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Regional short-term forecasting of ionospheric TEC and scintillation

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ABSTRACT

Ionospheric scintillation effects on GNSS signals are characterized by a considerable spatial and temporal variability, which depends on factors such as the frequency, zenith angle or angle between the ray path and the Earth‘s magnetic field. The contribution of these factors can be accurately defined based on the scintillation theory. However, scintillation dependencies on local time, season, solar and magnetic activity have a stochastic character, meaning that there is no unique relationship between the strength and/or occurrence of scintillation and the particular agent. Complexity of ionospheric electron spatial distribution and lack of detailed information on actual propagation conditions makes the problem of deriving scattered wave field properties extremely difficult. That is why it is so difficult to forecast the occurrence of scintillations, and therefore predict the impact of ionospheric disturbances on radio communications, navigation or positioning systems. To tackle the scintillation-related problems on modern GNSS application such as precise positioning techniques (RTK, NRTK etc.), several empirical and semi-empirical models of ionospheric scintillation have been proposed (see, e.g., [1], [2] and [3]). However, most of them suffer from low spatio-temporal resolution as, being climatological models, they cannot properly account for the actual conditions but rather give an average dependence of the propagation characteristics on helio-geophysical conditions.

Bearing this in mind, this paper reports about a recently model developed to forecast (from seconds to minutes in advance) ionospheric total electron content and scintillation parameters. The model has been developed and tested over the Brazilian ionosphere under different scintillation regimes in the framework of the recently concluded FP7 CALIBRA (Countering GNSS high Accuracy applications Limitations due to Ionospheric disturbances in BRAzil) project. The basic idea is to apply the transport theory for a scalar field to the parameters of interest (TEC, S_4, σ_Φ), assuming that the temporal gradient of a given parameter is a function of its spatial gradient and of the associated velocity field (unknown of the problem), as described in [4].

Experimental data from the CIGALA/CALIBRA network, a network of 50 Hz receivers in Brazil, are used to reconstruct **v**, the velocity field of the selected scalar field, for a given epoch ([5]) and then the continuity equation is applied to evolve in time such scalar field.. The general concept of the model formulation and its testing against test cases are here described.

The approaches used to predict TEC and scintillation parameters are slightly different. TEC forecasting is made by simply applying the continuity equation without any production or loss terms, while the prediction of scintillation parameters required the introduction of a source term in the continuity equation. Equation (1) and (2) represents the continuity equations for TEC and scintillation parameters, respectively:

$$\frac{\partial}{\partial t}\int_V dVf = -\int_{\partial V} ds \cdot (fv) \tag{1}$$

$$\frac{\partial}{\partial t}\int_V dVf = -\int_{\partial V} ds \cdot (fv) + \int_V dV(p-l) \tag{2}$$

The technical concept of the method is to reconstruct the velocity field **v** from TEC and scintillation parameters measurements and subsequently evolve the scalar field *f* according to equation (1) and (2) with the desired time resolution using an appropriate numerical integration scheme. In our case, the velocity field **v** is the velocity of the integrated electron density (TEC) for along the line of sight connecting the receiver and the satellite, while *f* is the scalar field of TEC for eq. (1), and similarly for S_4, σ_Φ in equation (2). In both equations, *V* is the total volume with boundary ∂V, while in eq. (2), *p* and *l* are the source term, i.e. the production and loss terms. The solution in both cases relies on discretizing the space into Delaunay triangles, on approximating TEC and scintillation parameters piecewise linearly on the triangular grid and on considering the velocity field constant over each triangle. An example of Delaunay triangulation of the spatial domain over Brazil is given in Figure 1a, while Figure 1b reports an example of reconstructed velocity field for TEC.

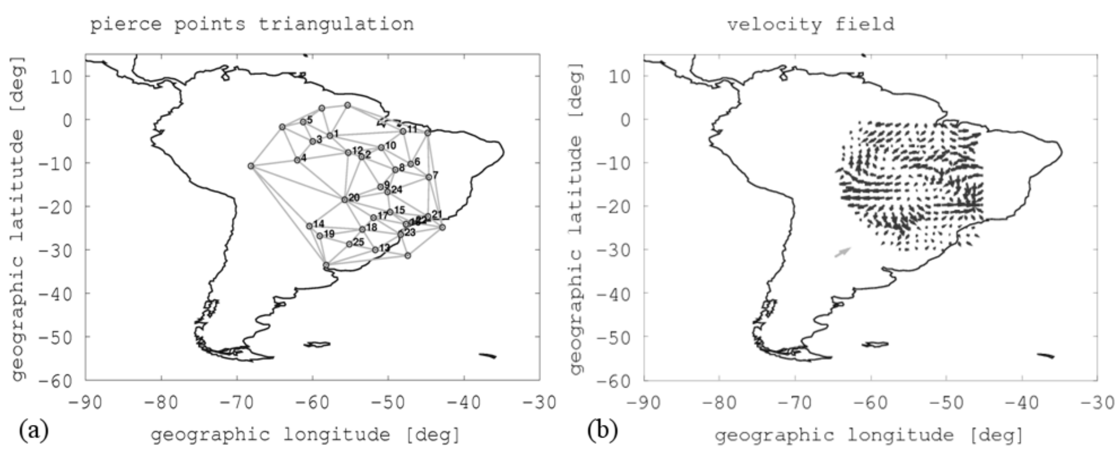

Figure 1. Example of Delaunay triangulation (a) and of reconstructed velocity field for TEC (b).

To test the performance of the model, data from the CIGALA/CALIBRA network covering the São Paulo state were used under different strong scintillation (S_4>0.7) scenarios between 25

November 2013 and 21 January 2014. The forecasting horizon has been set to 15 seconds for the TEC and to 1 minute for the scintillation parameters, i.e. their time rate in the CIGALA/CALIBRA network data files. As an example of the model results and performance, left part of Figure 2 shows the time profile of the difference between actual and 15 seconds in advance forecasted TEC for the day 269/2013 for each ionospheric pierce point over São Paulo state. The box indicates the post sunset hours, during which harsh scintillation conditions are expected. The corresponding distribution of such difference is on the right part of the figure. The standard deviation of such distribution is used as benchmark for the model accuracy. As expected, the model capability in forecasting the TEC is reduced during the post sunset hours. Similar performances are found for the forecasting of amplitude and phase scintillation parameters.

The model has been recently patented in Italy by SpacEarth Technology, a INGV spin-off and an international patenting procedure is ongoing.

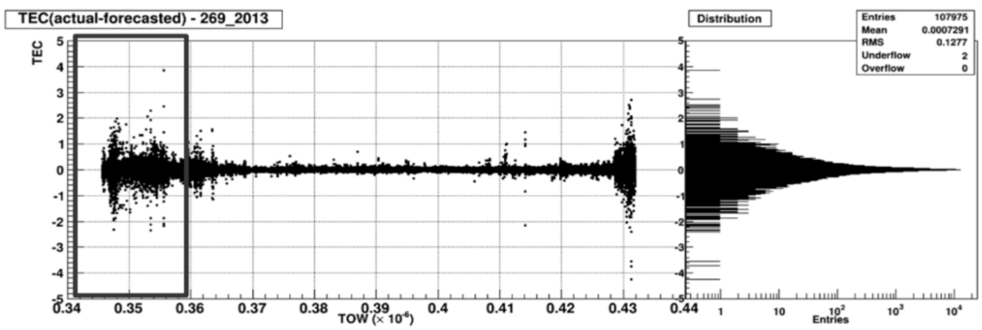

Figure 2. Example of model results in terms of time profile of difference between actual and 15 seconds in advance forecasted TEC for the day 269/2013 for each ionospheric pierce point over São Paulo state. The box indicates the post sunset hours. The corresponding distribution of such difference is on the right part of the figure.

Key words: Low latitude Ionosphere, GNSS, Scintillation, Modeling, Forecasting.

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