Quantitative Analysis of the Ionosphere Influence on the Neutral Bending Angle Error for GNSS Radio Occultation Based on COSMIC Data

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Abstract: Radio Occultation based on Global Navigation Satellite System signals (GNSS RO) is an increasingly important remote sensing technique. Its measurements are used to derived parameter of the Earth's atmosphere, e.g. pressure, temperature and humidity, with good accuracy. The systematic residual error present on the data processing is related to ionospheric conditions, such as the distribution of electrons and the resultant vertical gradient. This study investigates the relationship between these parameters and the residual ionospheric error (RIE) on the retrieved bending angle with special emphasis on the impact of small-scale vertical structures in the ionosphere. Chapman function combined with sinusoidal perturbations are used to model electron density profiles and compared to RO measurements of the ionosphere to perform the investigation. The results confirmed that the major ionospheric influence on the retrieval error is related to the F-peak electron density, whereas small-scale vertical structures play a minor role.

Goals

- Investigate the influence of small-scale vertical structures in electron density profiles on the residual ionospheric error after standard ionospheric correction: the disturbances are modelled as sinusoidal perturbations;
- Investigate the influence of the electron density peak on the F-layer range.
- Compare the RIE yielded by analytic model to electron density profiles retrieved from COSMIC measurements.

Standard Ionospheric Correction

$$\alpha_c(a) = \frac{\alpha_{L1}(a)f_{L1}^2 - \alpha_{L2}(a)f_{L2}^2}{f_{L1}^2 - f_{L2}^2} \quad (1)$$

Residual Ionospheric Error:

$$\Delta\alpha = |\alpha_c - \alpha_n| \quad (2)$$

Modelling the Atmosphere

Electron Density

$$\rho(r) = \rho_E(r) + \delta\, \rho_F(r) \quad (3)$$

Disturbance

$$\delta = 1 + \beta \sin\left(\frac{2\pi r}{L_0}\right) \quad (4)$$

Asymmetric Chapman Layer

$$\rho_{E,F}(r) = \rho_{maxE,F}\ \exp\left(\frac{1}{2}\left(1 - u_{E,F} - e^{u_{E,F}}\right)\right) \quad (5)$$

$$u_{E,F} = \frac{r - r_{0(E,F)}}{H_{E,F}} \quad (6)$$

Refractive index

$$n_{L1,2}(r) = n_{neutral}(r) + \frac{40.3\,\rho(r)}{f_{L1,2}^2} \quad (7)$$

Table 1: Parameters for the analytic model

β	0%, 1%, 3% and 10%
L_0	5 km
ρ_{maxE}	2x10^{11} el/m^3
ρ_{maxF}	[1, 4, 10, 40, 100, 400, 1000]x10^{10} el/m^3
r_{0E}	105 km
r_{0F}	300 km
H_E	10 km
H_F	50 km

Electron Density Profiles

For comparison with realistic conditions, twenty cases have been selected from a dataset of an empirical model for the ionospheric electron density. The dataset gathers ionospheric profile inverted from raw COSMIC measurements.

Occultation Scintillation Proxy Index (OSPI) have been applied to the electron density profiles in order to categorize clean and disturbed scenarios.

$$OSPI = \frac{\sigma\Delta\rho(r_{min}, r_{max})}{\rho_{maxF}} \quad (8)$$

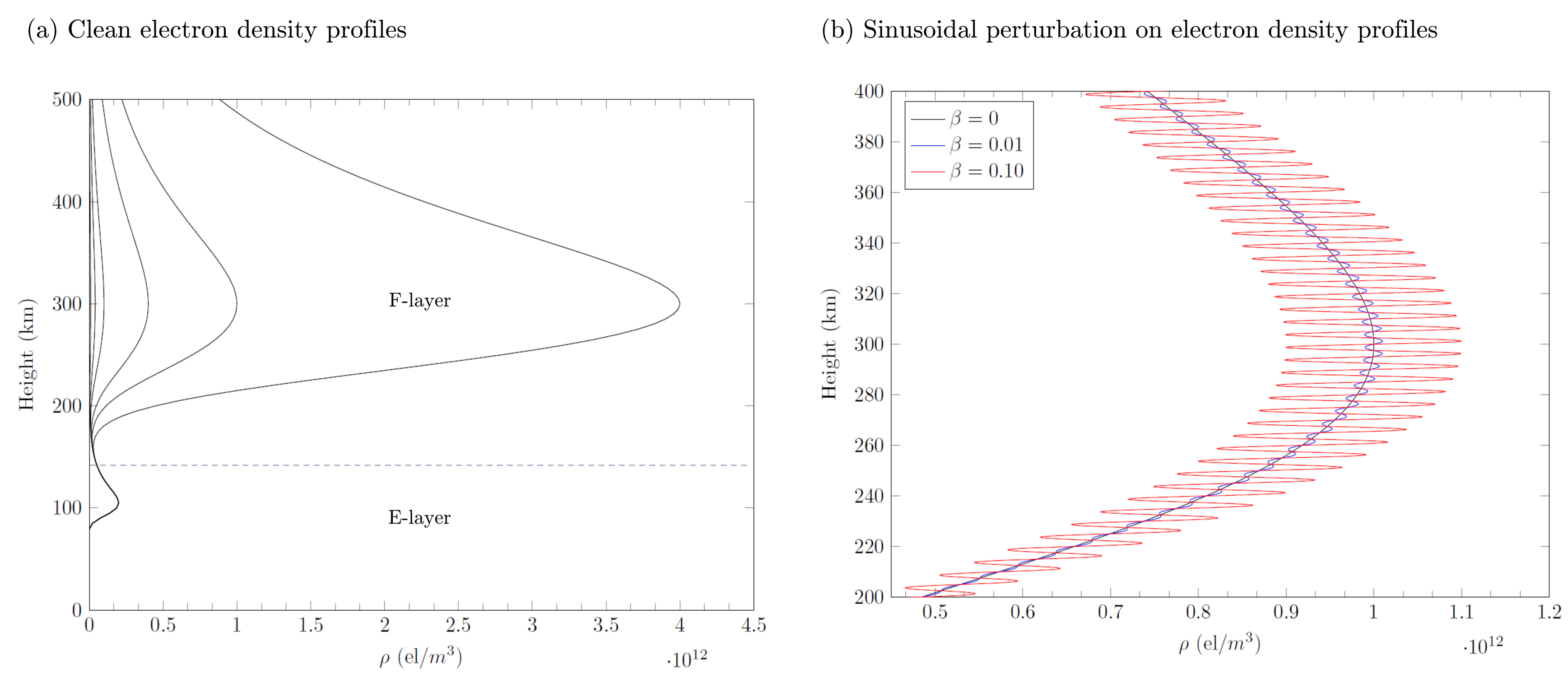

Figure 1: Electron density profiles modelled with Chapman function. (a) Profiles assuming $\beta = 0{,}00$ and (b) detailed view of disturbance

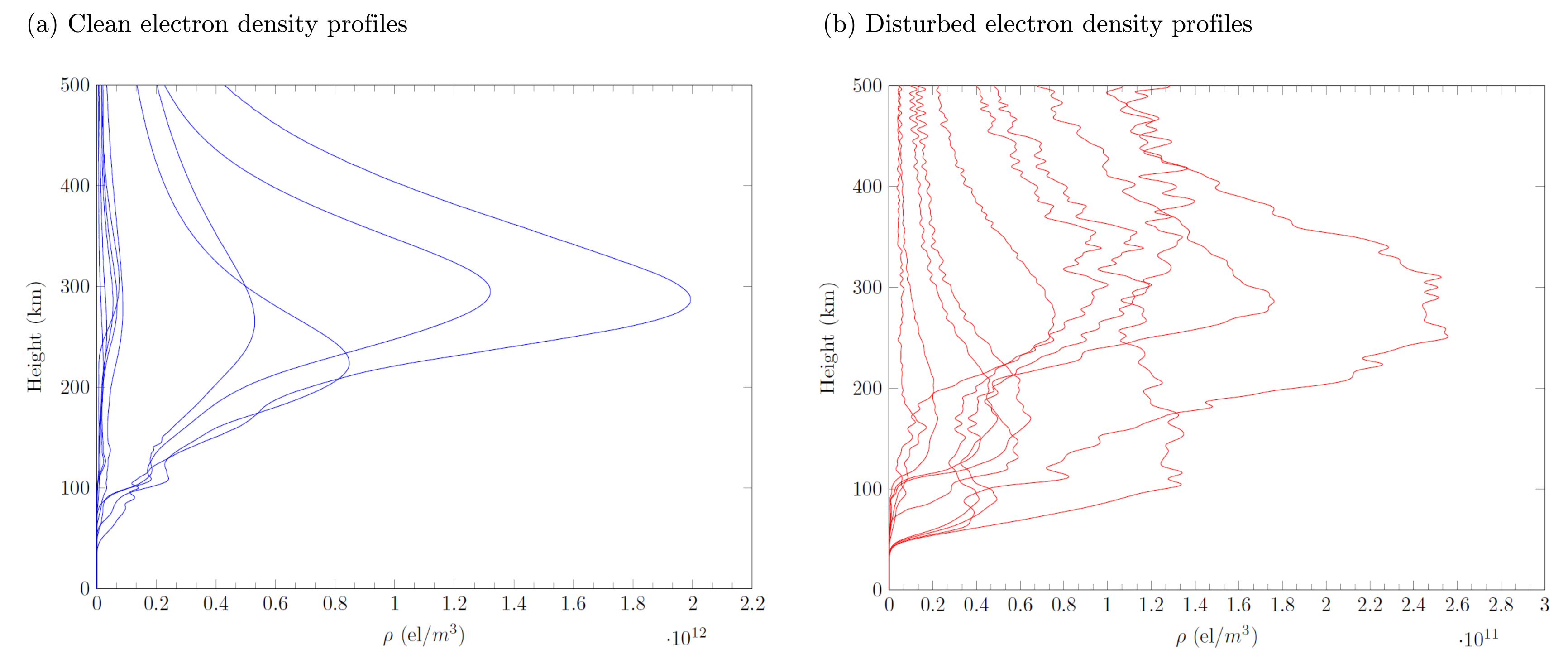

Figure 2: Electron density profiles based on COSMIC measurements with (a) OSPI < 0,001 and (b) OSPI > 0,0031.

Simulation & Results

A wave optics propagator assuming Multiple Phase Screen technique has been implemented to simulate the propagation of the GNSS signals through the Earth's atmosphere. The simulations considered exponential neutral refractivity for both analytic and realistic cases. The neutral bending angle given by the standard correction (α_c) is compared to a reference bending angle (α_n), retrieved from Abel Transform, which assumes an neutral atmosphere with exponential refractivity as well.

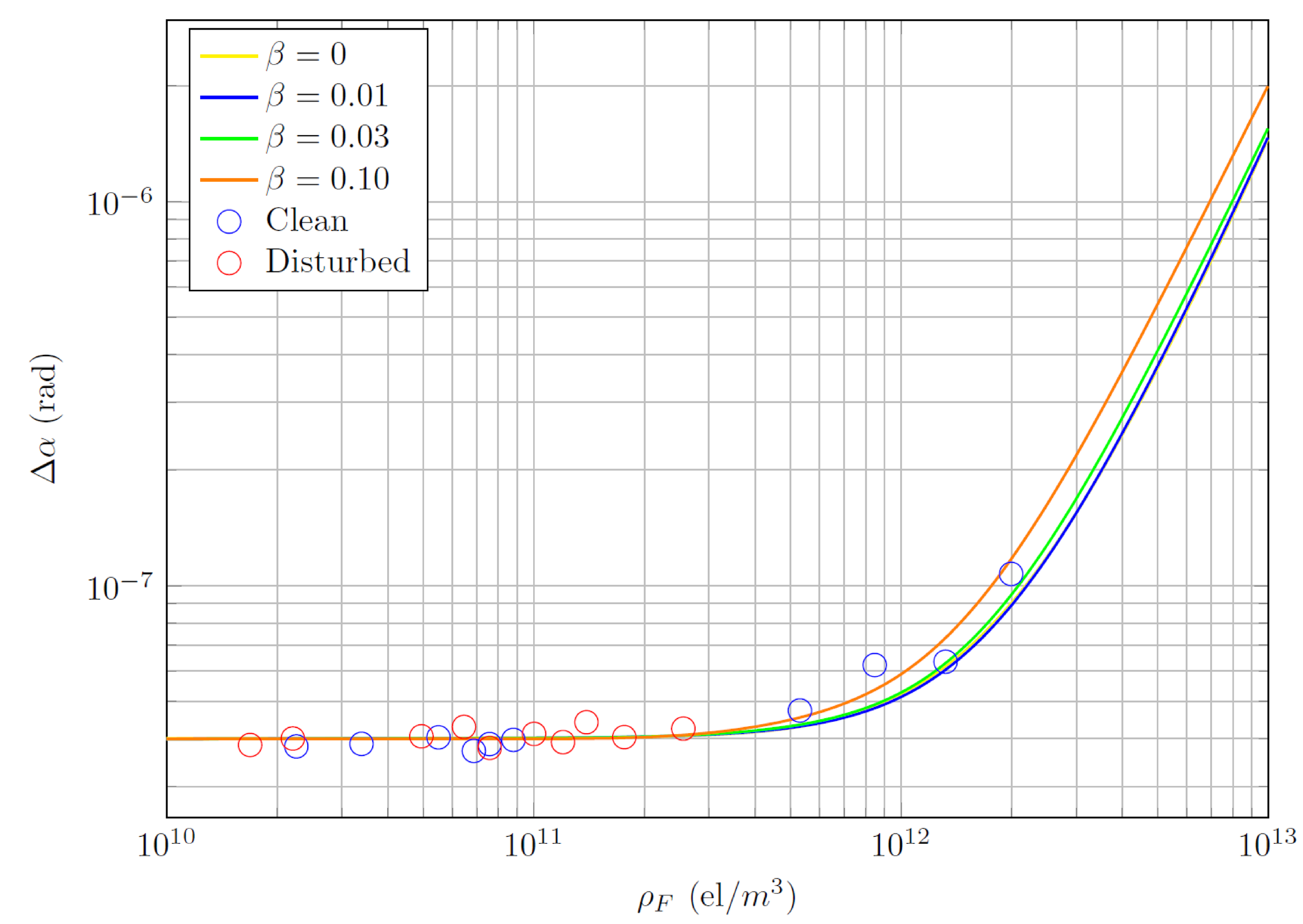

Figure 3: Neutral bending angle error as a function of the F-peak electron density. Comparison depicts an agreement between analytic (solid curves) and dataset cases (circles). The residual ionospheric errors presented in the plot correspond to the maximum RIE observed within 20 km and 40 km (impact height).

Conclusions

- Good agreement between the scenarios defined with analytic model and realistic profiles;
- Disturbance on the electron density profile presented minor influence on the residual ionospheric error. Results considering either analytic model or dataset cases support this conclusion;
- F-peak electron density has major contribution on the residual ionospheric error.

References
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