Influence of Different Ionospheric Disturbances on the GPS Scintillations at High Latitudes

V. B. Belakhovsky, Y. Jin and W. J. Miloch

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 42 m radar on Svalbard. We analyzed more than 100 events for years 2010–2017, when simultaneous EISCAT 42 m 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 rad. We observe that auroral precipitation during substorms leads to the greatest enhancement of the phase scintillation index (up to 3 rad). Thus, the substorm precipitation has the strongest impact on the scintillation of GPS radio signals in the polar ionosphere.

Keywords Ionosphere · Aurora · GPS receivers · Substorm

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

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T. B. Yanovskaya et al. (eds.), *Problems of Geocosmos—2018*, Springer Proceedings in Earth and Environmental Sciences, https://doi.org/10.1007/978-3-030-21788-4_24

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 (σΦ) and amplitude (S4) scintillation indexes. Amplitude scintillations are caused by the plasma irregularities with spatial scale 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 is identified as density increases above approximately 200 km. 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 [2]. Its origin is caused by the reconnection on the dayside of the magnetosphere and penetration of plasma through the polar cap into the ionosphere [3].

It is shown in the paper [4] 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 GPS signals scintillations?

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 42 m 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 Data Analyses

We have identified more than 100 cases for years 2010–2017 when the data from the EISCAT 42 m 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

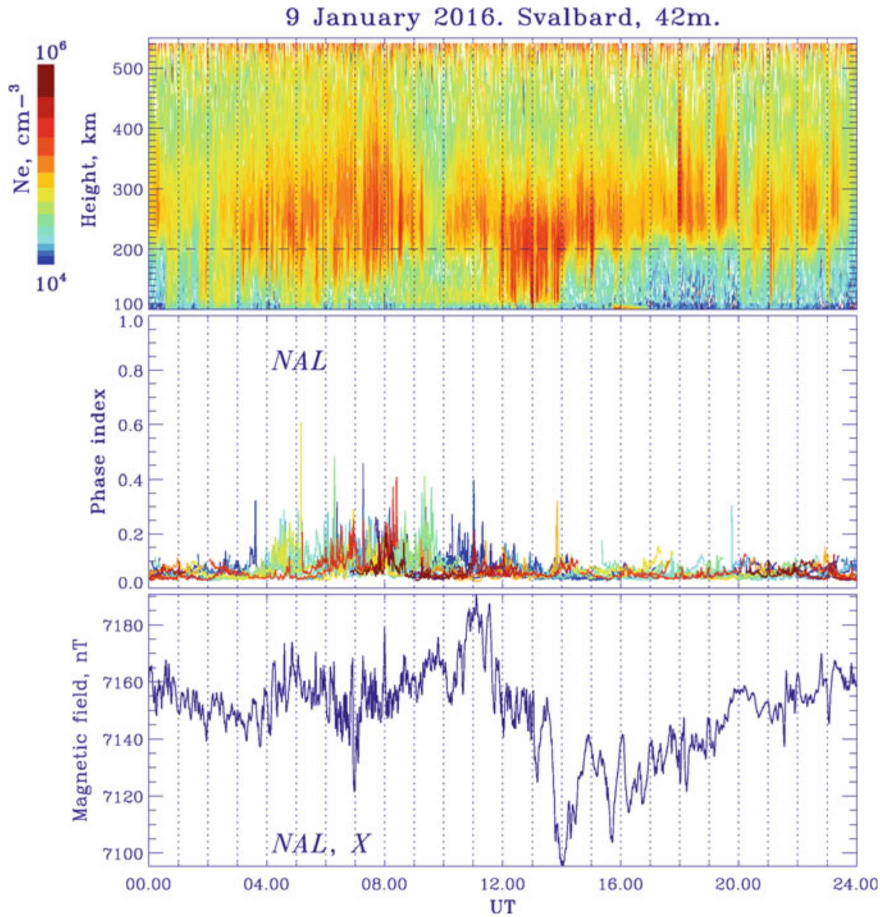

Fig. 1 Ionosphere density determined by the EISCAT 42 m radar in LYR, phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 9 January 2016

particle precipitation into the ionosphere associated with the appearance of the aurora was determined as the density increase between 100 and 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 shows an example of the morning-daytime precipitation for 9 January 2016. From 04 to 14 UT we see the ionosphere density increase at altitudes 100–200 km associated with the precipitation. The phase scintillation index has the value 0.4–0.5.

The example of the substorm precipitation and the GPS scintillations response to it is shown in Fig. 2 (11 December 2015). It can be noticed that the amplitude of the substorm at X-component of the geomagnetic field reach the value more than

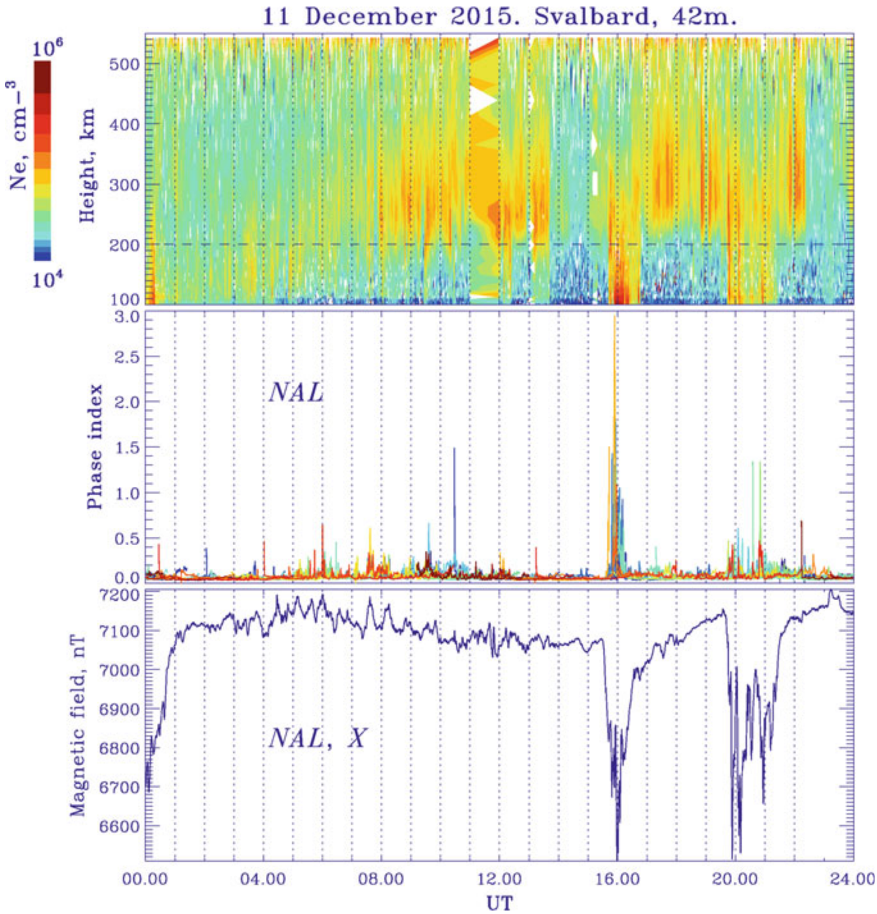

Fig. 2 Ionosphere density determined by the EISCAT 42 m radar in LYR, phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 11 December 2015

1000 nT at Hornsund (HOR) station, at NAL station the amplitude of the substorm was 600 nT. The substorm was accompanied by the strong increase of aurora intensity in different spectrum lines (not shown). The phase index reaches the value more than 3 approximately at 16 UT.

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

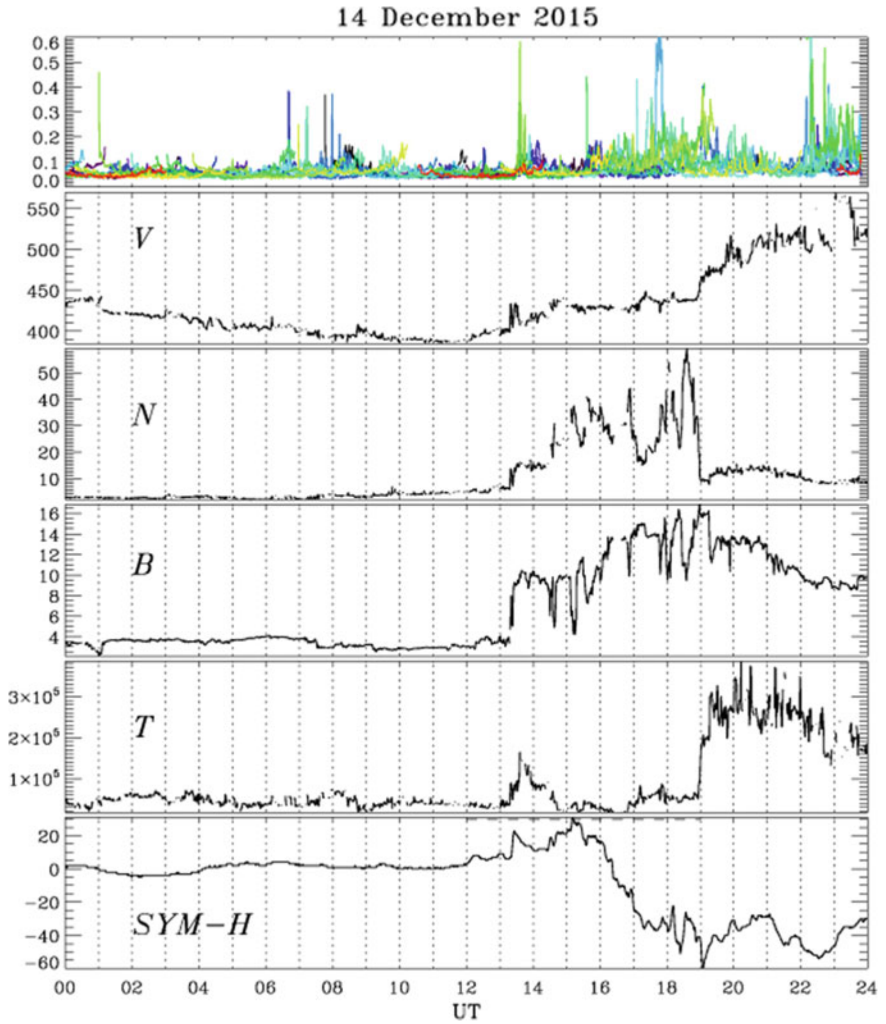

Fig. 3 The phase scintillation index determined from the GPS receiver at NYA station; solar wind parameters according to the OMNI database: velocity V [km/s], density N [cm^3], module of the interplanetary magnetic field B [nT], temperature [K]; SYM-H index

shock interaction with the Earth's magnetosphere leads to strong particle precipitation into the ionosphere [5]. Here the phase index reaches the value near 0.6. For the considered interplanetary shock cases the phase index reaches similar values.

The example of the polar cap patch (PCP) is shown on a Fig. 4 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

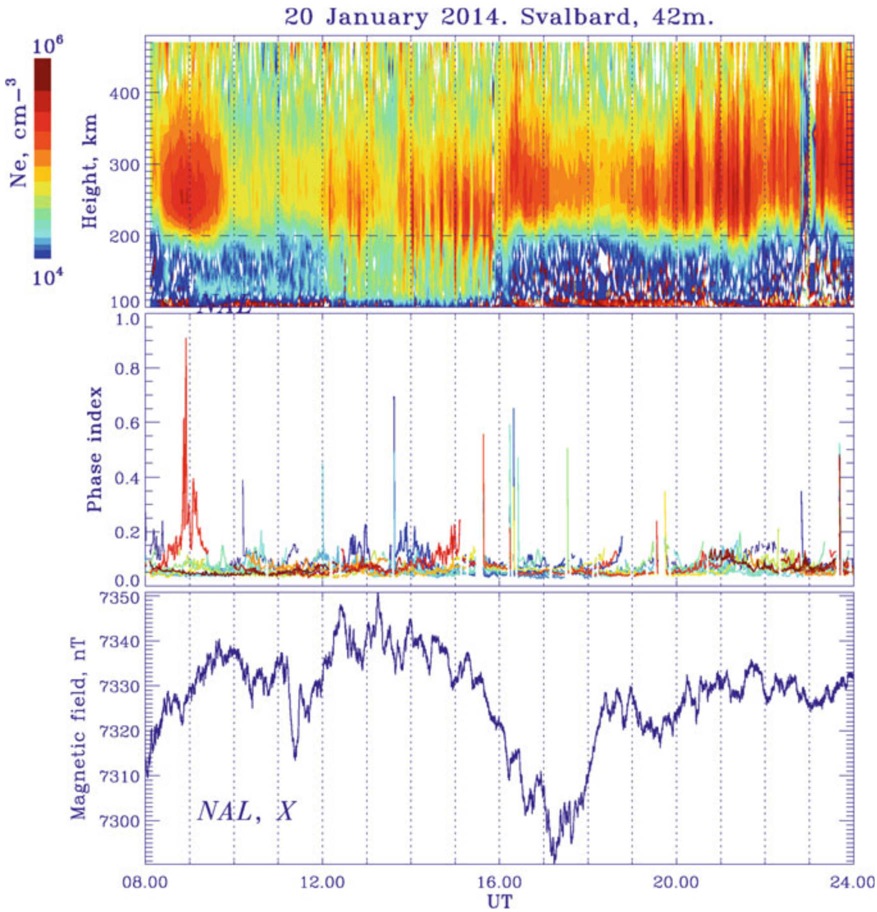

Fig. 4 Ionosphere density determined by the EISCAT 42 m radar in LYR, the phase scintillation index calculated form NYA GPS receiver, X-component of the geomagnetic field at NYA station for the 20 January 2014

shown). The Bz-component of IMF was negative during the appearance of PCP. The phase scintillation index reaches the value 0.9. For the all consider PCP cases phase index has the value less than 1.

4 Conclusion

We find that all considered geophysical phenomena (morning-dayside precipitation, nighttime substorm precipitation, shock induced precipitation, polar cap patch) give rise to increased scintillation levels. But 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. Thus, the substorm precipitation has the strongest impact on the scintillation of GPS radio signals in the polar ionosphere.

Acknowledgements The authors thank the Norwegian Polar Research Institute at Ny-Ålesund for assisting us with the GPS receiver in Ny-Ålesund, Bjørn Lybekk and Espen Trondsen for the instrument operations. The IMF data are provided by the NASA OMNIWeb service (http://omniwegsfc.nasa.gov).
The authors wish to thank IMAGE (http://www.ava.fmi.fi/image/), EISCAT groups for the available data. EISCAT is an international association supported by research organizations in China (CRIRP), Finland (SA), Japan (NIPR and STEL), Norway (NFR), Sweden (VR), and the United Kingdom (NERC). Data from EISCAT can be obtained from the Madrigal database http://www.eiscat.se/madrigal.
This study is supported by the RSF grant № 18-77-10018.

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