Ionospheric turbulent parameter inversion using scintillation log-amplitude spectra: performance and results

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Ionospheric scintillation is a threat for the availability of systems with high service disponibility such as GNSS services. Indeed, this phenomenon is characterized by an important fluctuation of the amplitude and phase of the signal in reception, that can lead to loss of lock and signal outages. Given the fact that scintillation is caused by small-scale irregularities of the ionospheric density (ranging from a few meters to tenth of kilometers), the phenomenon is usually localized, both temporally and spatially. Moreover, it has an important day-to-day variability. After decades of interest for that phenomenon, the forecasting of ionospheric scintillation is still in progress.

One of the first steps in our approach of forecasting the apparition and the intensity of scintillation is to be able to recover the physical state of the ionosphere from amplitude time series of a signal that underwent scintillation. The turbulence of the layer is usually described in terms of statistical turbulent parameters. Indeed, the analysis of the medium is too complex to be carried out with a determinist formalism. The capacity to process the data in order to estimate the statistical parameters of the ionosphere's turbulence is called inversion.

An inversion algorithm extracting the parameters considered as central in the study of the turbulence from GNSS observables has been developed. It is based on an analytical 3D theory of ionospheric scintillation [Rino, 1979][Wheelon, 2003][Galiègue et al., 2016]. The parameters of interest on which the study focuses are namely the height-integrated irregularities strength C_kL, the drift speed of the irregularities V_d and the statistical anisotropy of the irregularities along the geomagnetic field's direction A_z and the transverse direction A_y. The algorithm is designed to be used in the equatorial area, a region where scintillation has a high occurrence probability after sunset and where the development of a Safety of Life service for all users is foreseen. It takes in input single-frequency GNSS amplitude time-series. The validity of the inversion algorithm has been conducted through comparison of the parameters obtained through inversion of L1 and L2C signals, emitted from the same GPS satellites. The results have been convincing, showing that the frequency band over which the inversion is performed does not influence the output parameters, given that scintillation is intense enough to affect both frequency bands. The inversion algorithm has then been used to probe the equatorial ionosphere, and strengthen the knowledge of the ionospheric irregularities.

The SAGAIE network consists of five sub-Saharan stations deployed in West-Africa. The beginning of 50-Hz data collection in 2013 in Dakar and Lome coincided with the maximum of solar cycle 24. The use of this database enables to study the ionosphere's behavior in the descent phase of a solar cycle. We have hence access to intense and weak periods of solar activity, whose influence on scintillation can be studied.

The great number of ionospheric pierce point provided by the GPS constellation observed by SAGAIE enabled to study more than 130 000 scintillation events, giving birth to one of the largest study of the turbulent ionosphere ever set up. The literature's measurements of irregularities drift speed realized with radars (at lower frequency bands), or of $C_k L$ modeled by WBMOD compare satisfactorily with the ones obtained through inversion of the SAGAIE database. In addition to the seasonal variation of the main ionospheric parameters that have been derived, original links could also be drawn between the anisotropy ratios and the height-integrated irregularities strength, or between the ionospheric drift speed and the S_4 parameter.

The inversion algorithm is now being adapted to the particular conditions of high latitude, while inversion of the GLONASS and Galileo signals contained in the SAGAIE database from 2013 is being conducted. They aim at constituting a large turbulent parameters dataset, that will coupled to real-time inversion in a near future: this association shall produce turbulent parameters forecast, and its depending scintillation.

Key words: Ionosphere, GNSS, Scintillation, equatorial region, inversion process, spectral characterization.

1. **References:**

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