



HAL
open science

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

Vincent Fabbro, Laurent Féral, Hélène Galiègue, Sébastien Rougerie

► **To cite this version:**

Vincent Fabbro, Laurent Féral, Hélène Galiègue, Sébastien Rougerie. 3D to 2D approximation effect on propagation modeling, impact on scintillation indices in polar region. Beacon Satellite Symposium BSS 2016, Jun 2016, TRIESTE, Italy. hal-01353714

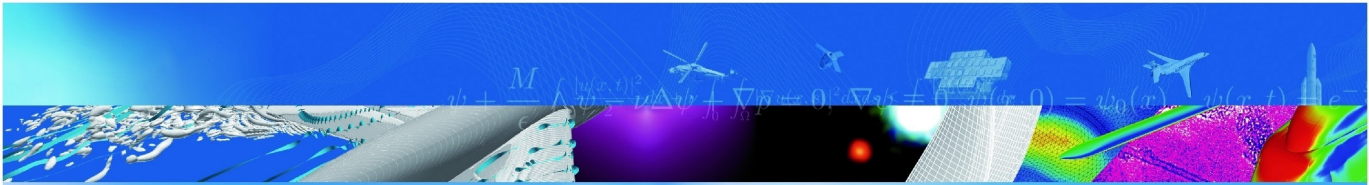
HAL Id: hal-01353714

<https://hal.archives-ouvertes.fr/hal-01353714>

Submitted on 12 Aug 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



COMMUNICATION A CONGRES

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

V. Fabbro (ONERA), L. Féral, H. Galiègue, S. Rougerie

Beacon Satellite Symposium BSS 2016

TRIESTE, ITALIE

27 juin-1 juillet 2016

TP 2016-453

70 2016
ans

ONERA

THE FRENCH AEROSPACE LAB

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

V. Fabbro¹, L. Féral², H. Galiegue³ and S. Rougerie⁴

¹ DEMR, ONERA, 2 avenue Edouard Belin, Toulouse, FRANCE.
(E-mail: vincent.fabbro@onera.fr)

² Laboratoire LAPLACE, GRE, Université Paul Sabatier, Toulouse, FRANCE.
(E-mail: lferal@laplace.univ-tlse.fr)

³ TELECOM-EMA, ENAC, 7 avenue Edouard Belin, Toulouse, FRANCE. .
(E-mail: helene.galiegue@enac.fr)

⁴ CNES, 18 avenue Edouard Belin, Toulouse, FRANCE. .
(E-mail: sebastien.rougerie@cnes.fr)

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 $\sigma_{\Delta N}^2 = 10^{18} m^{-6}$.

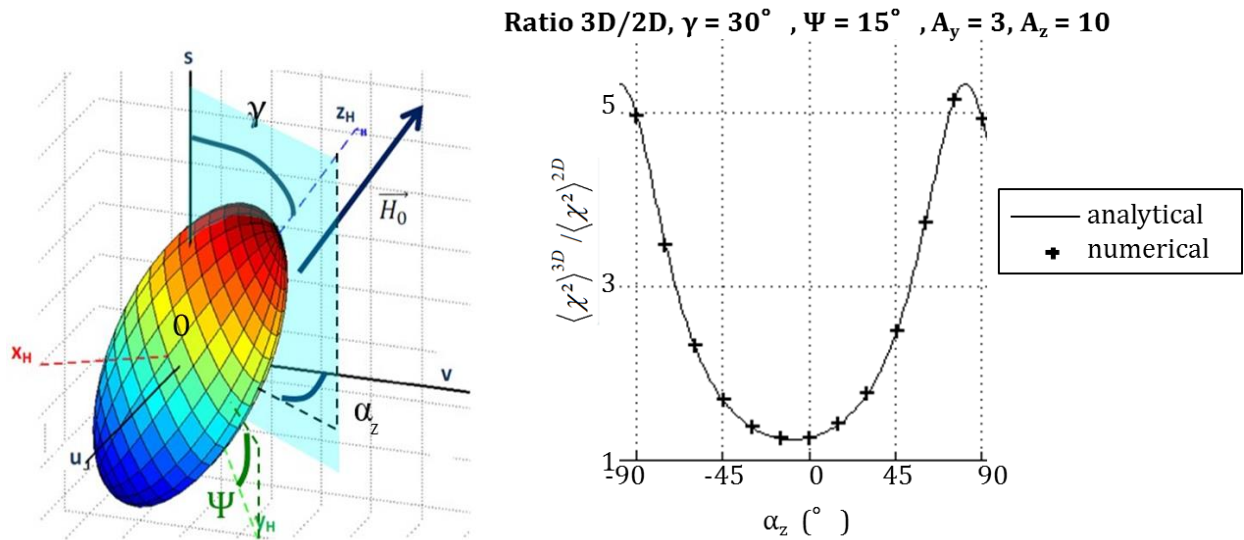


Figure 1. Left: high latitude configuration of anisotropy (\vec{H}_0 representing earth magnetic field), in blue the 2D cut plane of 3D to 2D reduction. Right: 3D to 2D log-amplitude variances ratio versus α_z angle.

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.

1. References:

[1] Béniguel Y., Adam J.-P., Jakowski N., Noack T., Wilken V., Valette J.-J., Cueto M., Bourdillon A., Lassudrie-Duchesne P., Arbesser-Rastburg B., Analysis of scintillation recorded during PRIS measurement campaign, *Radio Science*, vol. 44, RS0A30, 2009.

[2] Béniguel Y., Buonomo S., A Multiple Phase Screen Ionospheric Propagation Model to Estimate the Fluctuations of Transmitted Signals, *Phys. Chem. Earth (C)*, vol. 24, n°4, pp. 333-338, 1999.

[3] Fabbro, V., L. Féral (2012), Comparison of 2D and 3D electromagnetic approaches to predict tropospheric turbulence effects in clear sky conditions, *IEEE Trans. Antenn. Propag.*, 60, 4398 – 4407, doi: 10.1109/TAP.2012.2207070.

[4] Galiègue H. , Féral L., Fabbro V., Validity of the 2D electromagnetic approaches to predict 3D ionospheric scintillation effects: Log-amplitude and phase variances submitted to *Journal of Geophysical Research*.

[5] Knepp D. L., Multiple phase-screen calculation of the temporal behavior of stochastic waves, *proc. IEEE*, vol. 71, n°6, doi: 10.1109/PROC.1983.12660.

[6] Livingston R. C., Rino C. L., Owen J., Tsunoda R. T., The anisotropy of High-Latitude nighttime F region irregularities, *Journal of Geophysical Research*, vol. 87, n° A12, pp. 10,519-10,526, 1982.

[7] Rino, C. L. (1979), A power law phase screen model of ionospheric scintillation, 1. Weak scatter, *Radio Science*, vol. 14, n°6, pp. 1135-1143, doi: 10.1029/RS014i006p01135.

[8] Rytov, S. M., Yu. A. Kravstov, V. I. Tatarskii (1989), *Principles of statistical radiophysics*, 4. Wave propagation through random media, Springer – Verlag.

[9] Wheelon A. D. (2004), *Electromagnetic scintillation*, I. Geometrical Optics, II. Weak scattering, Cambridge University Press, doi: 10.1017/CBO9781139165297.

2. **Acknowledgements:** This work has been performed during Helene Galiegue PhD and funded by CNES and ONERA.