Some consequences of the dimensional reduction 3D/2D on the numerical prediction of ionospheric scintillation effects under weak and strong perturbation regimes

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1. Extended Abstract

The ionosphere's variable ionization rate leads to great fluctuations of the electron density over wide spatial ranges, from several thousand kilometers to a few centimeters, making the medium turbulent. These variations of the electronic content cause fast fluctuations of the amplitude and phase (i.e. scintillation) of an electromagnetic wave crossing the ionospheric plasma for frequencies up to ~12GHz. These sudden variations of the signal might cause a fall-out of the receiver's loop and reduce the radio link availability (earth-satellite telecommunication links, satellite to satellite link in occultation geometry, spaceborne Synthetic Aperture Radar, GNSS...). It is therefore necessary to quantify these ionospheric effects. The scintillation events are usually categorized in strong and weak scattering regimes [1], depending on the electronic strength of the turbulent eddies that impact the radiowave propagation. Because the ionospheric plasma instabilities are highly variable in time and space, the scintillation is described statistically, in terms of the log-amplitude and phase variances of the signal, or their associated temporal spectra.

The first way to derive these statistical quantities is to use a numerical approach. In order to solve the Helmholtz's equation in the ionosphere, the PWE-MPS (Parabolic Wave Equation–Multiple Phase Screen) approach combined with a spectral description of the turbulent irregularities has been extensively used in the literature. The resolution is then three-dimensional (3D-PWE), with two-dimensional phase screens (2D-MPS) transverse to the propagation direction. However, the computational time and resource necessary to solve this 3D formulation might become prohibitive. A classical assumption is to solve the propagation equation along a longitudinal cross section, defining a 2D-PWE/1D-MPS numerical scheme [1][2]. Yet, the ionospheric turbulence is clearly a 3D-process. Thus, the validity of the dimensional reduction classically performed must be questioned. Considering typical equatorial configurations, the scintillation effects are first derived from 3D-PWE/2D-MPS and 2D-PWE/1D-MPS simulations. Depending on the radio link configuration and the morphology of the ionospheric irregularities, some consequences of the dimensional reduction are then numerically assessed.

To better understand the consequences of the dimensional reduction, 3D and 2D analytical formulations of log-amplitude ($\langle\chi^2\rangle^{3D}$,$\langle\chi^2\rangle^{2D}$) and phase ($\langle\varphi^2\rangle^{3D}$, $\langle\varphi^2\rangle^{2D}$) variances are proposed under weak scattering assumption. The 2D formalism is original. Moreover, while the 3D derivations have been classically proposed in the geomagnetic coordinate systems, both formulations are here conducted in the line-of-sight coordinate system, making the result's interpretation easier. These 3D and 2D analytic derivations allow assessing quantitatively the potential errors introduced by 2D numerical schemes in weak scattering regime.

It follows that the validity of the dimensional reduction must now be investigated in the regime of strong fluctuations. As 3D-PWE/2D MPS and 2D-PWE/1D MPS numerical approaches apply whatever the regime, some results are first compared with [2]. Second, a preliminary study is lead in order to qualitatively assess the consequences of the dimensional reduction for strong fluctuations. The evolution of the scintillation effects are then analyzed in terms of 3D/2D log-amplitude and phase variances, as a function of the strength of the ionospheric irregularities.

Finally, this work should help system designers to use advisedly 2D-PWE/1D-MPS numerical schemes to predict ionospheric effects whatever the radio-link configuration, and whatever the perturbation regime (weak/strong).

2. References

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