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Statistics of ionospheric scintillation occurrence over European high latitudes

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ABSTRACT

Rapid fluctuation in the amplitude and phase of transionospheric radio signals caused by small scale ionospheric plasma density irregularities is known as scintillation. Over the high latitudes, irregularities causing scintillation are associated with large scale plasma structures and scintillation occurrence is mainly enhanced during geomagnetic storms. This paper presents a statistical analysis of scintillation occurrence on GPS L1C/A signal at a high latitude station located in Bronnoysund (geographic latitude 65.5°N, geographic longitude 12.2°E; corrected geomagnetic (CGM) latitude 62.77°N), Norway, during the periods around the peaks of solar cycles 23 (2002–2003) and 24 (2011–2013). The analysis revealed that the scintillation occurrence at Bronnoysund during both the solar maximum periods maximises close to the midnight magnetic local time (MLT) sector. A higher occurrence of scintillation is observed on geomagnetically active days during both the solar maximum periods. The seasonal pattern of scintillation occurrence indicated peaks during the summer and equinoctial months. A comparison with the interplanetary magnetic field (IMF) components B_y and B_z showed an association of scintillation occurrence with the southward IMF B_z conditions.

1. Introduction

Scintillation is characterised by rapid fluctuations in the amplitude and phase of transionospheric radio signals caused by small scale plasma density irregularities in the ionosphere (Kintner et al., 2001 and the references therein). It is well known that scintillation can impair the tracking performance of Global Navigation Satellite System (GNSS) receivers (Aquino et al., 2005; Sreeja et al., 2012 and the references therein), thereby affecting the required levels of availability, accuracy and integrity, and consequently the reliability of modern day GNSS based applications. The occurrence of scintillation shows large day-to-day variability with dependence on local time, season, latitude, longitude as well as solar and geomagnetic activity. The global morphology of ionospheric L-band scintillation is presented in Basu et al. (2002), which reports that the scintillation occurrence is intense over the equatorial latitudes (extending from 20°N to 20°S geomagnetic latitudes), moderate at high latitudes (65–90° geomagnetic latitudes) and almost absent at the mid-latitudes. In the equatorial and high latitudes, the processes that govern the generation and sustenance of irregularities causing scintillation are quite different, thereby leading to significant differences in the observed characteristics of scintillation effects. One of the observed differences is a relatively higher occurrence of amplitude scintillation over the equatorial latitudes and, in contrast, a higher occurrence of phase scintillation over the high latitudes.

At high latitudes, irregularities causing scintillation are associated with large scale plasma structures and scintillation occurrence is mainly enhanced during geomagnetic storms, even in the solar minimum years (Aarons et al., 2000; Ngwira et al., 2010 and the references therein). The plasma structuring is controlled by the magnetic coupling between the interplanetary magnetic field (IMF) and the magnetosphere (Hunsucker and Hargreaves, 2003). The large scale plasma structures convect across the polar region and cause destabilisation of the plasma, leading to the generation of small scale irregularities causing scintillation (Valladares et al., 1994 and the references therein). In the Northern Hemisphere, the irregularity oval is situated equatorward of the auroral oval and it expands equatorward with the increasing magnetic activity (Aarons and Allen, 1971).

Climatological studies have shown that over the northern and southern hemispheres, phase scintillation, as a function of magnetic local time (MLT) and geomagnetic latitude, is intense in the nightside auroral oval and on the dayside in the cusp region (Spogli et al., 2009; Li et al., 2010; Prikryl et al., 2011a). Several studies have reported the observations of auroral and cusp scintillation and the influence of the IMF on the formation and dynamics of plasma patches during severe geomagnetic storms

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(like the Halloween storm of October 2003 or the geomagnetic storms of November 2004 or April 2010) (Mitchell et al., 2005; De Franceschi et al., 2008; Meggs et al., 2008; Prikryl et al., 2011b; Kinrade et al., 2012, and the references therein). In a statistical study based on one year of data, Alfonsi et al. (2011) reported that in both the hemispheres, the IMF orientation influences mainly the scintillation distribution in MLT, thus highlighting the important role of the plasma inflow and outflow from and to the magnetosphere in the noon and midnight MLT hours. An analysis between the occurrence of scintillation and the southward IMF B_z conditions, along with the consequential impact on the tracking performance of a GNSS receiver located at a high-latitude station in Bronnoysund, Norway, was performed by Aquino and Sreeja (2013). Their analysis revealed that the scintillation occurrence for selected geomagnetically disturbed days at this station was associated with the southward IMF B_z conditions.

In this context, this paper investigates statistically the occurrence of scintillation during the periods around the maximum phases of solar cycles 23 and 24, at Bronnoysund (geographic latitude 65.5°N, geographic longitude 12.2°E; corrected geomagnetic (CGM) latitude 62.77°N), in Norway. The data and method of analysis used in this study are introduced in Section 2. Section 3 presents the results and discussions, whereas the conclusions are presented in Section 4.

2. Data and methodology

The present study is based on the ionospheric scintillation data recorded on the GPS L1C/A signal at Bronnoysund around the maximum phase of solar cycle 23 (April 2002–December 2003) by a NovAtel/AJ Systems GSV4004 (GPS Silicon Valley, 2004) receiver and around the maximum phase of solar cycle 24 (August 2011–June 2013) by a Septentrio PolaRxS (Septentrio PolaRxS, 2007) receiver. For each period, the data availability and with the averaged sunspot number (http://www.swpc.noaa.gov/ftpdir/weekly/RecentIndices.txt) are listed in Table 1. As this paper deals with a statistical representation, data from years 2002 and 2003 have been combined to represent the period around the maximum of solar cycle 23 (hereafter referred to as strong solar maximum), whereas data from years 2011, 2012 and 2013 have been combined to represent the period around the maximum of solar cycle 24 (hereafter referred to as weak solar maximum).

The PolaRxS and the GSV4004 receivers use similar algorithms to provide the amplitude scintillation index S_4 (standard deviation of the received signal power normalised by its mean value) and the phase scintillation index, SigmaPhi (standard deviation of the detrended carrier phase using a high pass filter with 0.1 Hz cutoff computed over 1, 3, 10, 30 and 60 s). Analyses presented in Sreeja et al. (2011) show that the scintillation indices recorded by the two receivers are comparable. In this study, the 60 s SigmaPhi (Phi60) values are used. The S_4 is not considered since it was generally very low, even during periods of enhanced Phi60, as is usually the case at high latitudes (Kintner et al., 2007; Ngwira et al., 2010). The percentage occurrence of Phi60 for 1 h MLT bin is calculated as

$$100 \times N(\text{Phi60} > \text{threshold})/N_{\text{total}} \quad (1)$$

where N (Phi60 > threshold) is the number of cases when Phi60 > threshold and N_{total} is the total number of data points in the bin. As this study focuses on the occurrence of moderate to strong levels of scintillation, the threshold for Phi60 is chosen as 0.3 (Aquino et al., 2005 and the references therein). The criterion

Table 1
Data availability over Bronnoysund along with the averaged sunspot number.

Year	Days of data	Averaged sunspot number
2002	251	177
2003	340	109
2011	142	80
2012	288	82
2013	148	94

defined as

$$R = 100\frac{\sigma(N_{\text{total}})}{N_{\text{total}}} > 0.025 \quad (2)$$

is chosen in order to remove the contribution of bins with poor statistics, where $\sigma(N_{\text{total}})$ is the standard deviation of the number of points in each bin (Taylor, 1997; Spogli et al., 2009; Prikryl et al., 2011a).

In this study, only measurements from satellites with an elevation angle greater than 15° are considered, in order to remove the contribution from non-scintillation related effects, such as multipath. This threshold on the satellite elevation angle implies that the CGM latitude range in the field of view from Bronnoysund at the sub-ionospheric height of 350 km is 54–72°N. Also, a lock time threshold of 240 s is used to allow the convergence of the phase detrending filter.

The characterisation of the IMF components (B_y and B_z) is performed using the measurements made by the Magnetic Field Experiment (MAG) on board the Advanced Composition Explorer (ACE) satellite (http://www.srl.caltech.edu/ACE/). For this study, the hourly averaged IMF data is used. The planetary geomagnetic activity index, K_p, is obtained from the World Data Center for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/).

3. Results and discussions

The percentage occurrence maps of Phi60 > 0.3 over Bronnoysund during the strong (left panel) and weak (right panel) solar maximum periods as a function of MLT and CGM latitude is shown in Fig. 1. The maps have a resolution of 1 h in MLT and 1° in CGM latitude. The red lines represent the average equatorward and poleward positions of the statistical auroral oval for moderate geomagnetic activity level, IQ=3 (Feldstein, 1963; Holzworth and Meng, 1975).

It can be observed from Fig. 1 that the percentage occurrence of scintillation, as expected, is higher during the strong solar maximum as compared to the weak solar maximum. The occurrence of scintillation maximises (>30%) close to the midnight, i.e. within the 23–02 h MLT sector and between 60 and 65°N CGM latitudes, during both the strong and weak solar maximum periods. The range of geomagnetic latitudes in the field of view from Bronnoysund at the sub-ionospheric height of 350 km and an elevation threshold of 15° falls on the edges of the IQ=3 auroral oval during the midnight MLT sector, thus explaining the high scintillation occurrence. Further, from Fig. 1 it is clear that the scintillation occurrence maximises near the CGM latitude of Bronnoysund (i.e. around 62.77°N), suggesting the field aligned nature of the irregularities. This is in agreement with what is presented in Kersley et al. (1988), where they have shown a similar feature in the occurrence of VHF scintillation at the European high latitude station of Kiruna (geographic latitude 67.83°N; geographic longitude 20.43°E; and CGM latitude 64.3°N). It can also be observed that during the strong solar maximum, scintillation occurrence shows a secondary peak