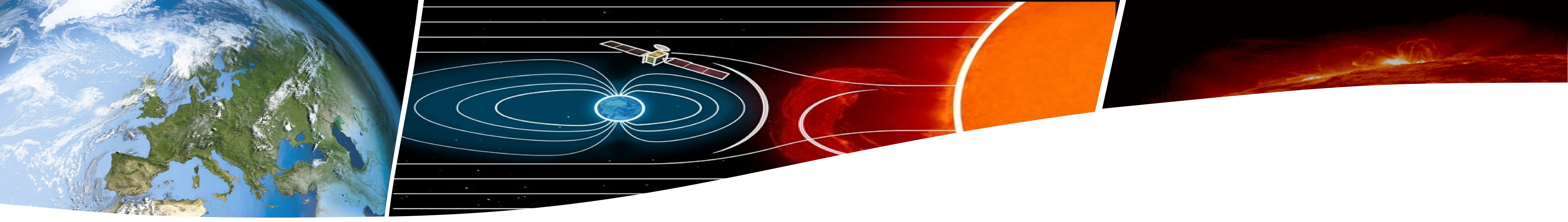

Scintillation on transionospheric radio signals

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Motivation / Introduction

A radio wave propagating in the upper and lower atmosphere of the earth suffers a distortion of phase and amplitude. When it crosses ionospheric irregularities, the radio wave experiences fading, phase distortions, angle of arrival fluctuations. These signal fluctuations are known as scintillation and vary significantly with magnetic and solar activity, day of the year, time of the day, operating frequency, or communication link geometry.

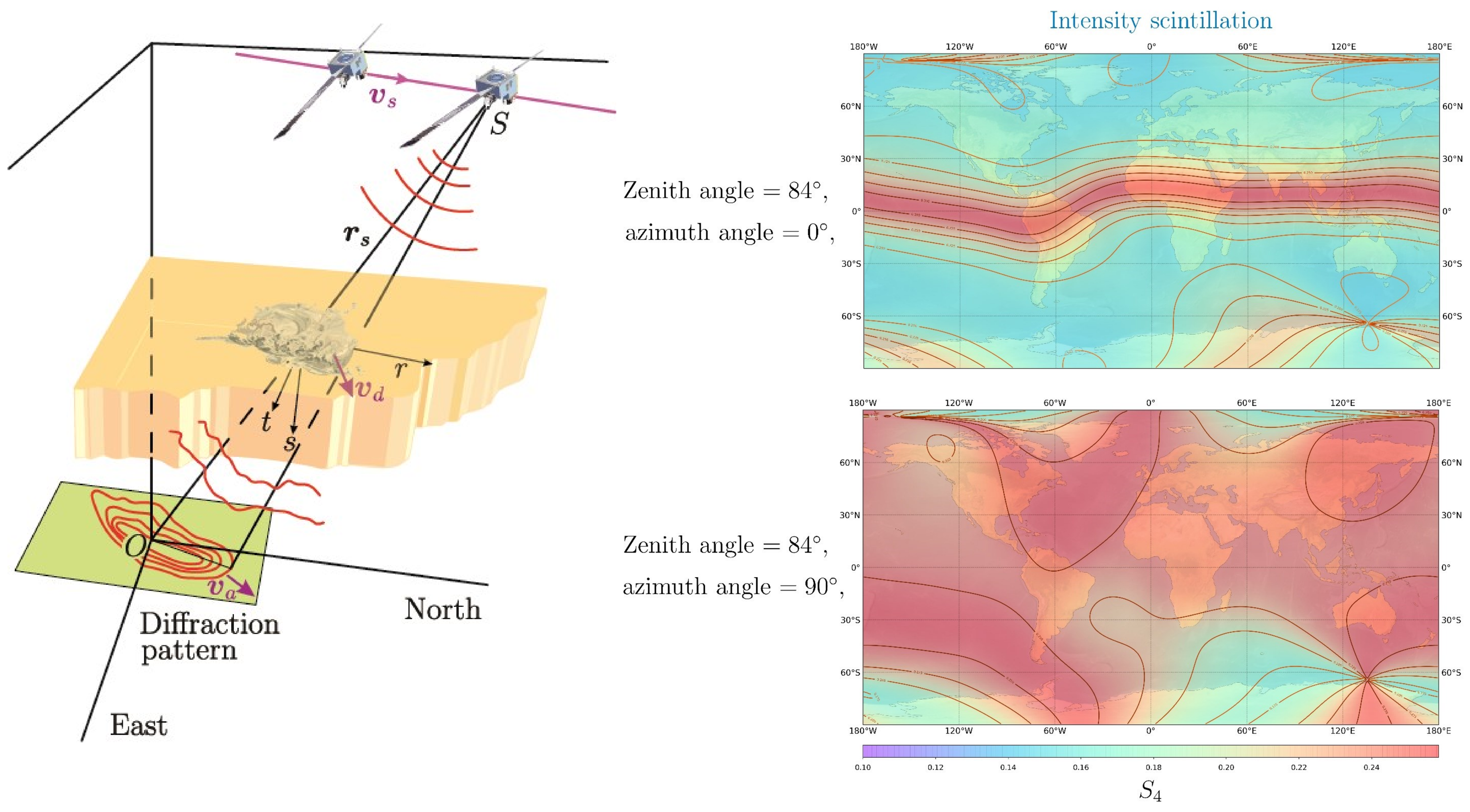
Scintillation phenomena have negative impact on the robust and reliable performance of many services, such as GNSS positioning, navigation, and timing. It is responsible for degradation of images from radio telescopes and synthetic aperture radars. It distorts and degrades signals from communication and remote-sensing satellites. The estimation and forecast of scintillation levels is essential for risk assessment for Ground Based Augmentation Systems.

In our Institute of Solar-Terrestrial Physics we conduct the fundamental research aiming to describe different aspects of scintillation phenomena. We also model scintillation levels by means of numerical simulations in the framework of the Global Ionospheric Scintillation Model (GISM). The scintillation indices obtained with the GISM are planned to be provided as one of the IMPC services.

Scintillation modeling

The figure below (left) shows the typical scattering geometry of a signal sent by a satellite . The signal propagates through a layer of the disturbed ionosphere and scatters on the ionospheric irregularity. The latter can be considered as being the bunch of tangled vortices and blobs of different sizes and electron densities. The phase of the propagating wave exhibits random modulation while scattering on such electron density inhomogeneities. When observed on the ground, the signal wave forms a complex diffraction pattern. Across such a pattern the correlation analysis may reveal both phase and amplitude fluctuations, i.e., phase and amplitude scintillation. The latter are characterized by phase, σ_φ, and amplitude, S_4, scintillation indices, which are related to the variances of the corresponding quantities.

The scintillation-producing ionospheric irregularities are primarily aligned along the geomagnetic field and are elongated along this direction. This results in the anisotropy of associated scintillation and in the so-called geometric enhancement of the scintillation indices. Scintillation is enhanced if the signal propagates along the direction of irregularity's elongation. The figure below (right) shows an example of scintillation anisotropy and scintillation geometric enhancement effects.



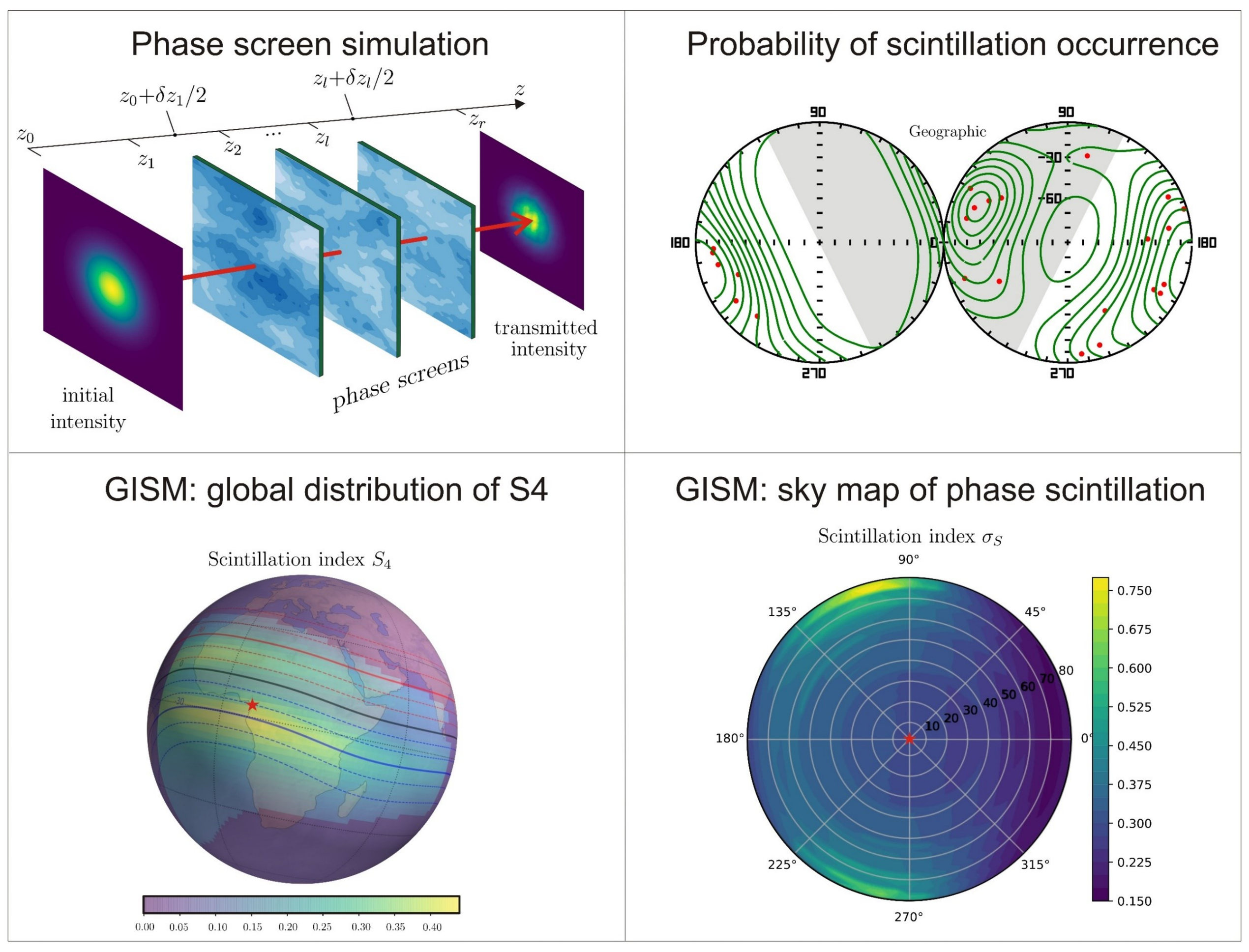
Left: geometry of typical propagation of radio signal through disturbed ionosphere.
Right: geometric enhancement of amplitude scintillation at large zenith angles. Maps at two azimuthal directions are given in order to show the anisotropy of scintillation indices. To illustrate the anisotropy phenomenon, the electron density is set to constant for the whole globe.

Scintillation simulation

Scintillation phenomena can be also simulated on the computer. Simulations are based on the random phase screen simulation technique. The random medium in this technique is represented as a set of properly generated random phase-modulating plates placed along the propagation path of the signal wave. Each screen modulates the phase of the propagating wave. Simulation of propagation is repeated multiple times and based on the collected data, the statistical quantities such as the scintillation indices are obtained.

An important part of simulation relies in the inferring the probability of occurrence of scintillation-associated irregularities. The simulated scintillation indices should be thus understood as the conditional expectations related to the occurrence probability of ionospheric irregularities.

Our Institute is in charge of further development of the Global Ionospheric Scintillation Model (GISM) that has been handed over by our colleagues from the IEEA (France). This model is based on the mentioned simulation principles and some of its outputs are shown below:



Outlook / Conclusion

Ionospheric scintillation is the rapid modification of phases and amplitudes of radio waves caused by small scale structures in the ionosphere. Severe scintillation has a negative impact on many life-critical services. It can prevent a GNSS receiver from locking on the signal. This may make impossible to calculate the position of the object of interest such as a landing aircraft or a docking vessel. The connected risks and losses might be high. Therefore, the ability to model, to simulate, and to predict scintillation phenomena is of great importance.

In our Institute we conduct both fundamental research of scintillation phenomena and service provision of scintillation-related products. Our recent studies were focused on the proper inclusion of anisotropy effects in the scintillation theory. The dependence of scintillation levels on local geomagnetic field, the observer's zenith and azimuth angles, the anisotropy of ionospheric irregularities has been thoroughly studied. The resulting theoretical model is implemented for proper phase screen generation technique, used in the computer simulation of scintillation phenomena. The corresponding simulation program, the GISM, is planned to be deployed as one of the IMPC services. This program is intended to deliver in the nearest future various scintillation products such as: global distributions of scintillation indices, sky maps of scintillation for specified ground stations, communication outage regions for UHF communication satellites, to name just a few.

References:

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