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IMPACT OF THE SUBSTORMS AND POLAR CAP PATCHES ON GPS RADIO WAVES AT POLAR LATITUDES

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Abstract. The comparative research of the influence of substrorm precipitation and polar cap patches (PCP) on the GPS signals disturbances in the polar ionosphere was done. For this aim we use the GPS scintillation receivers at Ny-Ålesund, operated by the University of Oslo. The presence of the auroral particle precipitation and polar cap patches was determined by using data from the EISCAT 42m radar on Svalbard. We consider tens of events when the simultaneous EISCAT 42m and GPS data were available. We demonstrate that substorm-associated precipitations can lead to a strong GPS phase (σ_Φ) scintillations up to ~2 radians which is much stronger than those usually produced by PCPs. At the same PCPs can lead to strong ROT (rate of total electron content) variations. So our observations suggest that the substorms and PCPs, being different types of the high-latitude disturbances, lead to the development of different types and scales of ionospheric irregularities.

1. Introduction. The Global Navigation Satellite Systems (GNSS) become more important for modern society. Among the different GNSS GPS is a mostly used for the ionosphere studies because there are a lot of 2-frequency GPS receivers all over the world. The ionosphere as a medium for the radio waves propagation can have a negative influence on the quality of received signal. Irregularities in the plasma density distribution can lead to fast fluctuations of amplitude and phase of the signal which is referred to as ionosphere scintillations [1]. The strong scintillations reduce the quality of the signal and even lead to the signal loss. Thus, the investigation of GPS scintillations is an important aspect of space weather. The level of scintillations is characterized by the phase (σ_Φ) and amplitude (S_4) scintillation indexes.

Amplitude scintillations are caused by the plasma irregularities with scale sizes ranging from tens to hundreds of meters, while the phase scintillations are caused by the irregularities with the sizes from hundreds of meters to several kilometers. Ionospheric scintillations are most severe in the equatorial region and at high latitudes [2].

The most severe disturbances in polar ionosphere are substorms and polar cap patches. Polar cap patches are 100–1000 km islands of enhanced plasma density being segmented from the dayside high-density plasma in the cusp region [3].

In paper [4] it was found that polar cap patches have their biggest impact on GPS signals once they reach the nightside auroral oval, in particular when combined with upward field-aligned currents. It is shown in the paper [5] that PCP can produce GPS scintillations quite comparable with scintillations during the particle precipitation with appearance of strong green aurora.

In the present work we address the following question: substorm particle precipitation or polar cap patches have stronger impact on the scintillations of GPS signals.

2. Data used. The Ny-Ålesund (NYA) GPS scintillation receiver of the University of Oslo (UiO) was the main instrument used in our study. Upon availability of data, the Skibotn (Norway, mainland) GPS receiver was also used. The phase (σ_Φ) and amplitude scintillation indices (S_4) are also calculated and recorded automatically.

For the describing the ionospheric plasma parameters (density, ion and electron temperature, line of sight ion velocity as a function of range) we used the Svalbard EISCAT 42m radar. The beam of the EISCAT 42m radar is directed along the geomagnetic field (azimuth = 184°, elevation = 82°). IMAGE magnetometer data was used for the geomagnetic field observations. OMNI database was used for the evaluating the solar wind and interplanetary magnetic field parameters.

3. Data analyze. In the present study, we considered the influence of nighttime substorm precipitation and polar cap patches on the GPS scintillations. We focused mainly on the phase scintillation index because amplitude scintillation index (S_4) practically has no large variations at high latitudes. The presence of the particle precipitation into the ionosphere associated with the appearance of the aurora was determined as the density increase between 100-200 km altitudes according to the EISCAT radar data. The presence of the polar cap patches was determined as a strong density increase above 200 km altitude. In general we identified about a hundred of different cases for years

2010-2017 when the data from the EISCAT 42m radar was available, however, in this paper we present only typical examples. The presented conclusions are valid for the common picture.

3.1 Substorm precipitation. The example of the substorm precipitation and the GPS scintillations response to it is shown in Figure 1 (11 December 2015). It was observed two substorms during this day. The first one was at 15.30-17.00 UT, the second one was at 20.00-22.00 UT. It was polar substorms because it mainly observed at latitude higher than 70º.

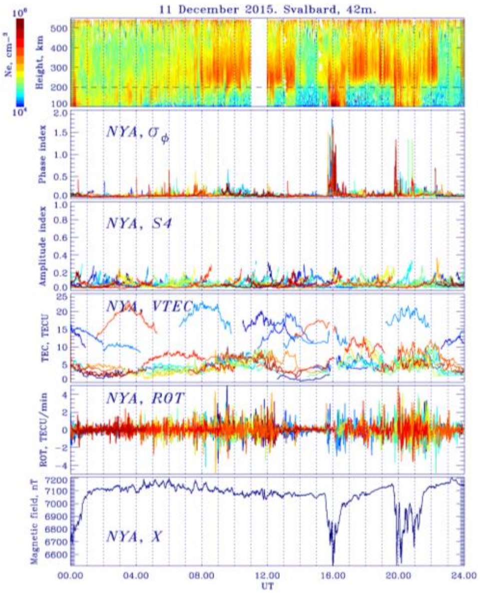

Figure 1. Ionosphere plasma density according to the EISCAT 42m radar data; phase scintillation index and amplitude scintillation index according to the GPS receiver at NYA station; TEC and ROT variations according to the GPS receiver at NYA station; geomagnetic field variations (X-component) at NYA station for the 11 December 2015.

It can be noticed that the amplitude of the first substorm reaches the value about 1400 nT at Hornsund (HOR) station, at NAL station the amplitude of the substorm was 600 nT. The second substorm was has lower amplitude than first substorm (600 nT at HOR station). These substorms was observed without geomagnetic storm (SYM-H ≈ - 10 nT), however the solar wind speed was quite high (V = 640-680 km/s) according to the OMNI database.

The phase index reaches the value about 2 radians approximately during the first substorm. The growth of the phase scintillation index was seen not mainly during the substorm expansion phase (30-40 minutes). During the second substorm the phase scintillation index has the lower value (0.5-1.5 radians). The growth of the phase scintillation index was seen as sharp increases during 5-10 minutes time intervals.

Substorms do not lead to the great TEC increase. It is seen the absence of the TEC data during the substorm. It testifies about the phase failure of GPS signal. The ULF waves in Pi3 frequency range embedded into the substorm structure can have contribution into the particle acceleration into the ionosphere which leads to such strong values of the phase scintillation indexes.

3.2 Polar cap patches. The example of the evening-nighttime polar cap patches (PCP) is shown on Figure 2 for the 10 February 2015.

The PCP was observed at 19.00-23.30 UT as a density increase above 200 km according to the EISCAT data. At NYA GPS receiver the phase scintillation index reaches the medium value (0.4 radians). However the ROT variations for the PCP reach the high values (10-15 TECU/min).

During the PCP appearance the Bz-component of IMF has negative values (-6 nT) during 3 hours. It leads to the development of the small substorm. The amplitude of the substorm is 120-140 nT in X-component of the geomagnetic field at NYA station. The PCP is also identified in the aurora intensity variations as forms propagating from the polar to low latitudes in 630.0 nm (red line) emission (not shown) at 19.00-23.00 UT.

For the all consider PCP cases phase index has the value less than 1.

4. Conclusions

It is considered the influence of substorms and polar cap patches on perturbations of GPS signals with using receivers on Svalbard and in Skiboth. Substorms (even without PCP) lead to the maximum values of the phase scintillation index (1.5-2 radians). The growth of the phase index observed mainly during the substorm expansion phase. ULF waves in Pi3 frequency range during a substorm producing auroral arcs can lead to such high values of the phase index.

Polar cap patches leads to the prolonged variations of phase index with smaller values (less than 1). At the same time polar cap patches can lead to strong ROT variations (10-15 TECU/min) in comparison with the substorms disturbances. So our observations suggest that the substorms and PCPs, being different types of the high-latitude disturbances, lead to the development of different types and scales of ionospheric irregularities.

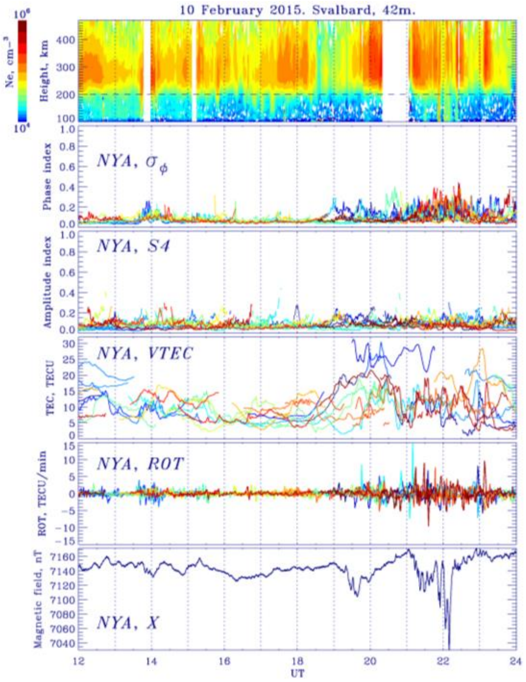

Figure 2. Ionosphere plasma density according to the EISCAT 42m radar data; phase scintillation index and amplitude scintillation index according to the GPS receiver at NYA station; TEC and ROT variations according to the GPS receiver at NYA station; geomagnetic field variations (X-component) at NYA station for the 10 February 2015.

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