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3D to 2D approximation effect on propagation modeling, impact on scintillation indices in polar region

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ABSTRACT

Ionospheric scintillations, in particular at equatorial and polar latitudes, are responsible of GNSS receiver loss of lock and accuracy decreasing. To improve the future GNSS systems, an understanding of the effect of the ionospheric irregularities is necessary, completed by an accurate propagation modeling across this layer. The inhomogeneous ionospheric layer responsible for the scintillation effects is classically represented by its spectral density function (or spectrum) in propagation modeling. The inhomogeneity spectrum is anisotropic due to Earth magnetic field influence and to induced ionospheric currents [6]. Propagation across this inhomogeneous layer can be modeled by asymptotic methods based on Rytov theory when the ionospheric turbulence is weak [8][9], and by numerical approach as Parabolic Wave Equation (PWE) resolution associated with Multiple Phase Screen (MPS) [5][3]. The PWE-MPS technique is valid in strong scattering regime and can consider a variability of ionospheric turbulence characteristics along the path. As PWE-MPS technique in 3D can be time and memory space consuming, some authors assume a dimensional reduction of the problem from 3D to 2D [1]. The latter is assumed to be valid in equatorial region, where the irregularities are highly elongated along the earth magnetic field, mainly perpendicularly to the Line Of Sight direction for earth satellite links [2][7]. Nevertheless, the validity of this approximation for other configurations, as for instance in polar region where the morphology of irregularities is different, is still open. This paper proposes to quantify the consequences of the dimensional reduction on the prediction of log-amplitude and phase variances from 2D numerical schemes.

Particularly, to get a better formulation of the problem and to highlight the dimensional reduction influence, the problem is solved in the LOS (Line Of Sight) geometry. On the one

hand, under Rytov approximation, log-amplitude and phase variances (variables directly related to S_4 and σ_φ indices respectively) are derived asymptotically for 2D and 3D configurations, . On the other hand, the same quantities are computed numerically, from 3D PWE/MPS and 2D PWE/MPS. The impact of dimensional reduction 2D to 3D is then studied considering log-amplitude and phase variances ratio, versus the geometric configuration of the radio link.

An example is presented in fig.1. In the left figure the geometry is represented, with s the axis characterizing LOS axis, (u, v, s) coordinates characterizing the 3D space problem. The earth magnetic field $\vec{H}_0$ is characterized in the 3D geometry by the angles α_z, γ and Ψ. The inhomogeneous medium is anisotropic with a main elongation along the earth magnetic field, characterized by the anisotropy ratios $A_z = 10$ and $A_y = 3$. This configuration is a possible representation of a polar anisotropic medium geometry. After dimensional reduction the problem is reduced to a 2D plane passing by (O, s) and forming an angle α_z with (u, O, s) plane (cf. colored plane in fig1-left). The ionospheric layer has been chosen at an altitude of 350 km, with a thickness of 50 km, the outer scale length of inhomogeneities L_0 is 5 km, the spectral slope p was 4 and the Total Electron Content variance $\sigma_{\Delta N}^2 = 10^{18} m^{-6}$.

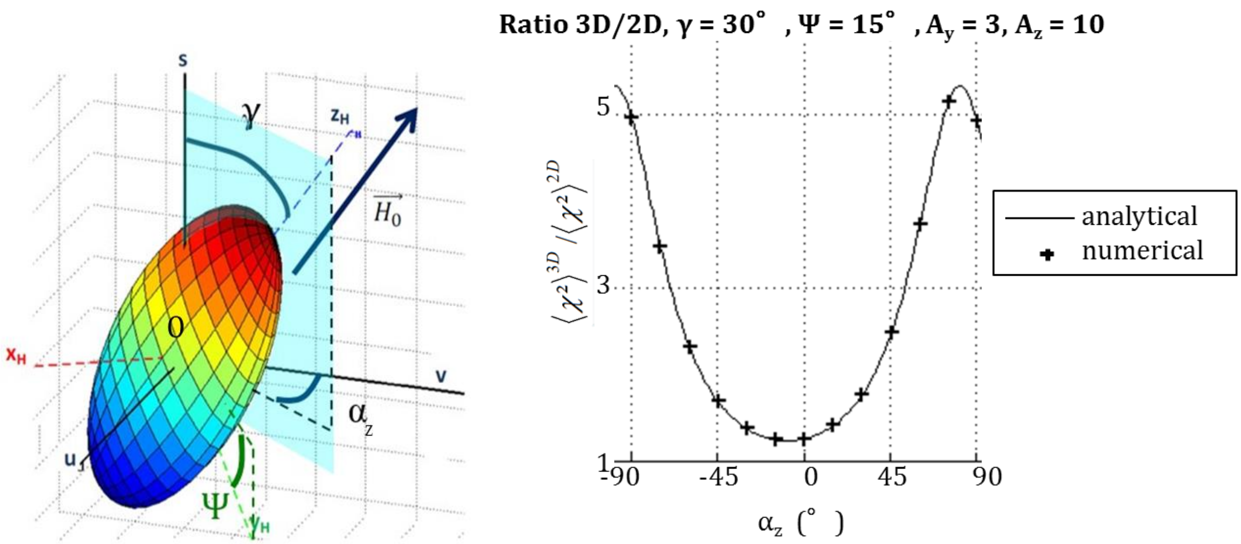

Figure 1. Left: high latitude configuration of anisotropy ($\vec{H}_0$ representing earth magnetic field), in blue the 2D cut plane of 3D to 2D reduction. Right: 3D to 2D log-amplitude variances ratio versus α_z angle.

The 2D/3D ratio of log-amplitudes, equivalent to S_4^2 index ratio in low scattering regime, is represented in fig.1 (right) versus the angle α_z. The impact of the 2D plane position on 3D/2D log amplitude variances ratio is varying between 1 up to more than 5 in this configuration. Under low scattering regime, the same results have been obtained with numerical approach (using PWE-MPS technique) and asymptotic formulations (based on

Rytov approximation). This illustration shows the potential consequences of a bad choice of the 2D plane for a 3D to 2D dimensional reduction. All the details of this theoretical analysis can be found in [4]. The dimensional reduction is characterized theoretically under low scattering regime and numerically. The variances ratio obtained, for log-amplitude and phase, can be used as correction ratio to compensate the dimensional reduction approximation while benefiting from a considerably reduced computational load for 2D numerical schemes.

Key words: Ionosphere, GNSS, Scintillation, polar region, Parabolic Wave Equation, Phase Screen.

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