Scintillations on LEO polar orbiting beacon signals in presence of Sporadic E layers recorded by EISCAT

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Abstract

Ionospheric plasma density irregularities may cause rapid fluctuations in the intensity and phase of radio waves propagating through. Usually, scintillation events are modelled in the diffractive scattering approach which is valid for weak scattering conditions. Some mathematical tricks help then in reproducing high levels of scintillation, lacking of full physical meaning. Strong scintillation events are better modelled in the refractive scattering approach, which includes weak scattering conditions. A few parameters (e.g., spatial correlation length and drift velocity) are of key importance in understanding which approach may be correct.

Two EISCAT measurement campaigns were set up in the framework of the Trans-National Access programme, in order to infer and calculate all those parameters useful for numerical modelling of scintillation events. The radar measurement results are compared with transionospheric radio signals at VHF, UHF, and L band in order to understand the feasibility and appropriateness of the two approaches.

1 Introduction

Transionospheric radio waves may experience random fluctuations in amplitude and phase, due to diffraction when traversing drifting small scale plasma density irregularities. Received radio signal components show irregular (stochastic) fluctuations of amplitude and phase. If other parameters of received signals like polarization, angles of arrival, etc., are considered, they also show scintillation effects. All scintillation effects strongly depend on the frequency of the signal component considered. The principles of wave propagation lead to the conclusion that the scintillating signals must have encountered irregular fluctuations of the refractive index somewhere along the propagation path. Since satellite to ground radio links use frequencies which are well above the maximum electron plasma frequency of the ionosphere, irregular fluctuations of the signal amplitude and phase can be produced by electron density inhomogeneities in the ionosphere or by irregular fluctuations of neutral gas densities in the troposphere/stratosphere. This applies also for even higher operational frequencies. In the following we restrict observations to ionospheric irregularities. These depend on magnetic and solar activity, time of day, season of the year and magnetic latitude of the observation point. The properties of the ionospheric irregularities change with time and most of them are drifting. Overall, the ionospheric plasma can be considered as a random inhomogeneous medium, where medium to small scale structures in the electron density distribution have an anisotropic turbulent 2-D spatial spectrum [1].

Several theories have been developed for describing scintillation phenomena, including the phase screen, Rytov, and parabolic equation method. Weak and strong scattering regimes are usually distinguished when solving the propagation problem [2]. Efforts need to be focused into distinguishing refractive scattering from diffractive scattering cases and the geophysical conditions for the onset of electron density structures originating refractive scintillations [3]. The most important aspect of all modelling efforts is an appropriate and realistic description of the irregularities which are responsible for radio waves scintillation as observed at the ground. The estimate of similar plasma density irregularities has been done by using in-situ data as well as by means of measurements carried out by coherent and incoherent scatter radars. Scintillation producing plasma structures have been inferred at low latitudes. Such work has only been done at high latitudes to a minor extent. With particular reference to the description of strong scattering conditions, further information on plasma density irregularities is needed: namely, details about their electrodynamics, their geometry with respect to the geomagnetic field, their spatial electron density fluctuations.

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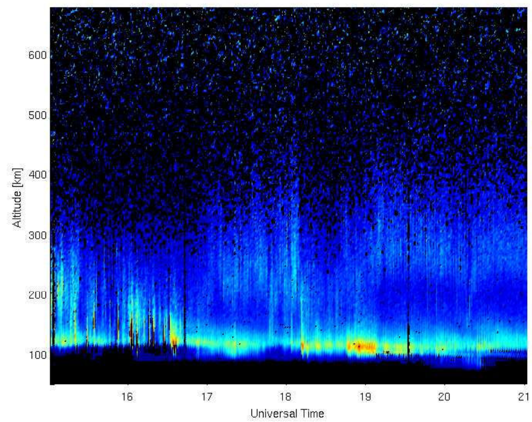


Figure 1: The electron density profile as measured by EISCAT in the day 26 November 2009.

2 The experiments

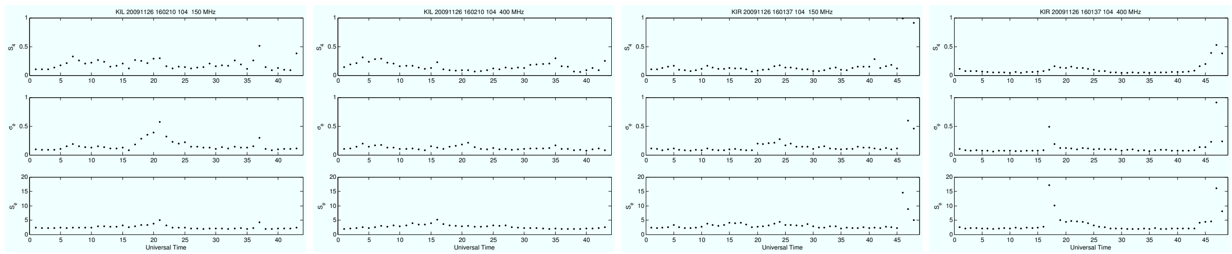
Under the Trans-National Access (TNA) programme two measurements campaigns have been carried out by using EISCAT radar network. The first campaign took place in the week 13-17 June 2009 while the second one took place in the week 23-27 November 2009. The incoherent scatter measurements have been conceived in order to observe ionospheric structures with different geometries: (a) field aligned, (b) along magnetic East, and (c) vertical. Both VHF and UHF methods were used in performing these measurements. The experiments were carried out in the local night sector, namely between 17 LT and 22 LT. In some cases, sporadic E (Es) layers have been observed, probably produced according to the ions accumulation driven by magnetospheric electric fields [4].

The comparison of LEO beacon signals with incoherent scatter radar measurements aimed at the calculation of parameters enabling for the modelling of strong scattering conditions. The modelling effort is needed to extract information on plasma density irregularities as related to the production of radio waves scintillation. In particular, the ionospheric irregularities need to be characterised in terms of (a) their drift velocity and direction as compared with simultaneous scintillation data at VHF, UHF, L band, (b) their shape with respect to magnetic field lines as compared to simultaneous scintillation data, (c) their correlation length during both weak and strong scattering regimes, and (d) their structure as related to multiple scattering occurrence.

Beacon signals received from Tsykada polar orbiting satellites at 150 MHz and 400 MHz have been recorded during the EISCAT measurement campaigns. After suitable detrending, scintillation and TEC rate of change have been calculated and compared with the structures observed by the incoherent scatter radar network. Several ground stations in the European auroral sector are considered for this purpose. The most intense Es layers were able to produce moderate to high scintillation events at different ground stations. L band scintillation data are also taken into account. In this case, GPS L1 raw data have been detrended in order to calculate typical scintillation indices [5]. A number of stations in the Euroepan auroral sector have been considered just to spatially integrate the information derived from beacon signals.

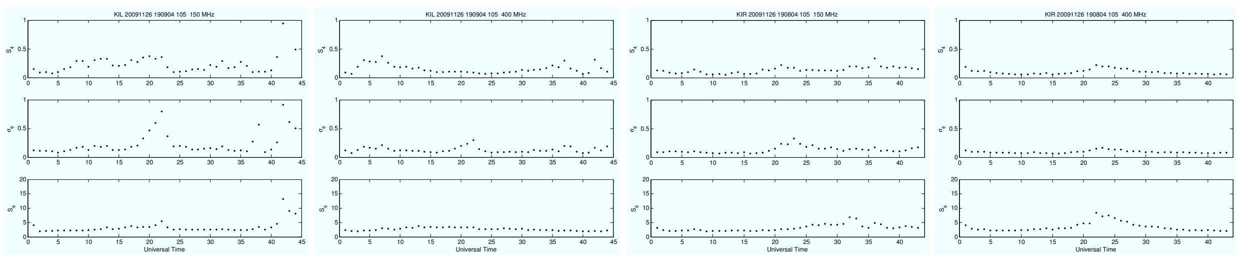
A particular case is shown in Figure 1, where the electron density profile was estimated by using EISCAT backscattered power. The measurement in Figure 1 refers to the day 26 November 2009, between 16UT and 22UT. Two particular events occurred during this measurement: one between 16UT and 17UT and another between 18UT and 1930UT. Those events seem to be connected with some sort of sporadic E layer.

At the same time, radio signals received from polar orbiting Tsykhada satellites (used for tomographic imaging) at 150 MHz and 400 MHz were recorded at some ground stations. Figure 2 shows the scintillation indices (S_4, σ_ϕ and S_ϕ) caclulated from the received signals sampled at a 50 Hz rate during the pass of a Tsykhada satellite. The pass shown in Figure 2 was simultaneous to the event recorded by EISCAT between 16UT and 17UT. Figure 2 shows the



(a) (b) (c) (d)

Figure 2: Scintillation indices from Tsykhada satellites as received from Kilijarvi and Kiruna between 16UT and 17UT of 26 November 2009: (a) Kilijarvi 150 MHz, (b) Kilijarvi 400 MHz, (c) Kiruna 150 MHz, (d) Kiruna 400 MHz.



(a) (b) (c) (d)

Figure 3: Scintillation indices from Tsykhada satellites as received from Kilijarvi and Kiruna between 18UT and 19UT of 26 November 2009: (a) Kilijarvi 150 MHz, (b) Kilijarvi 400 MHz, (c) Kiruna 150 MHz, (d) Kiruna 400 MHz.

scintillation indices as recorded from Kilijarvi (top plots) and from Kiruna (bottom plots). It can observed that a slight enhancement in the scintillation indices (particularly evident on σ_ϕ) was more evident on the 150 MHz signals on both stations, while the indices showed a smoother behaviour for the same ray paths. The situation was more evident for a pass around 1909UT in coincidence with the event occurring between 18UT and 1930UT, as detected by EISCAT. Those features would suggest a possible alignement of the ray path with magnetic field line. This would actually mean that the refractive scattering should be replacing the diffractive scattering.

3 Conclusion

The comparison of EISCAT measurement with scintillation indices measured over satellite radio signals confirmed the assumption that refractive scattering would be progressively responsible for high scintillation events. This is confirmed by the fact that the spatial correlation length was found to increase for those irregularities causing higher scintillation indices.

4 Acknowledgments

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5 References

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