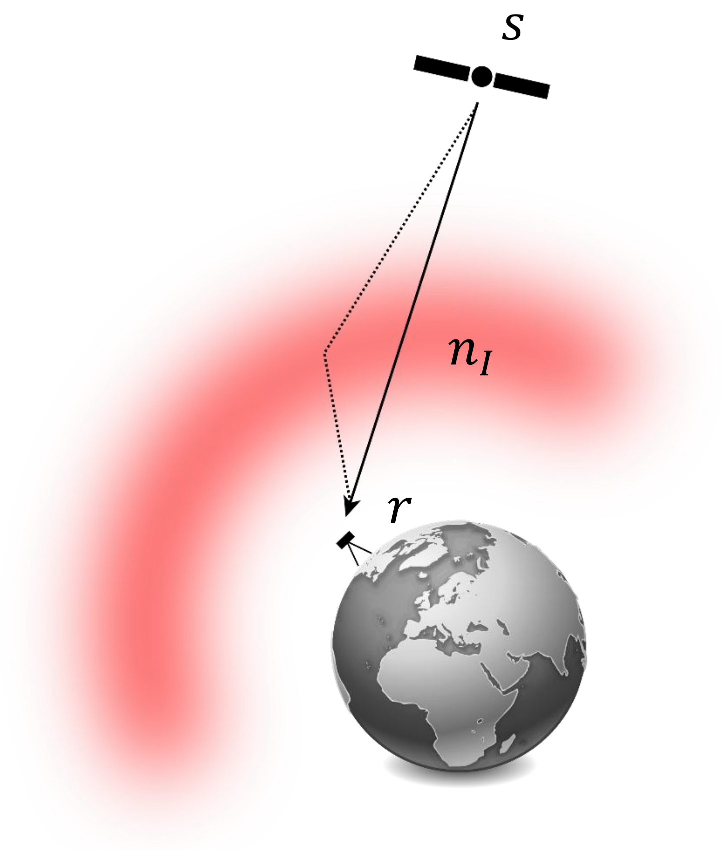
Conclusions

The Ionosphere is a Plasma ionised by Solar Radiations and characterised by an electron density highly variable in Space and Time





The electron density of the Ionosphere is responsible for Refraction effects of GNSS radio signals

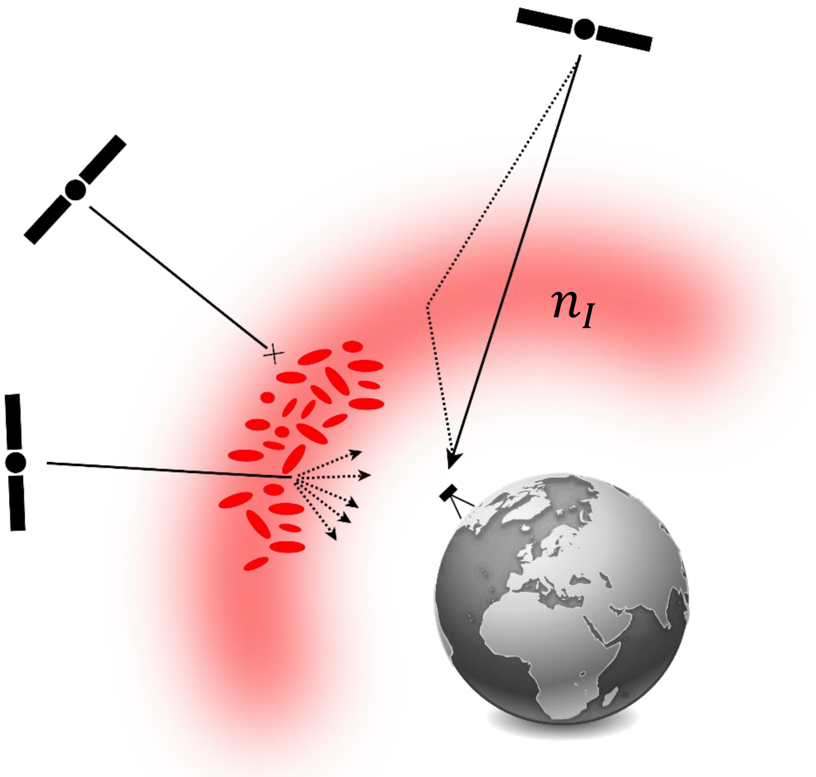


Ionospheric Delay

$$n_I = \frac{c}{v} \approx 1 \pm \frac{40.3}{f^2} N_e$$

$$I \approx \pm \frac{40.3}{f^2} \int_r^s N_e \, dl = \pm \frac{40.3}{f^2} sTEC$$

Small-Scale Irregularities in the electron density of the Ionosphere are responsible for Diffraction effects of GNSS radio signals



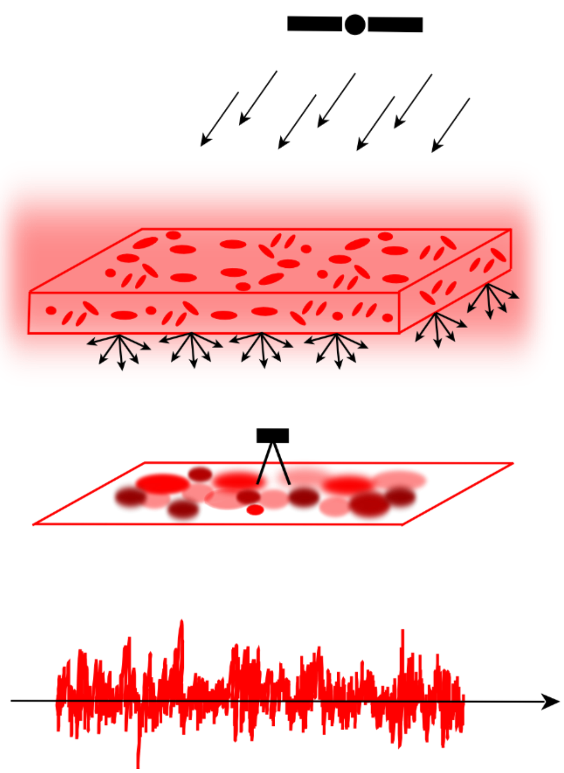
Fluctuation of the GNSS signal phase

$$\sigma_\varphi = \sqrt{\langle \theta^2 \rangle - \langle \theta \rangle^2}$$

Fluctuation of the GNSS signal amplitude

$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$

Ionospheric Scintillations are rapid fluctuations of the signal phase and amplitude due to small-scale irregularities in the electron density of the Ionosphere



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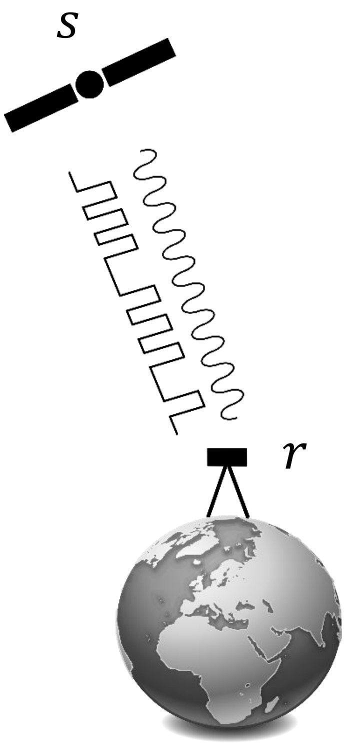
Our Research focuses on two main Absolute GNSS Positioning Algorithms: the Standard Point Positioning (SPP) and the Precise Point Positioning (PPP)



SPP = Standard Point Positioning

$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

PPP = Precise Point Positioning

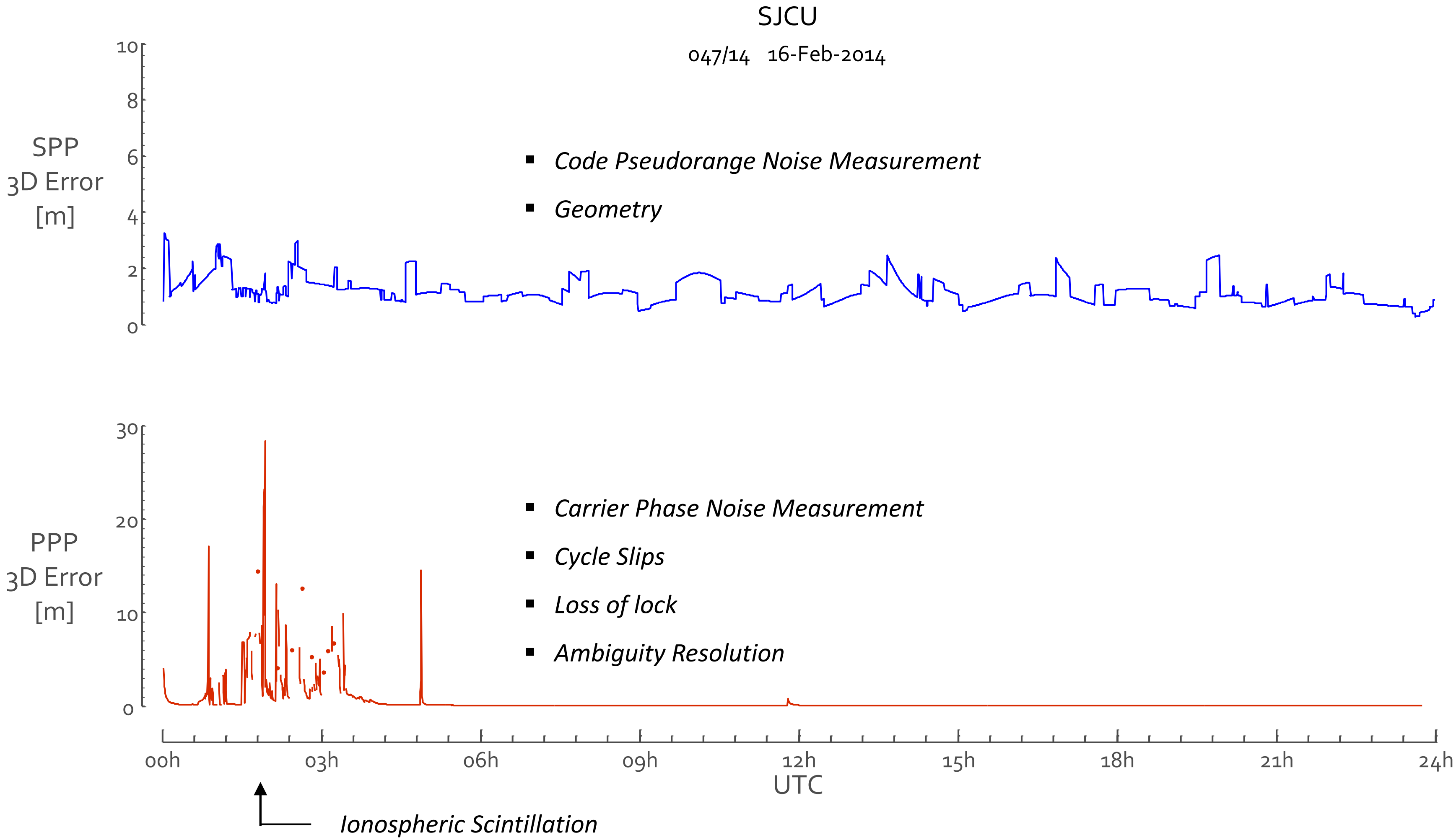
$$P_r^s(\mathrm{t}) = D_r^s + T_r^s + I_{r,k,m}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,k,m}^s + \varepsilon_{r,k,m}^s$$

$$\phi_r^s(\mathrm{t}) = D_r^s + T_r^s - I_{r,k,\phi}^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_k N_{r,k}^s + M_{r,k,\phi}^s + \varepsilon_{r,k,\phi}^s$$

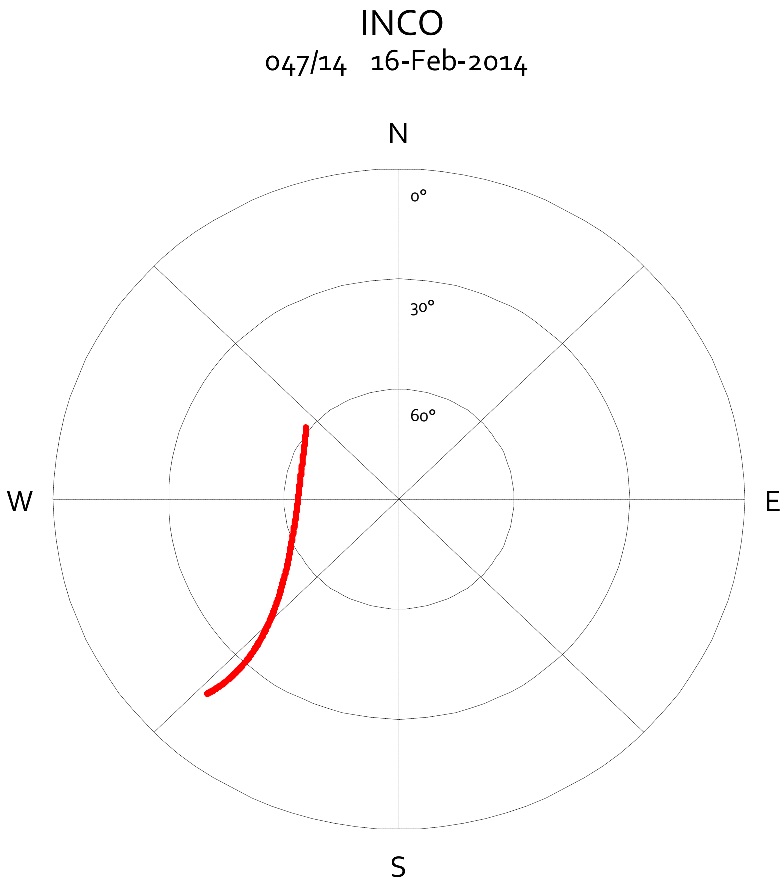
$$P_{r,IF}^s(\mathrm{t}) = D_r^s + T_r^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + M_{r,IF,m}^s + \varepsilon_{r,IF,m}^s$$

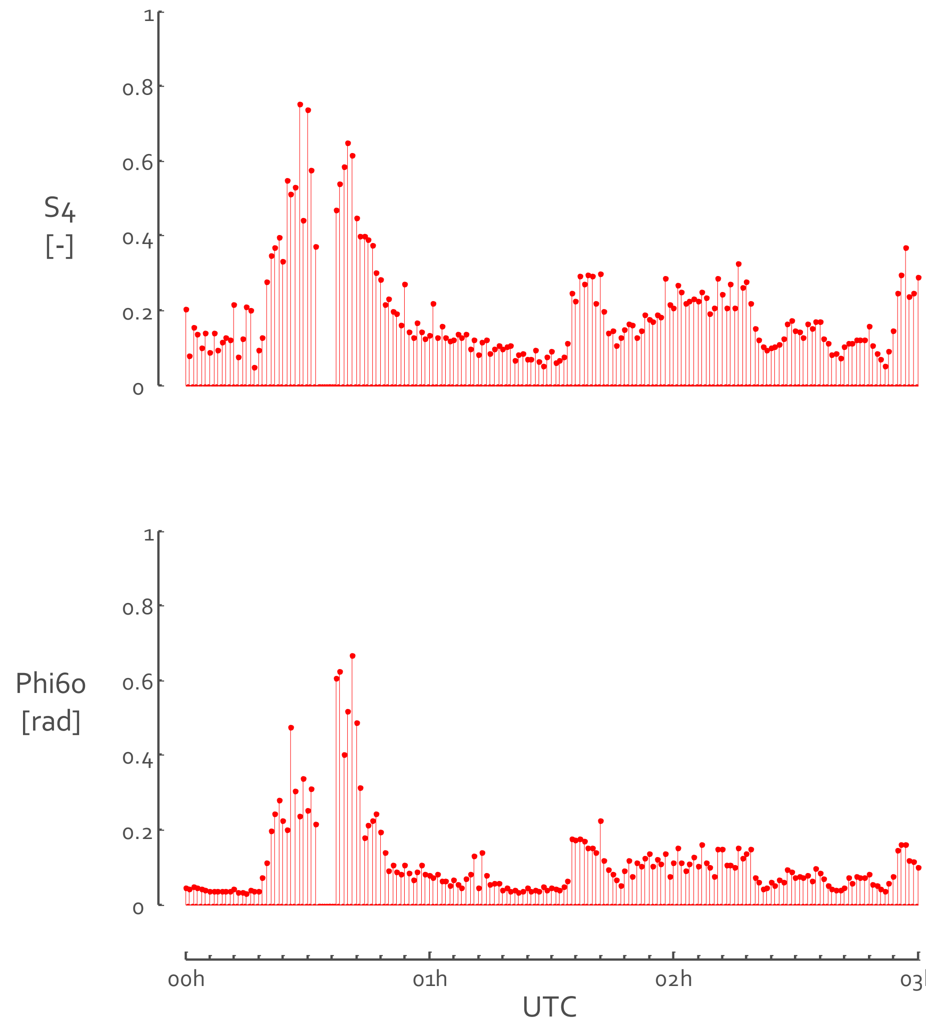
$$\phi_{r,IF}^s(\mathrm{t}) = D_r^s + T_r^s + \mathrm{c}\,(\Delta t^s - \Delta t_r) + \lambda_{IF} N_{r,IF}^s + M_{r,IF,\phi}^s + \varepsilon_{r,IF,\phi}^s$$

The Precise Point Positioning is very sensitive to Ionospheric Scintillations which may totally degrade its performances and reliability



GNSS signal scintillations show signs of Spatio-Temporal Dependence





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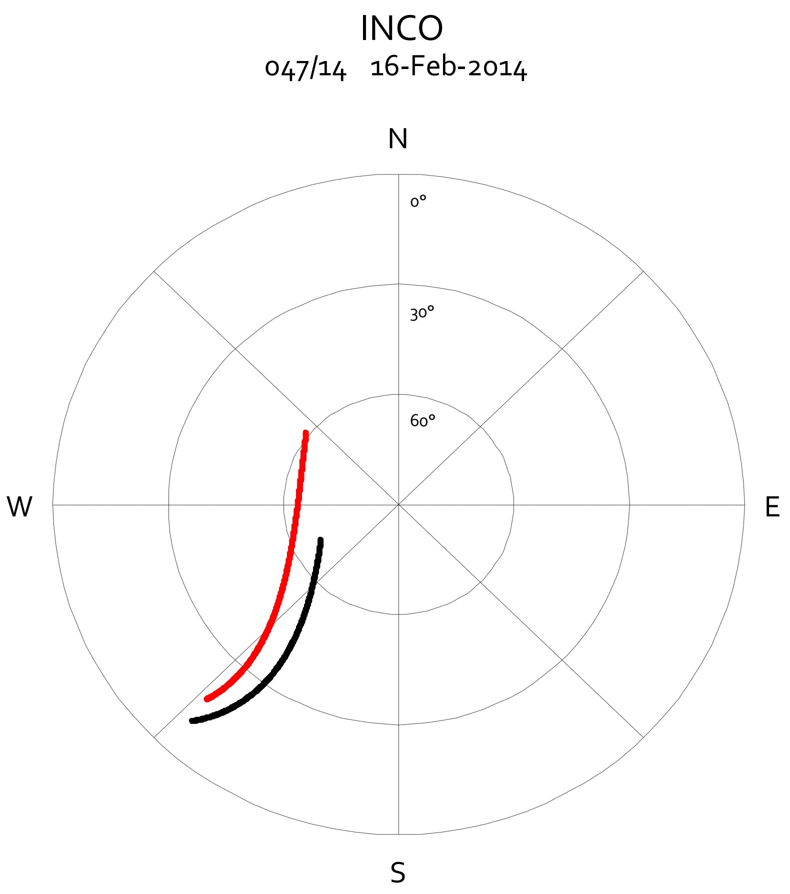

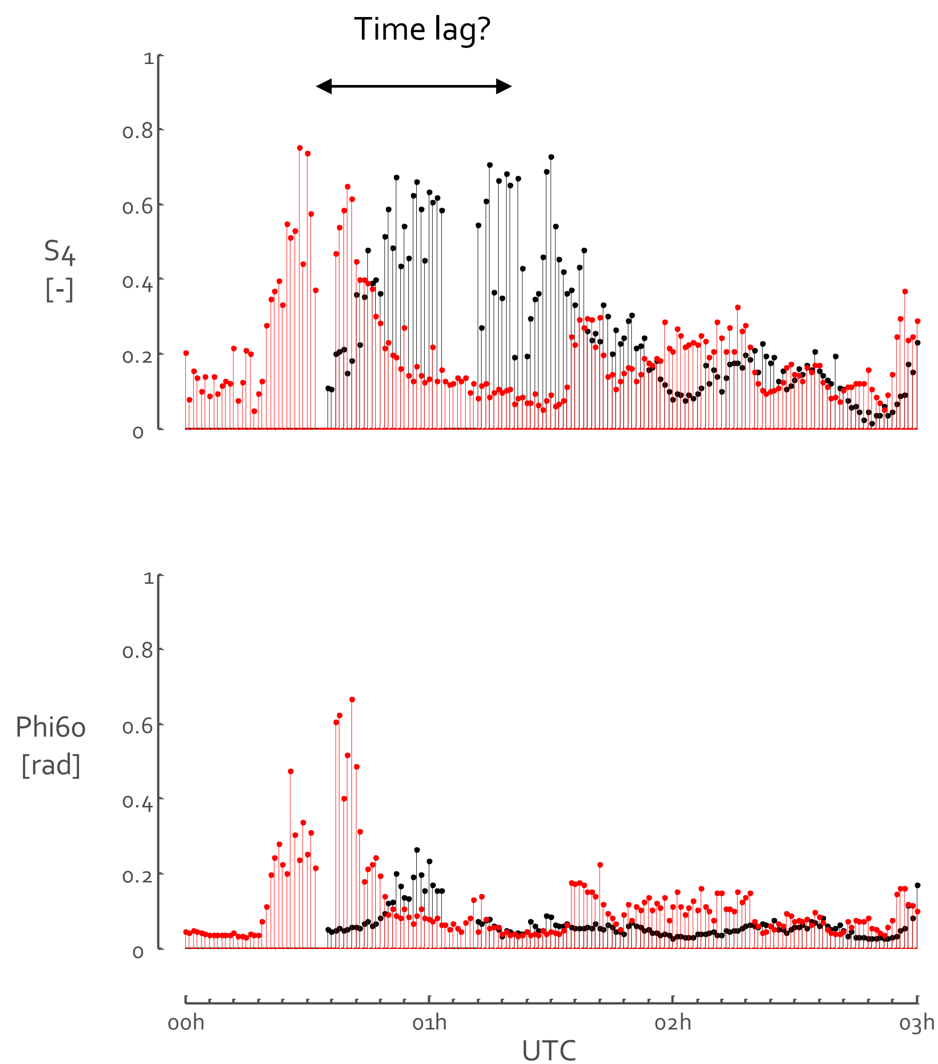

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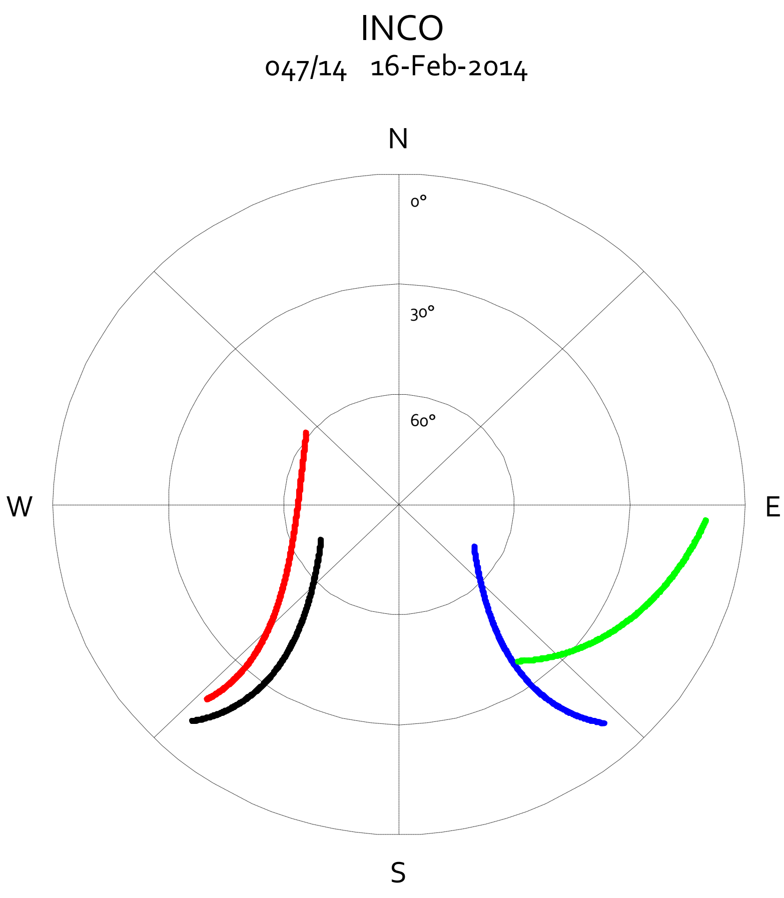
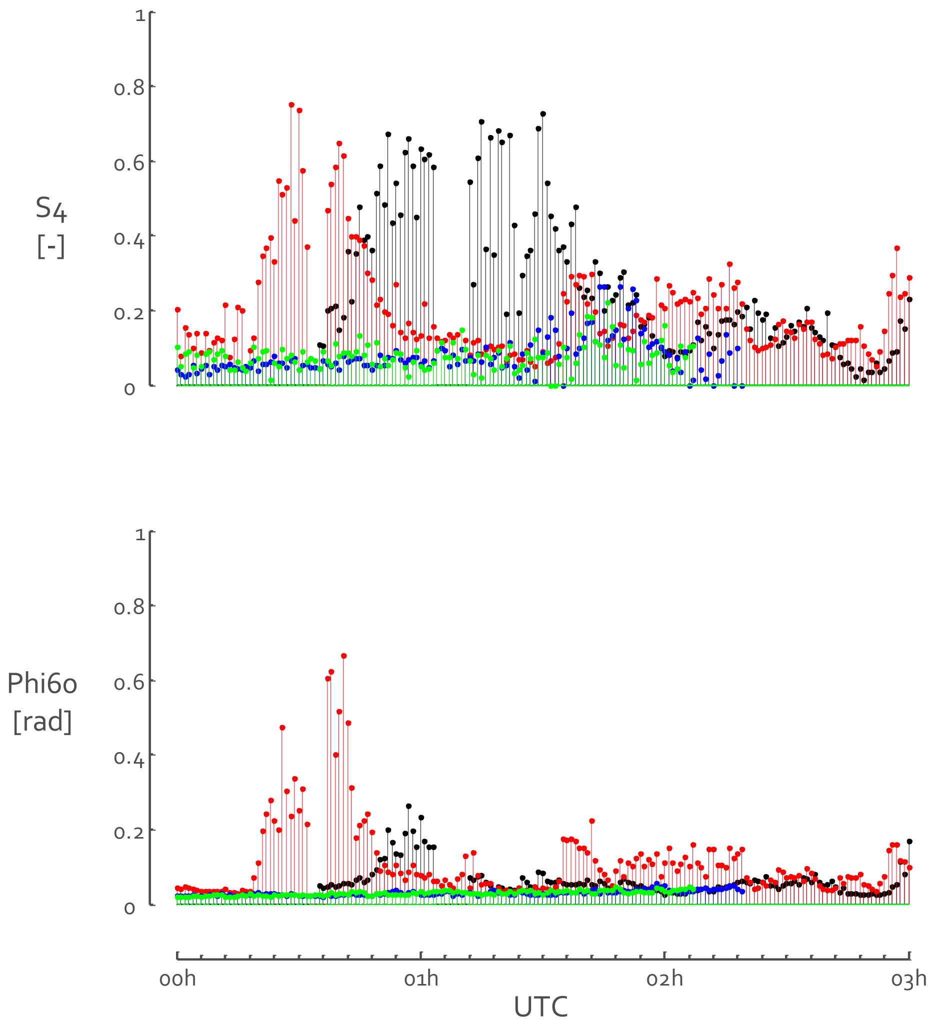
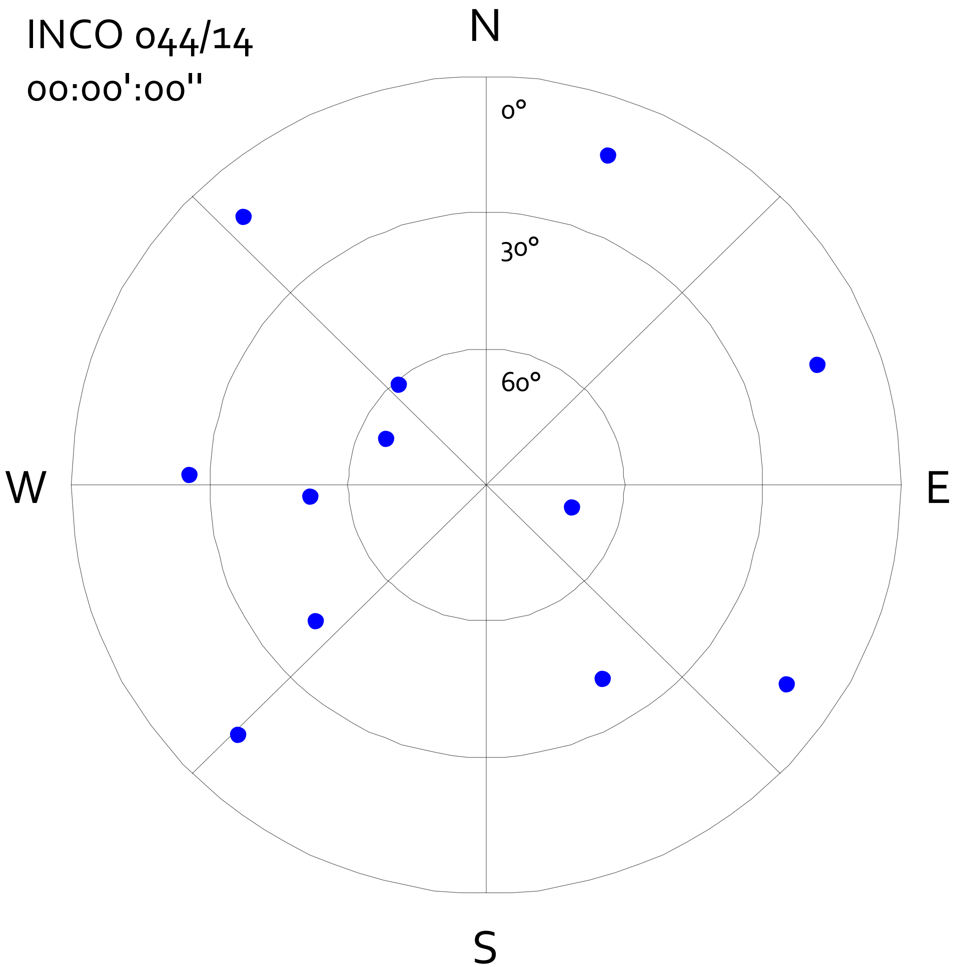


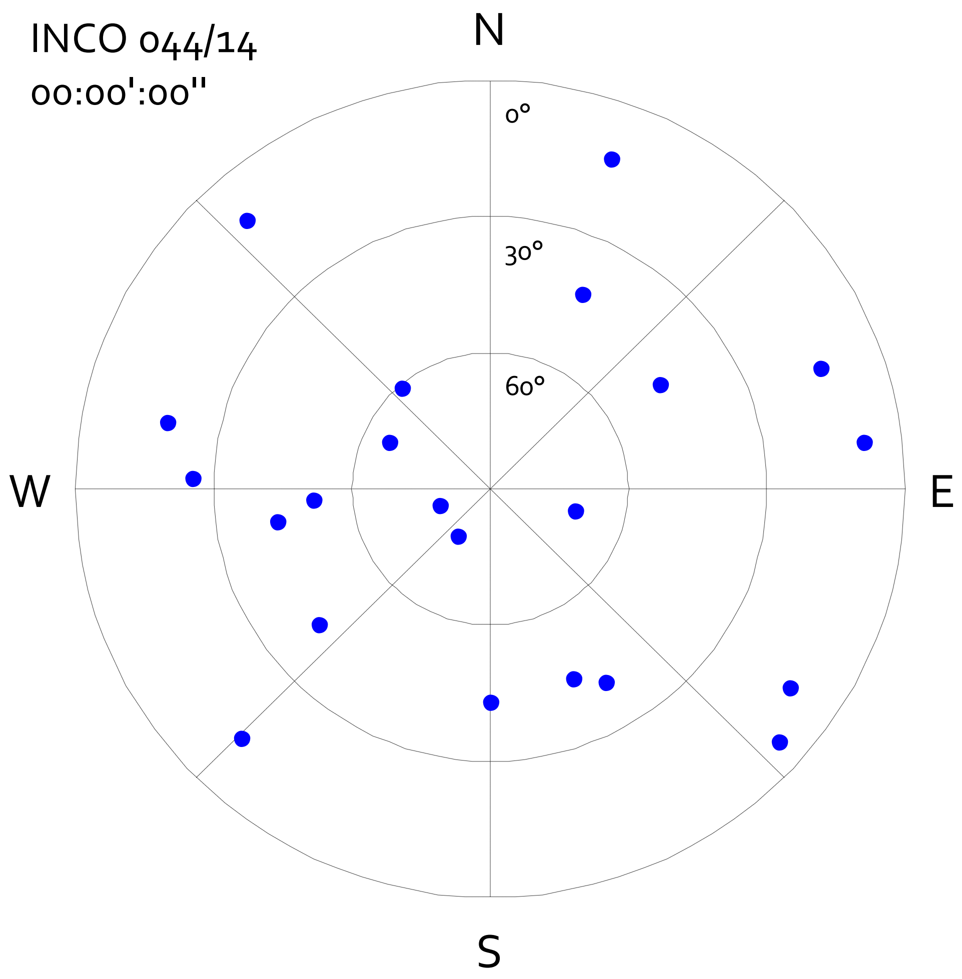


The Ionospheric Scintillation GNSS Survey needs to be densified in order to perform a proper Spatio-Temporal Analyse



GPS

The Ionospheric Scintillation GNSS Survey needs to be densified in order to perform a proper Spatio-Temporal Analyse



Multi-GNSS

The Ionospheric Scintillation GNSS Survey needs to be densified in order to perform a proper Spatio-Temporal Analyse

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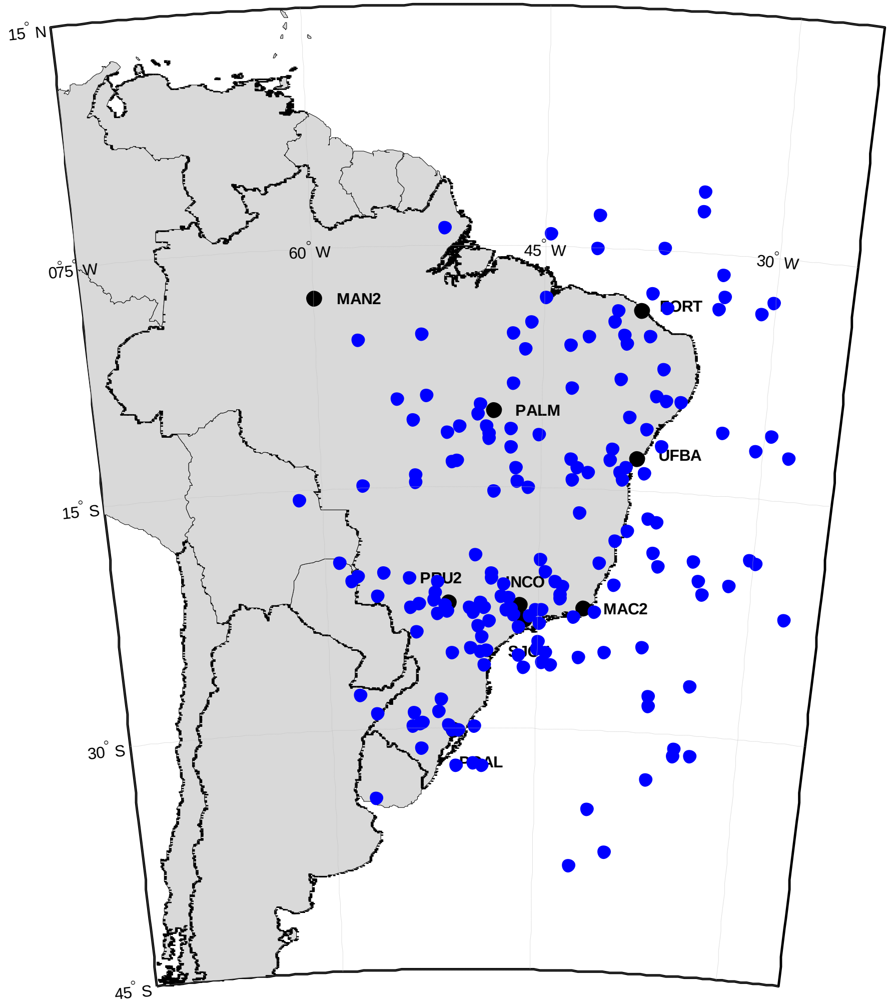

Multi-GNSS

Multi-ISMR

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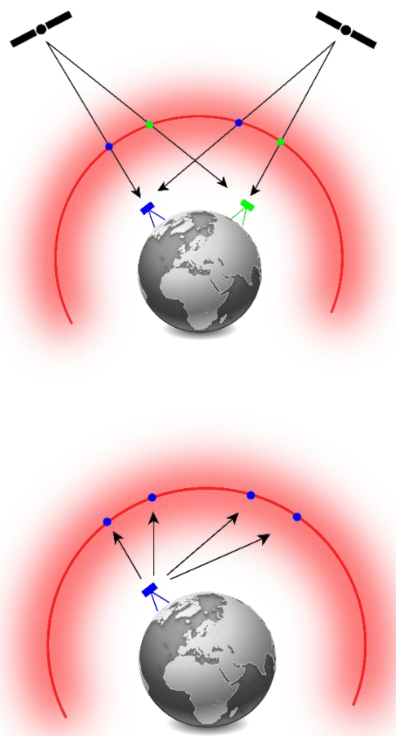
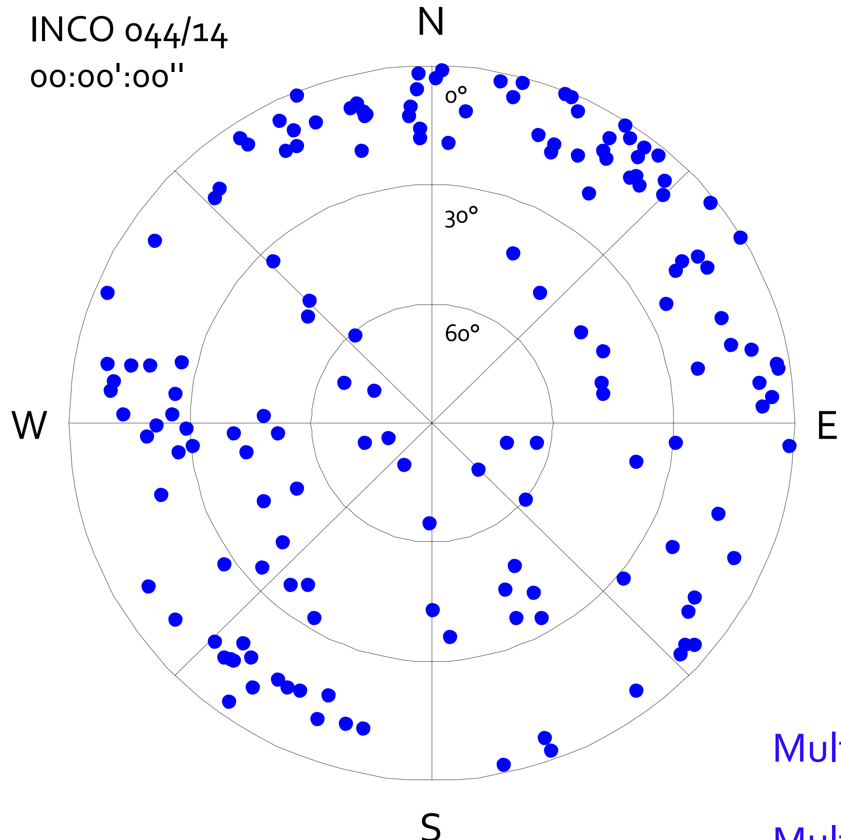




Multi-GNSS

Multi-ISMR

Spatial Autocorrelation can be detected and quantified by using specific SAC indices

Moran's I

$$I = \frac{N}{\Sigma_i \Sigma_j w_{ij}} \frac{\Sigma_i \Sigma_j w_{ij} (v_i - \bar{v})(v_j - \bar{v})}{\Sigma_i (v_i - \bar{v})^2}$$

$$v_i = S4_i$$

$$w_{ij} = \frac{1}{d_{ij}}$$

Geary's C

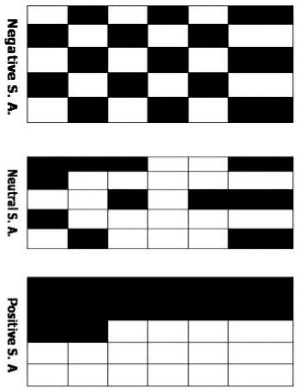
$$C = \frac{(N-1)}{2 \Sigma_i \Sigma_j w_{ij}} \frac{\Sigma_i \Sigma_j w_{ij} (v_i - v_j)^2}{\Sigma_i (v_i - \bar{v})^2}$$

$E[I] - V[I]$

$I < 0$ $\quad C > 1$

$I \sim 0$ $\quad I \sim 1$

$I > 0$ $\quad I < 1$



$E[C] - V[C]$

Hypothesis Test

Ho: The situation is the result of a stationnary point process, i.e. there is no significative spatial dependency.

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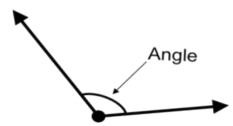

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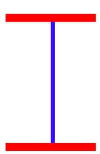

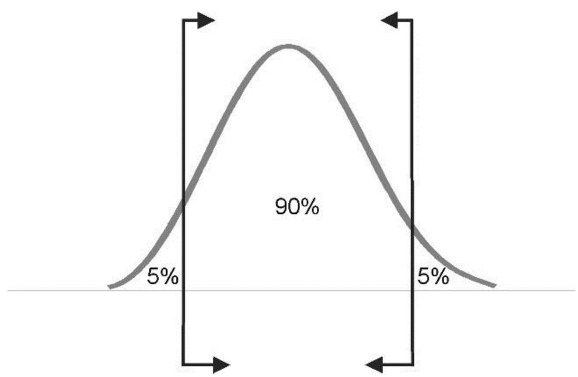

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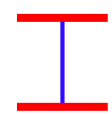

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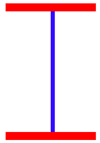

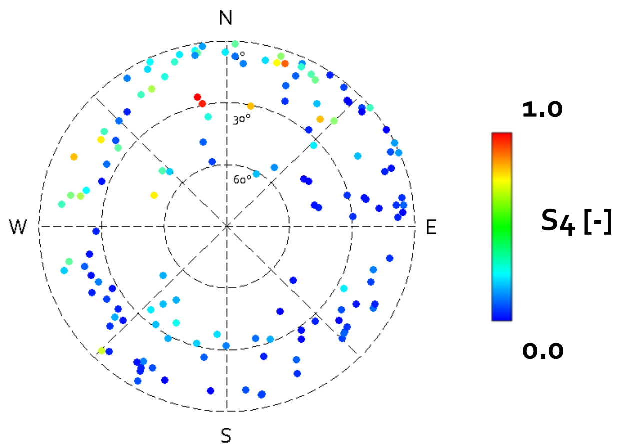

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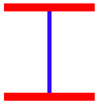

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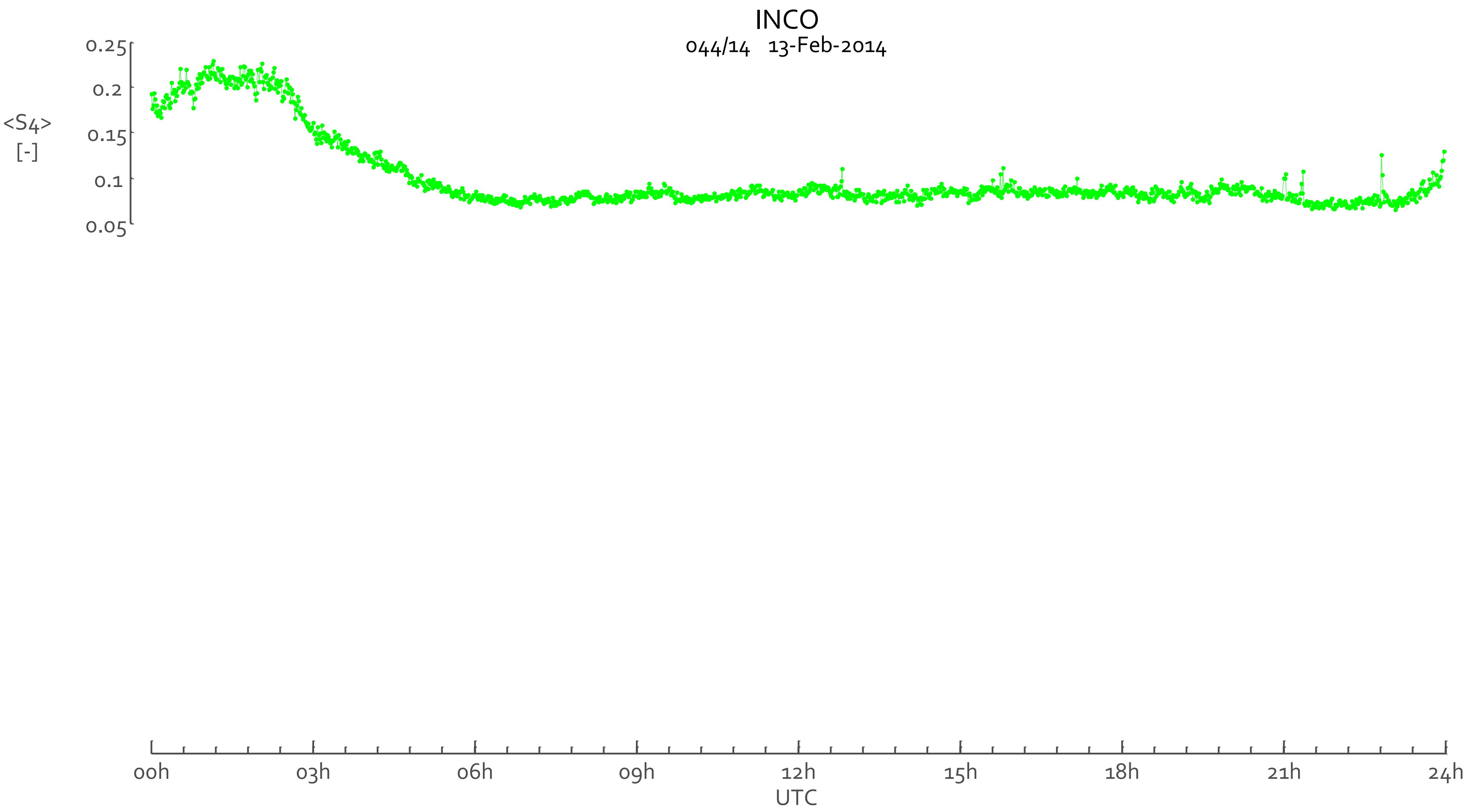
The Global Spatial Autocorrelation inside the data set is Significative only during the occurrence of Ionospheric Scintillations



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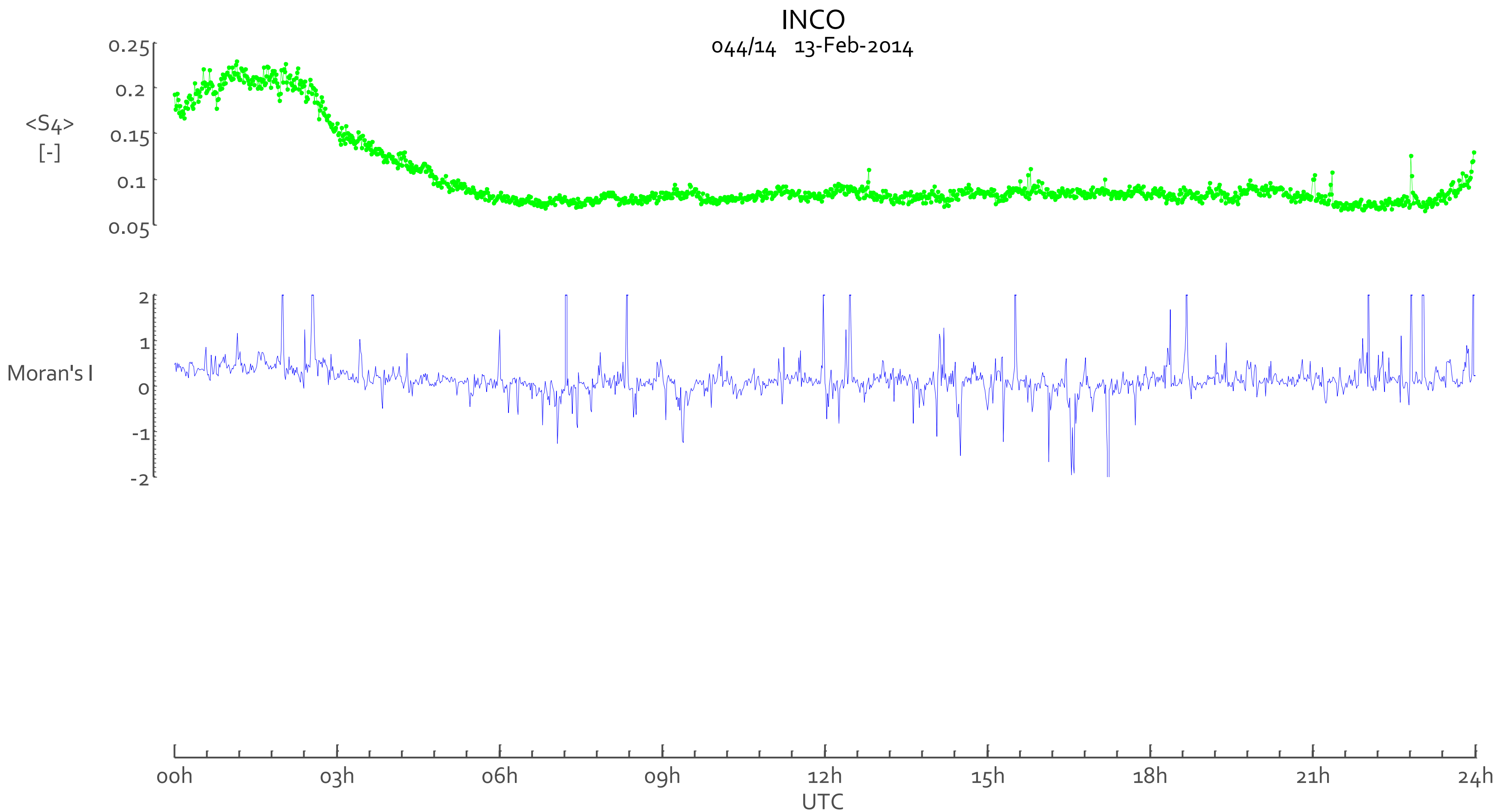

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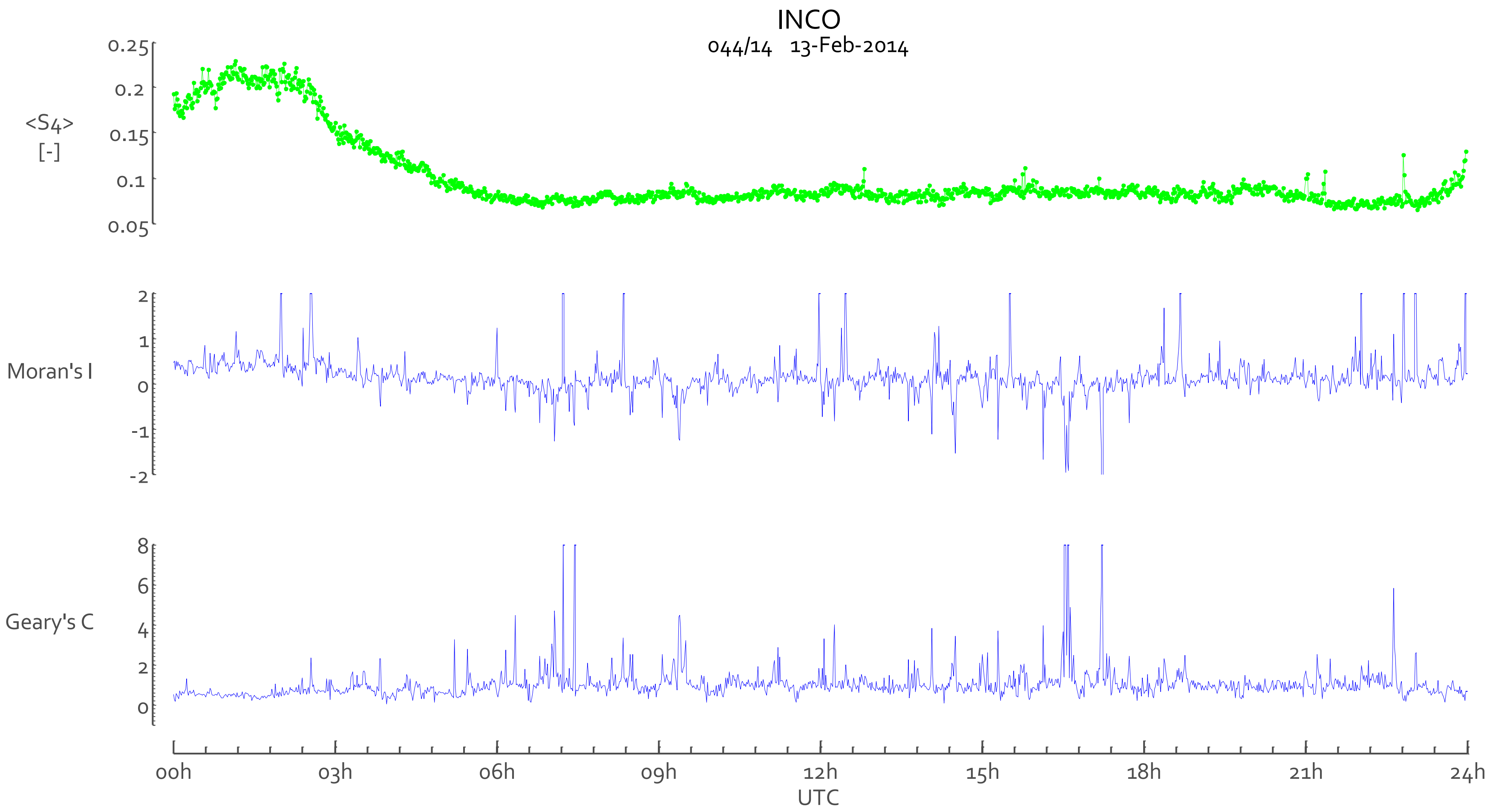

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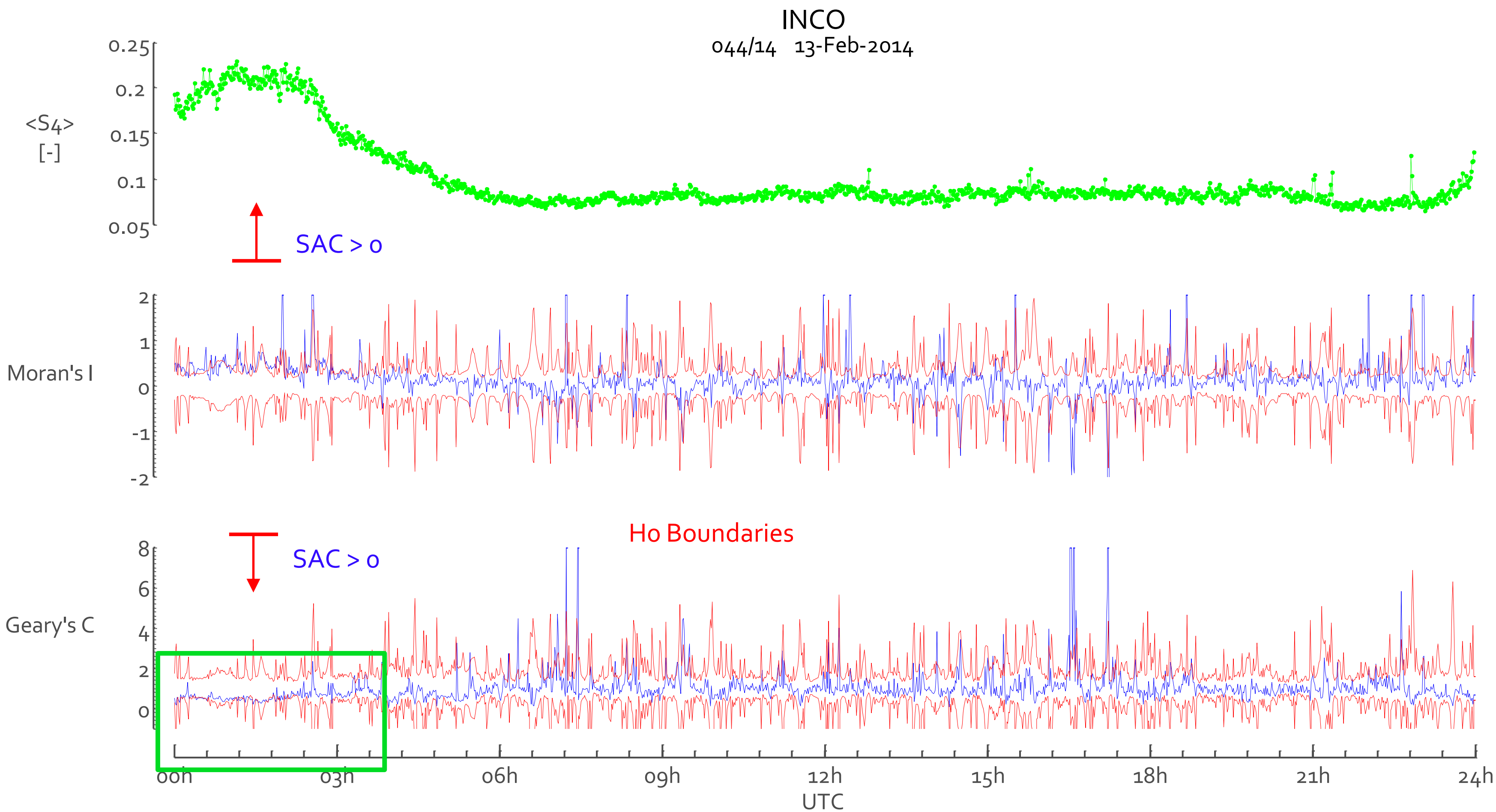

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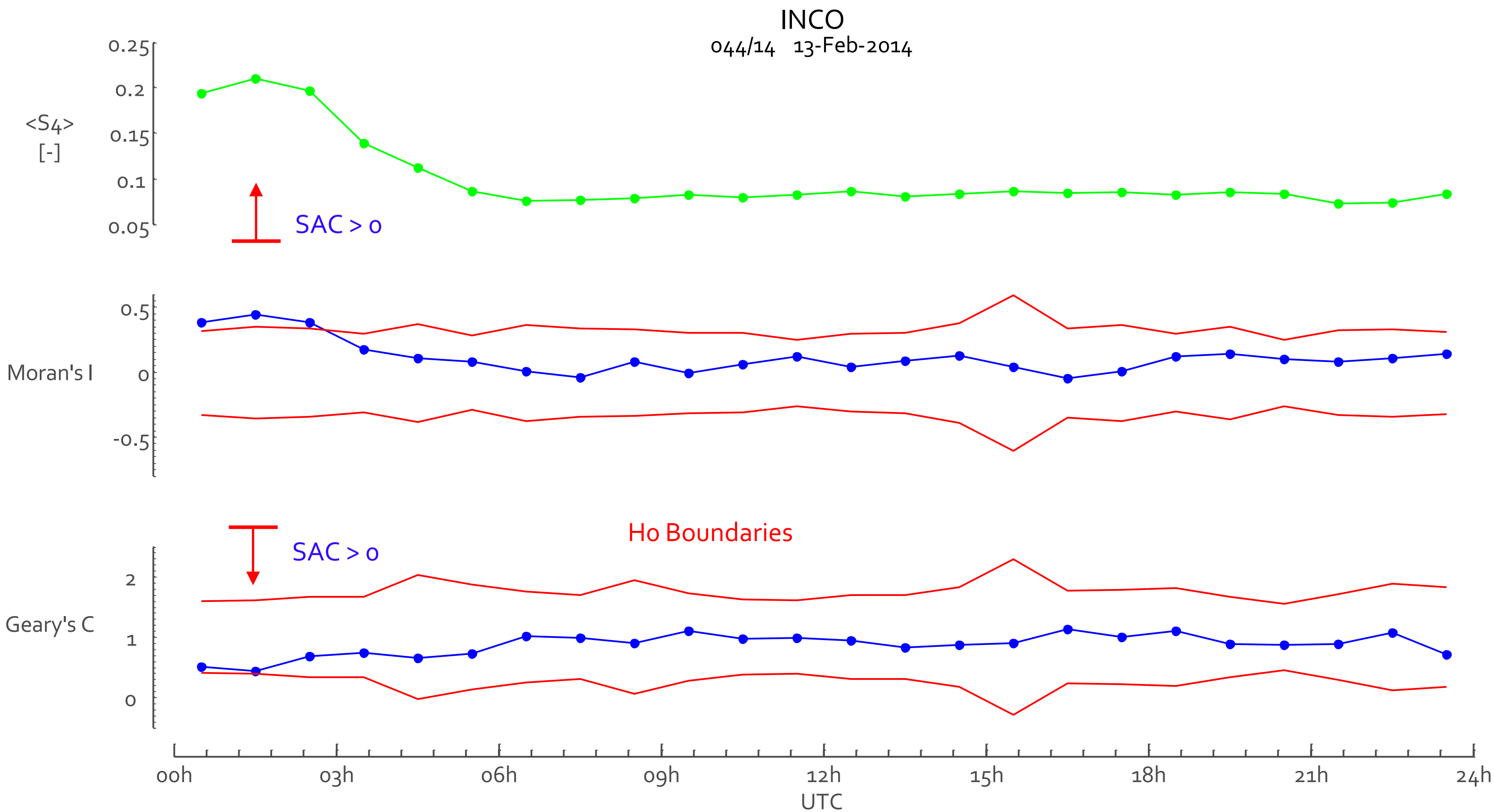

Conclusions

- We developed a methodology in order to exploit the availability of **Multi-GNSS** observations from an ISMR Network for the **Spatio-Temporal Analysis** of **Ionospheric Scintillations** (based only on GNSS Measurements).

- By using this methodology, we lead a first analysis of the **Spatial Dependency** of Ionospheric Scintillation Observations. We measured the **Spatial Autocorrelation** of the S_4 observable and showed it was clearly significative but only in the presence of (strong) Ionospheric Scintillations, supporting a possible spatial interpolation at these times.

- We will extend the **Spatio-Temporal Analysis** to other parameters.

- We will perform a **Local Spatial Autocorrelation** Test to **locate** and determine the **scale** of the detected « hot spots ».

- We will implement specific **Spatial Interpolation Techniques** to produce a « Scintillation Sky Map ».

- We will integrate the Spatio-Temporal Analysis in the **PPP algorithm**.

Acknowledgements

- The ISMR data used for part of the presented work have been kindly provided by the Nottingham Geospatial Institute (NGI) of the University of Nottingham (UoN), UK, the Faculty of Science and Technology (FST) of the Universidade Estadual Paulista (UNESP), Brazil, and the European GNSS Agency (GSA) in the frame of the CIGALA/CALIBRA project.

- The research is performed at the Geomatics Unit of the University of Liège (ULg), Belgium, under the supervision of Pr. René Warnant and with the collaboration of Dr. Yves Cornet.

- In the frame of this project, a collaboration was established with Pr. Marcio Aquino and Dr. Craig Hancock from the Nottingham Geospatial Institute (NGI) of the University of Nottingham (UoN), UK.

- This research is funded by the National Fund for Scientific Research of Belgium (F.R.S.-FNRS).

- SPP and PPP Positions were computed by using the gLAB software developped by the gAGE group of the Technical University of Catalonia (UPC).

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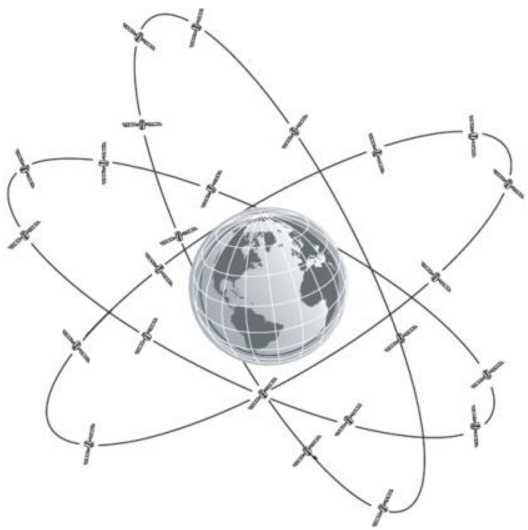

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