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THE INFLUENCE OF DIFFERENT AURORAL IONOSPHERE DISTURBANCES ON THE GPS SCINTILLATIONS

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Abstract. In this work we compare the influence of auroral particle precipitation and polar cap patches (PCP) on scintillations of the GPS signals in the polar ionosphere. 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 analyzed more than 100 events for years 2010-2017, when simultaneous EISCAT 42m and GPS data were available. For some of the events, the optical aurora observations on Svalbard were also used. We consider the following types of the auroral precipitation: i) the dayside and morning precipitation, ii) precipitation on the nightside during substorms, iii) precipitation associated with the arrival of the interplanetary shock wave. All considered types of ionospheric disturbances lead to enhanced GPS phase scintillations. For the polar cap patches, the morning and daytime precipitation (i), and precipitation related to the shock wave (iii), the phase scintillations index reaches values less than 1 radian. We observe that auroral precipitation during substorms leads to the greatest enhancement of the phase scintillation index (up to 3 radians). Thus, the substorm precipitation has the strongest impact on the scintillation of GPS radio signals in the polar ionosphere.

1. Introduction

The Global Navigation Satellite Systems (GNSS) play an important role for the modern society. However, the ionosphere as a medium for the radio waves propagation can have a negative influence on the quality of received signal. Irregularities in plasma density distribution can lead to the fast fluctuations of amplitude and phase of the signal which is referred to as ionosphere scintillations [*Basu et al.*, 2002]. 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 (S4) 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 kilometeres.

The most powerful disturbances in the polar ionosphere are particle precipitation and polar cap patches (PCP). The PCP are identified as a density increase above approximately 200 km at least twice that of the background density [*Crowley*, 2000]. It is well known that the appearance of these structures is accompanied by the increase of the airglow intensity in 630.0 nm spectrum lines [*Hosokawa et al.*, 2006]. Its origin is caused by the reconnection on the dayside of the magnetosphere and penetration of plasma through the polar cap into the ionosphere [*Lorentzen et al.*, 2010]. Patches exit the polar cap into the auroral oval and are called auroral blobs [e.g., *Robinson et al.*, 1985; *Jin et al.*, 2014].

It is shown in the paper [*Jin et al.*, 2010] that PCP can produce GPS scintillations quite comparable with scintillations during the particle precipitation with appearance of strong green aurora. Thus, in the present work we address the following question: what disturbances in the polar ionosphere (particle precipitation or polar cap patches) have stronger impact on the scintillations of GPS signals?

2. Data

We focused on the geophysical observations on Svalbard. The Ny Alesund (NYA) GPS scintillation receiver of the University of Oslo was the main instrument used in our study. Upon availability of data, the Skibotn (Norway, mainland) GPS receiver was also used. For describing the ionospheric plasma parameters (density, velocity, ion and electron temperature) we used the Svalbard EISCAT 42m radar. The beam of this radar is directed along the geomagnetic field. For some convenient cases the optical observations of the aurora on Svalbard was used. 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. Analysis of ionosphere disturbances

We have identified more than 100 cases for years 2010-2017 when the data from the EISCAT 42m radar was available. This report presents only some typical examples. In this study, we considered the influence of four geophysical phenomena on the GPS scintillations: morning-daytime precipitation, nighttime substorm precipitation, precipitation associated with the interplanetary shock arrival and polar cap patches. We focused mainly on the phase scintillation index because amplitude scintillation index (S4) 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.

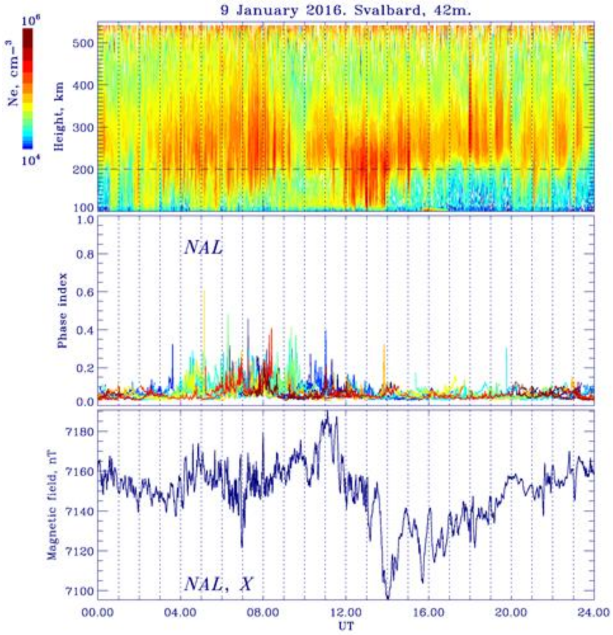

Figure 1. Ionosphere density determined by the EISCAT 42m radar in LYR, phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 9 January 2016.

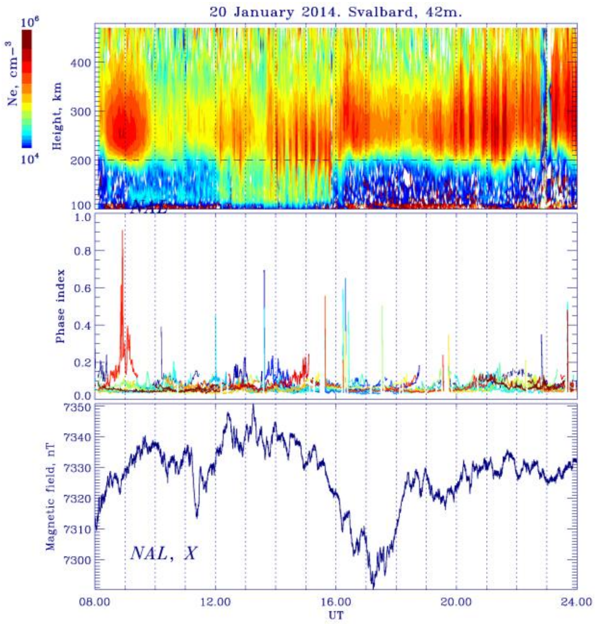

Figure 2. Ionosphere density determined by the EISCAT 42m radar in LYR, phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 20 January 2014.

3.1. Morning-daytime precipitation

Fig. 1 shows an example of the morning-daytime precipitation for 9 January 2016. From 04-14 UT we see the ionosphere density increase at altitudes 100-200 km associated with the precipitation. The aurora observations on LYR station show the existence of bright aurora in 577.7, 630.0 nm spectrum lines (not shown). The phase scintillation index has the value 0.4-0.5.

3.2. Polar cap patches

The example of the polar cap patch (PCP) is shown on a Fig. 2 for the 20 January 2014. The PCP is observed at 08-10 UT as a density increase above 200 km according to the EISCAT data. The PCP is also identified in aurora intensity variations as forms propagating from the polar to low latitudes in 630.0 nm (red line) emission (not shown). The Bz-component of interplanetary magnetic field (IMF) was negative during the appearance of PCP. It testifies the presence the good conditions for the growth of the reconnection of the dayside magnetopause. The phase scintillation index reaches the value 0.9. For the all consider PCP cases phase index has the value less than 1.

3.3. Substorm precipitation

A series of substorms was observed 11 December 2015 geomagnetic stations of IMAGE profile at 16 UT and at 20 UT (Fig. 3). It can be noticed that the amplitude of the substorm reach the value more than 1000 nT at Hornsund (HOR) station, at NAL station the amplitude of the substorm was 600 nT. It is seen a strong increase of ionosphere density according to the EISCAT 42m data (Fig. 4). The substorm was accompanied by the strong increase of aurora intensity in different spectrum lines (not shown). The phase scintillations index reaches the value more than 3 approximately at 16 UT. But for the second substorm it reaches the value a bit more than 1.

3.4. Precipitation associated with the interplanetary shock arrival

The example of the interplanetary shock influence on scintillations of GPS signals is shown in Fig. 3 for the event of 14 December 2015. The interplanetary shock is accompanied by an abrupt increase of the solar wind velocity, density, temperature, module of the interplanetary magnetic field (IMF) according to the OMNI database, abrupt growth of the SYM-H index. The NYA stations at moment of interplanetary shock arrival located on the dayside (16 MLT). We do not have the EISCAT data available for most of the shock events, but it is well known that the interplanetary shock interaction with the Earth's magnetosphere leads to strong particle precipitation in wide spectrum range into the ionosphere [*Zhou et al*, 2003]. Here the phase index reaches the value near 0.6. For the considered interplanetary shock cases the phase index reaches similar values.

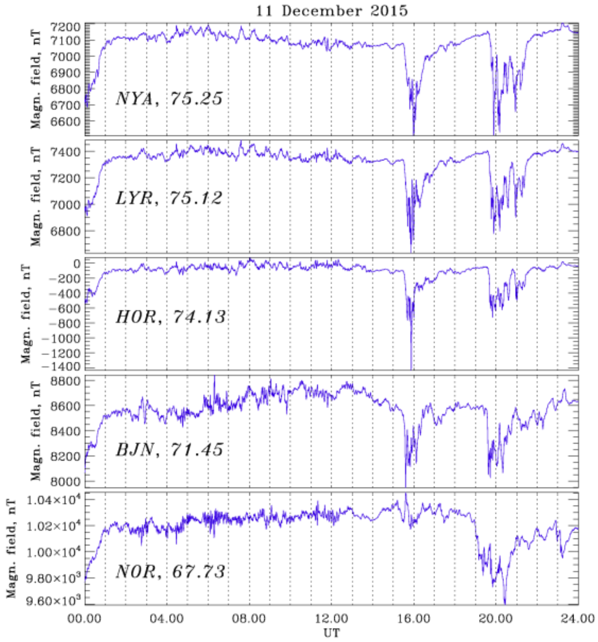

Figure 3. X-component of the geomagnetic field at NYA-LYR-HOR-BJN-NOR meridian profile of stations for the 20 January 2014.

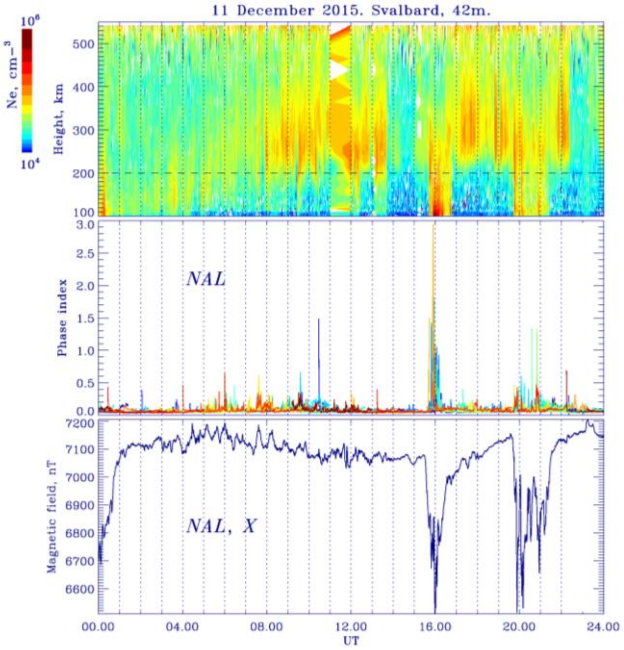

Figure 4. Ionosphere density determined by the EISCAT 42m radar at LYR, the phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 20 January 2014.

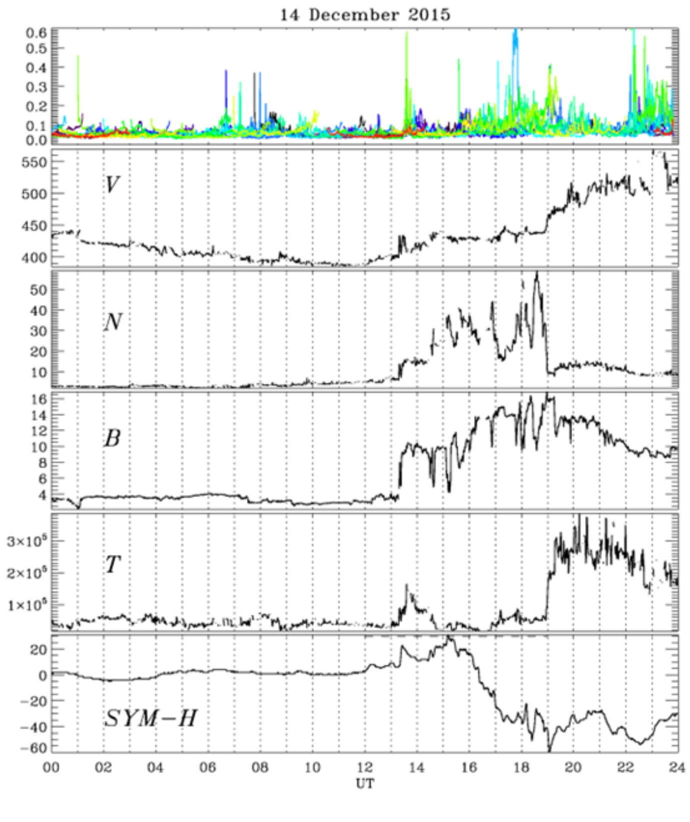

Figure 5. The phase scintillation index calculated from the GPS receiver at NYA station; solar wind parameters according to the OMNI database: velocity V [km/s], density N [cm^{-3}], module of the IMF B [nT], temperature [K]; SYM-H index.

4. Conclusions

So, we have found that all considered geophysical phenomena (morning-dayside precipitation, nighttime substorm precipitation, shock induced precipitation, polar cap patches) give rise to increased GPS phase scintillation levels according to the high-latitude observations on Svalbard. The particle precipitation during substorm lead to the strongest scintillations (the phase scintillation index reaches values even close to 3) of the GPS signals in the polar ionosphere. During other types of ionosphere disturbance the phase index does not reach the value 1. Thus, the substorm precipitation has the strongest impact on the scintillation of GPS radio signals in the polar ionosphere.

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References

1. Basu S., K.M. Groves, S. Basu, P.J. Sultan. Specification and forecasting of scintillations in communication/navigation links: Current status and future plans, Journal of Atmospheric and Solar-Terrestrial Physics, 64(16), 1745–1754. 2002.
2. Crowley G., A.J. Ridley, D. Deist, S. Wing, D.J. Knipp, B.A. Emery, J. Foster, R. Heelis, M. Hairston, and B.W. Reinisch. Transformation of high-latitude ionospheric F region patches into blobs during the March 21, 1990, storm // J. Geophys. Res., 105(A3), 5215–5230, doi:10.1029/1999JA900357. 2000.
3. Hosokawa K., K. Shiokawa, Y. Otsuka, A. Nakajima, T. Ogawa, and J.D. Kelly, Estimating drift velocity of polar cap patches with all-sky airglow imager at Resolute Bay, Canada, Geophysycal Research Letters, 33, L15111, doi:10.1029/2006GL026916. 2006
4. Lorentzen D.A., J. Moen, K. Oksavik, F. Sigernes, Y. Saito, and M.G. Johnsen, In situ measurement of a newly created polar cap patch, Journal of Geophysical Research, 115, A12323, doi:10.1029/2010JA015710. 2010.
5. Jin Y., Moen J., Miloch W. GPS scintillation effects associated with polar cap patches and substorm auroral activity: direct comparison, Journal of Space Weather and Space Climate, 4, A23. 2014.
6. Robinson R.M., R.T. Tsunoda, J.F. Vickrey, and L. Guerin. Sources of F region ionization enhancements in the nighttime auroral zone // J. Geophys. Res., 90(A8), 7533–7546, doi:10.1029/JA090iA08p07533. 1985.
7. Zhou X.-Y., Strangeway R.J., Anderson P.C., Sibeck D.G., Tsurutani B.T., Haerendel G., Frey H.U., Arballo J.K. Shock aurora: FAST and DMSP observation, Journal of Geophysical Research, 108:8019. doi:10.1029/2002JA009701. 2003.