IONOTOMO: Ionospheric Tomography by OTH radar

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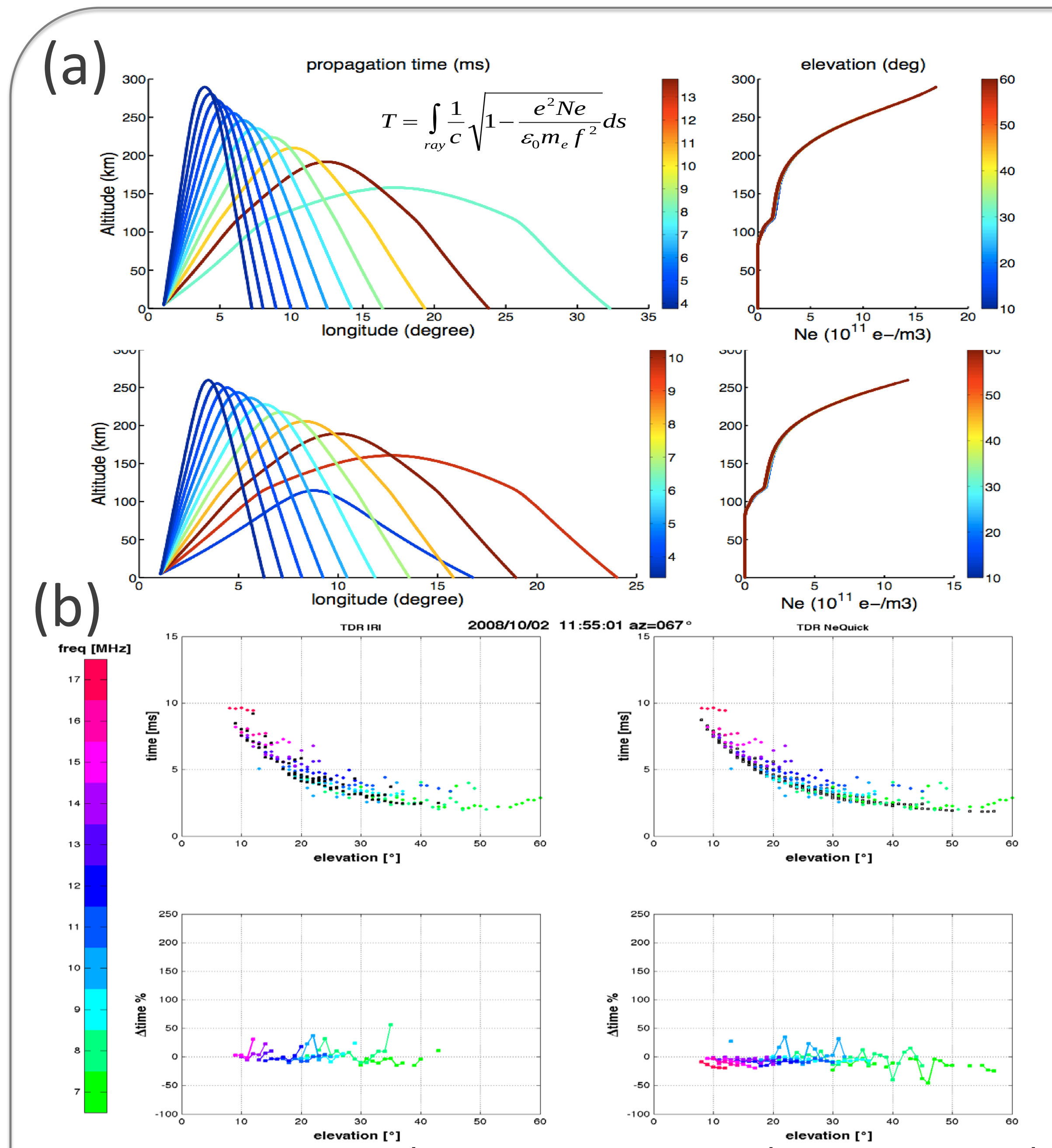
Abstract: Most of the recent methods in ionospheric tomography are based on the inversion of the Total Electron Content (TEC) measured by ground-based GPS receivers [e.g., Garcia et al. 2008]. As a consequence of the high frequency of the GPS, the electron density structure is principally well reconstructed at the F2 region, where the ionosphere reaches the maximum of ionization, neglecting the lower ionosphere. Here we present a new tomographic method of the lower ionosphere, based on the full analysis of over-the-horizon (OTH) radar data. Previous studies in ionospheric tomography by OTH radar (Fridman and Fridman, 1994; Ruelle and Landeau, 1994; Landeau et al., 1997; Fridman, 1998) are all based on the inversion of the leading edge echo curve, consequently an important amount of valuable information present in the data is necessarily neglected. To overcome this limit, we set up an inverse problem based on the ray-tracing tool TDR: comparing data with the synthetic propagation of electromagnetic wave in an a priori heterogenic 3D ionosphere (NeQuick) we achieve to map lateral variations in plasma density. The major advance of our methodology is to take into account, numerically and jointly, the variation from the electron density model and the perturbation in the ray-path. The developed methodology will be presented in details using a set of synthetic benchmark tests.

OTH-Radar data & synthetics

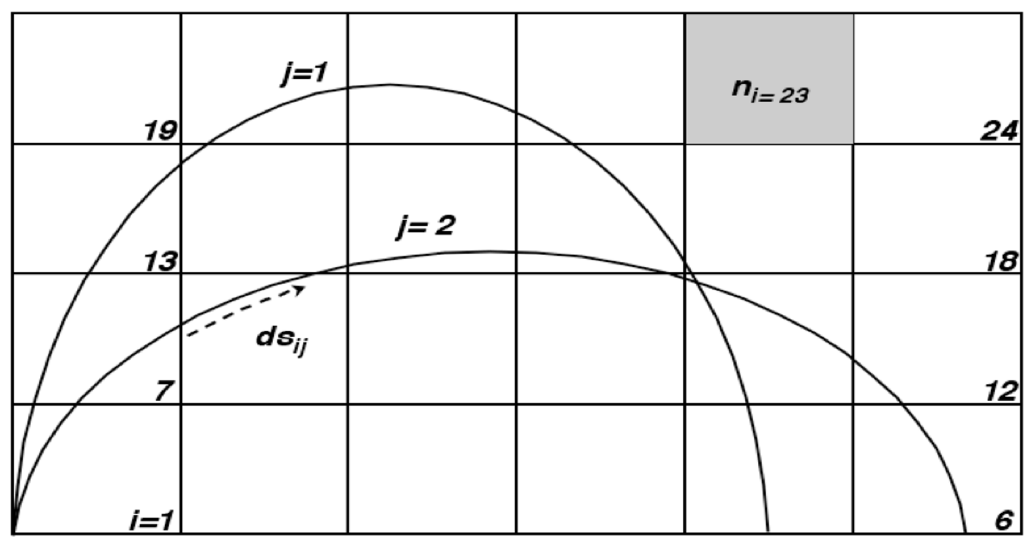


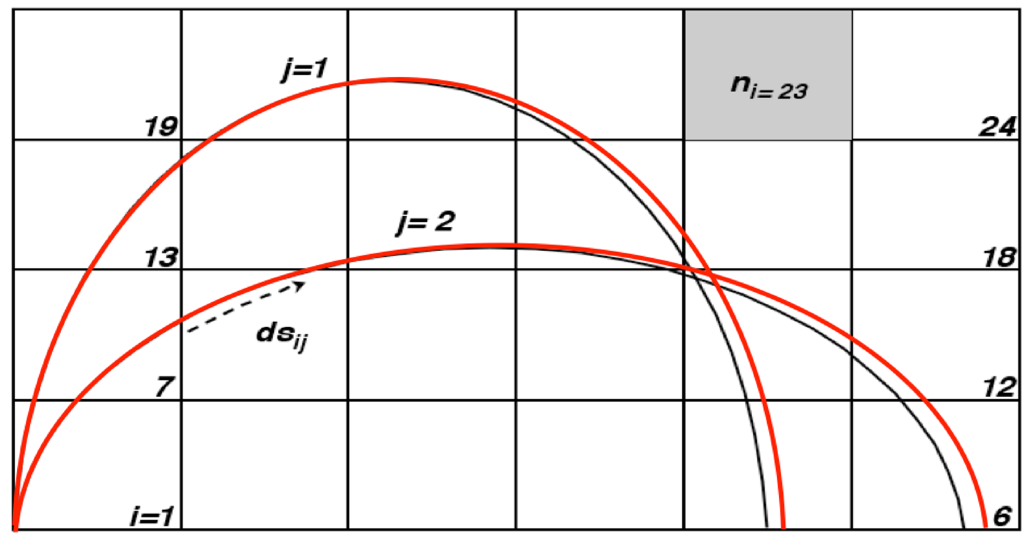
$$T^{data} = \int_{ray} \frac{ds}{c} - 40.3\int_{ray} \frac{N_e^{real}}{cf^2} ds = \underbrace{\int_{ray} \frac{ds}{c} - 40.3\int_{ray} \frac{N_e^{synth}}{cf^2} ds}_{T^{synth}} - 40.3\int_{ray} \frac{\partial N_e^{real}}{cf^2} ds$$

Electromagnetic (EM) waves emitted at high frequencies (HF, 3-30 MHz) have the intrinsic property to be refracted by the ionosphere [e.g., Schunk & Nagy, 2000]. The refraction index *n* of an EM wave propagating into the ionospheric plasma at frequency *f* depends on the electron density *Ne*; the electron charge *e* and mass *m* and the vacuum permittivity ε_0. OTH radars usually work taking advantage of this refraction. We developed here a methodology applied to monostatic OTH-Radar, e.g. Nostradamus [Bazin et al., 2006]. Synthetic ray-paths are shown in (a), comparisons between Nostradamus a data and synthetics (with IRI and NeQuick models) are shown in (b).

Linear and Non-Linear Inversion method

The linear inversion takes into account only the velocity variation of EM waves induced by *δNe*. Additionally, the non-linear inversion takes also into account the geometric ray-path variation induced by *δNe* [Snieder & Spencer, 1993].





$$dT_j = T_j^{data} - T_j^{synth} = -40.3\int_j \frac{\partial_i N_e^{real}}{cf_j^2} ds_{ij}$$

$$dT = A \cdot \partial N_e \Rightarrow^{-1} \partial N_e = A^{-1} \cdot dT = (A^T \cdot A + \lambda I)^{-1} \cdot A^T \cdot dT$$

λ is the damping parameter

$$dT_j = T_j^{data} - T_j^{synth} = -40.3\int_j \frac{\partial_i N_e^{real}}{cf_j^2} ds_{ij} \quad A\partial N_e$$

$$-\left[40.3\int_j \frac{N_{ei}^{synth} + \partial_i N_e^*}{cf_j^2} ds_{ij} - 40.3\int_{j^*} \frac{N_{ei}^{synth} + \partial_i N_e^*}{cf_j^2} ds_{ij}^*\right] \quad A''\partial N_e$$

The matrix A'' is numerically computed from the linear matrix A and an imposed cell perturbation δNe^*.

$$dT = A\partial N_e + A''\partial N_e \Rightarrow^{-1} \partial N_e = (A + A'')^{-1}\, dT$$

$$\partial N_e^* \text{ (e.g., 1\%)} \rightarrow A'' = dT^* / \partial N_e^* - A$$

Conclusion & References

We presented here a new methodology to determinate local ionospheric electron density from monostatic OTH-Radar data (*e.g.*, Nostradamus). The presented inverse method takes into account the EM wave velocity variation, as well as the ray-path deformation, both produced by the electron density variation δNe. We highlight that the non-linear solution taking account both effects is more stable and strongly independent of the damping parameter λ, consequently it could be used for real-data inversion and routinely estimation of plasma density.

[Fridman and Fridman, 1994] J. Atmos. Terr. Phys., 56, 115-131, 1994. [Ruelle and Landeau, 1994] J. Atmos. Terr. Phys., 56, 103-114, 1994. [Landeau et al., 1997] J. Atm. Solar Terr. Phys., 59, 125-138, 1997. [Fridman, 1998] Radio Sci., 33, 1159-1171, 1998. [Garcia & Crespon, 2008] Radio Sci., 43, RS2014, 2008. [Snieder & Spencer, 1993], Geophys. J. Int., 115, 456—470.

Inversion Results

The solutions presented here are obtained with a single iteration and fixed damping parameter λ