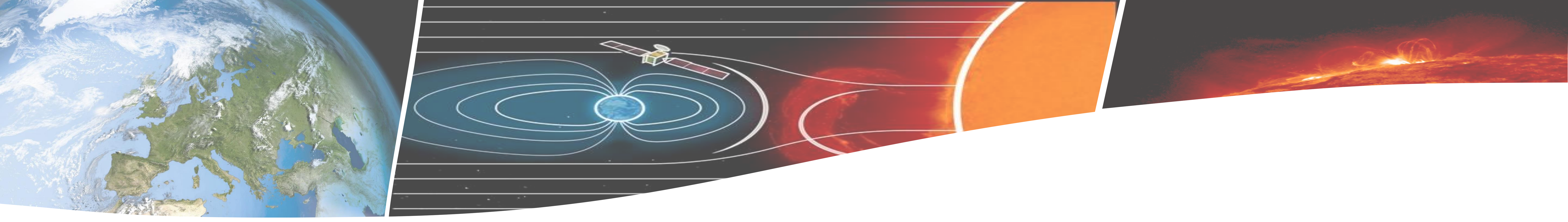

Extension of scintillation modeling capabilities with the GISM to polar regions

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Introduction

Recently we acquired the Global Ionospheric Scintillation Model (GISM) which is based on the multiple random phase screen method [1]. Currently this model is capable to cover the low-latitude regions only and our efforts are focused on the model extension to high- and polar latitudes before deploying the model in the operational service. For this purpose, it is planned to use the recently developed method of phase gradient screens that allows to simulate refractive-type of scintillation caused by scattering on strong ionospheric gradients [2]. The climatology of the required gradient field is deduced from the in-situ measurements of electron density onboard of Swarm satellites spanning the period of 10 years of data collection. In this connection, the method of empirical orthogonal functions has been used to relate the gradient values and the relevant driving parameters such as the solar flux index, solar wind coupling parameter, strength of the geomagnetic field, etc. Another source on gradient strength required for simulation comes from the ROTI model developed by Y. Jin et al. [3].

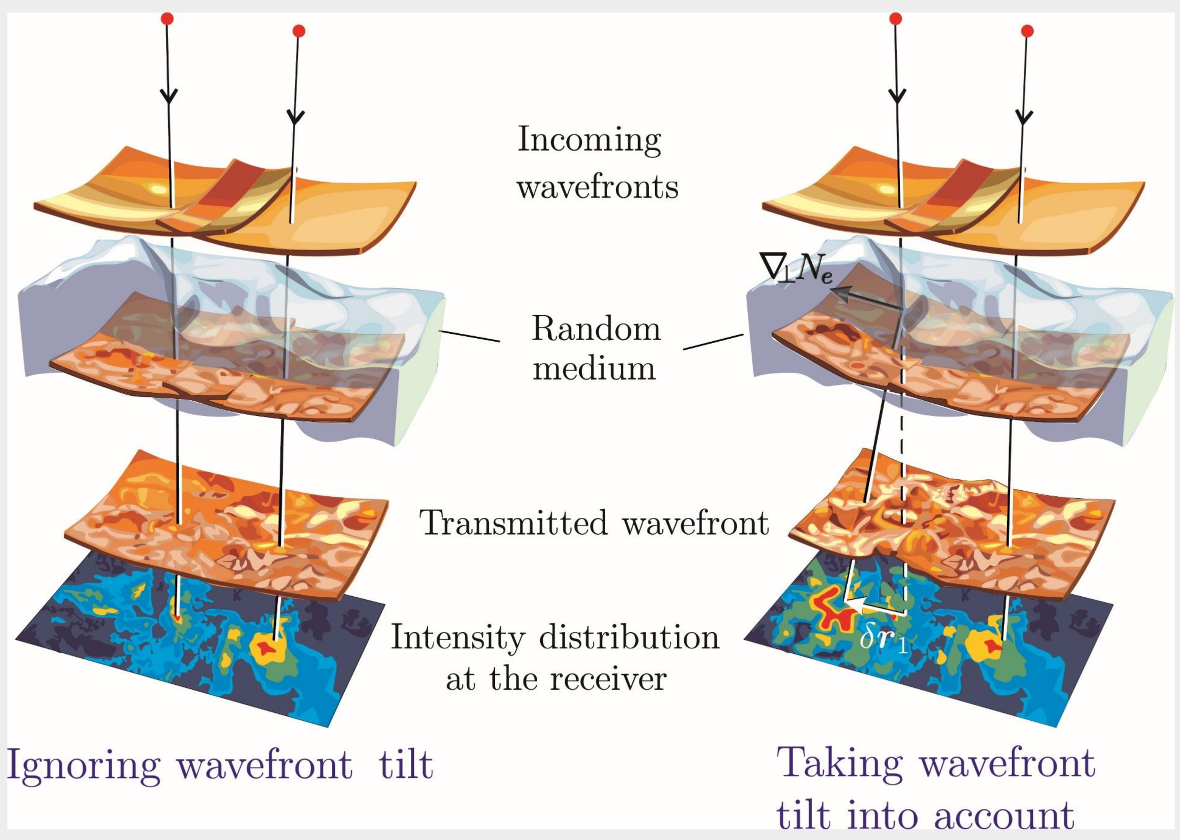
Methods

Recently, we proposed the phase gradient screen model [2] to simulate random refractive effects (refractive scintillation) on the propagation of radio waves through the randomly inhomogeneous ionosphere. Refractive scintillation arises from the random refractive bending of signal rays at sharp boundaries of ionospheric irregularities, i.e. at locations characterised by large ionospheric gradients.

Refractive scintillation is simulated by adding the term

$$\delta\varphi_{refr} \sim \nabla_{\perp} TEC \cdot \nabla_{\perp} N_e \sim \frac{1}{v_{drift}} ROTI \cdot \nabla_{\perp} N_e \qquad (1)$$

to the conventional phase screen and then simulating the wave propagation from the resulting phase screen to the receiver location. Here $\nabla_{\perp} TEC$ is the spatial gradient of the total electron content transverse to the propagation direction, N_e is the electron density field, v_{drift} is the plasma drift velocity and $ROTI$ is the temporal gradient of the TEC. Equation (1) follows if one considers the second-order corrections with respect to the fluctuating part of N_e in the decomposition of the phase disturbance of the propagating wave [2].



Ordinary phase screen (left) and gradient phase screen (right) acting on the propagating wave. The gradient phase screen takes into account the beam bending effects, which also result in additional curvature of the phase front (phase scintillation) and additional amplitude fluctuations (amplitude scintillation).

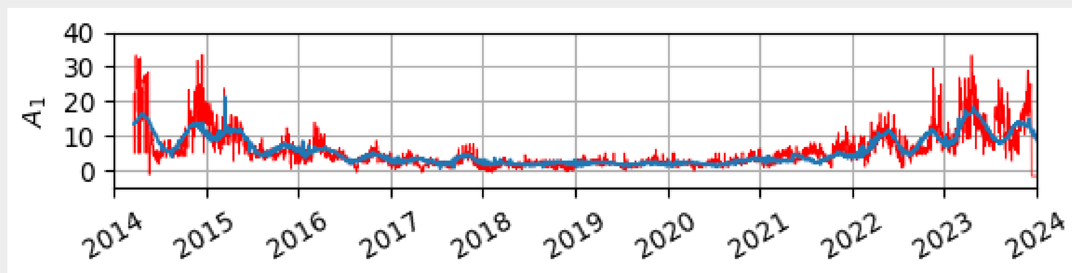
Preliminary Results

The current version of the GISM does not support scintillation simulations over polar regions. In these regions scintillation manifest themselves primarily in signal phase fluctuations and have predominantly refractive nature. We plan to implement the idea of phase gradient screens for simulating high-latitude scintillation with the GISM.

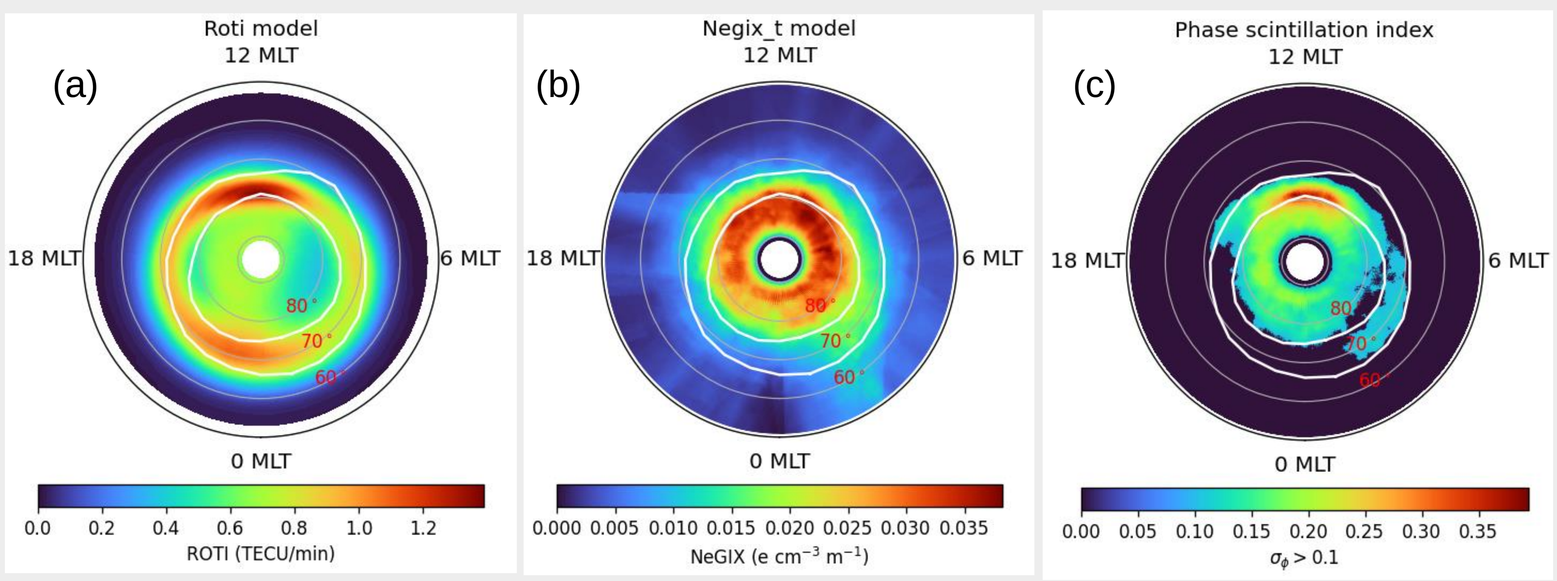
For the $ROTI$ component in (1) we use the empirical model of Yaqi Jin et al. [3] that is based on the empirical orthogonal function (EOF) method and uses the day of the year, $F_{10.7}$, Dst, K_p, B_{total}, B_y, B_z, E_{KL} values as the model driving parameters (see for details the original publication).

For the component $\nabla_{\perp} N_e$ in (1), we constructed a similar model by using the electron density gradient data from the Swarm satellite mission collected during 2014-2023 (NeGIX data product). Due to the limited spatial coverage of Swarm satellites over the polar ionosphere during the day, the model uses only one term in the EOF decomposition. The driving parameters are doy, $F_{10.7}$, sunspot, Dst, K_p, A_p, B_{total}, B_y, B_z, E_{KL}.

Both models allow one to simulate phase scintillation with morphology similar to the observed [4].



Coefficient of EOF decomposition for the NeGIX: red- empirical values, blue – the linear regression model



Models for ROTI (a), Negix (b), and phase scintillation index (c) for 28th of August 2024 (doy=241) with driving parameters taken from omniweb.gsfc.nasa.gov for that day. The boundaries of the auroral oval are also shown as white lines.

Conclusion

- The phase gradient screen approach is effective for simulating high latitude phase scintillation index.
- The algorithm requires the knowledge of the values of TEC and electron density gradients (or, equivalently, of ROTI and NeGIX) for the region of interest. We use the empirical models for ROTI and NeGIX, which require similar sets of driving geophysical parameters.
- The phase screen simulation technique discussed will be integrated into GISM in the near future.

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