

Effect of ionospheric irregularities on GPS signals during declining phase of solar cycle 23 at Bhopal

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Abstract. The present investigation is dedicated to the evaluation of GPS performance under disturbed geomagnetic conditions at the equatorial region. When GPS signals encounter the ionospheric irregularities of different size developed during high geomagnetic or solar activity, they undergo rapid changes in their phase and amplitude, known as scintillations. We have studied the occurrence characteristics of scintillation events during geomagnetic storms of different intensity at the crest of equatorial anomaly station Bhopal (23.2N, 77.6E). To accomplish this study we have used two data sets: Disturbed Storm Time (Dst) index and Amplitude Scintillation (S4) index. The geomagnetic storm activity is characterized by the Dst index and the evaluation of GPS performance during disturbed geomagnetic condition is realized through S4 index. We have selected thirty one geomagnetic storms that occurred during the year 2004 and 2005. We then classified these geomagnetic storms and scintillation events into weak, moderate and intense and weak, moderate and strong according to Dst index and S4 index respectively. During all the storm events we observed a good number of scintillation events. We then performed the correlation analysis between the Dst index and S4 index, to find out the impact of storm intensity on the occurrence of scintillation events.

1. Introduction

Ionosphere is a dispersive medium produced by ionization of gases and molecules by ionizing radiations from the sun. F-region of the ionosphere which is generally lies between 250 km to 400 km above the earth has a huge amount of free electrons. At times, F-region of the ionosphere get disturbed and small scale irregularities develop. When local electron density differs significantly from the surrounding electron density it produces localized ionospheric irregularities. Sufficiently intense irregularities scatter the radio waves and produce rapid fluctuations (Scintillations) in the amplitude and phase of the radio signals. Scintillation especially in the L-band has received a great concern of researchers over the decades because of its impact on communication and navigation systems like Global Positioning System (GPS). Scintillation has the capacity to affect the accuracy and reliability of GPS system by degrading the performances of GPS receivers. Variability of ionospheric irregularities is of serious concern to GPS system because these irregularities affect the amplitude and phase of trans-ionospheric radio (satellite) signals. Amplitude scintillation may induce signal fading and when depth of fading exceeds the fade margin of a receiving system, message errors are introduced in satellite communication systems. Amplitude scintillation leads to loss of lock by degrading the carrier-to-noise ratio (C/N_0) to below the receiver lock threshold [1], requiring the receiver to attempt reacquisition of the satellite signals. Losing signal is a major concern in GPS receiver navigation performance [2, 3]. Fortunately, many of the important characteristics of scintillation are already well



known [1,3, 4, 5]. These studies revealed that scintillation activity varies with Season, local time, operating frequency, geographic location, magnetic activity and 11 year solar cycle. To determine the impact of scintillation on GPS, it is important to clearly understand the location, magnitude and frequency of occurrence of scintillation effects. Scintillation activity is most severe and frequent in and around the equatorial region, especially a few hours after sunset. Scintillation is more intense in the anomaly regions ($\pm 25^\circ$ equator) than at the magnetic equator because of special characteristics of the equatorial ionosphere. The combination of electric and magnetic fields about the Earth produce free electrons to be lifted vertically and then diffuse northward and southward. Due to this process ionization over the magnetic equator reduces directly and increased the ionization over the anomaly regions. Low-latitude scintillation is seasonally dependent and is limited to local night-time hours. High latitude or polar scintillation is frequent but less severe in magnitude than that of the equatorial regions. The scintillation occurrence at auroral latitudes is strongly dependent on geomagnetic activity levels, but can occur in all seasons and is not limited to local night-time hours. Scintillation very rarely occurred in the mid latitudes, it occurs only during very intense magnetic storm periods [6, 7]. In low latitudes while both amplitude and phase scintillations may occur but in general amplitude scintillation is more severe than phase scintillation [8, 9]. Both amplitude and phase scintillations can degrade the GPS positioning performance by increasing the tracking error, number of cycle slips and probability of loss of lock. Forecasting of the scintillation occurrence for the local time, season, solar cycle and during the geomagnetic disturbances are very important for the radio communication.

2. Data sets and methodology

To accomplish this study we have used two data sets: Dst index and S4 index. The geomagnetic storm activity is characterized by the Dst index. The Dst index, is the global index to monitor the worldwide magnetic storm level. We have collected the data for Dst indices with 1h resolution from the Space Physics Data Facility OMNI website at <http://omniweb.gsfc.nasa.gov/>. On the basis of Dst index thresholds we classified the selected geomagnetic storms into three categories as intense storms ($Dst \leq -100\text{nT}$), moderate storms ($-100\text{nT} < Dst \leq -50\text{nT}$) and weak storms ($Dst \geq -50\text{nT}$). The evaluation of GPS performance during disturbed geomagnetic condition is realized through amplitude scintillation index (S4). In this study, the ionospheric scintillations has been measured using high data-rate NovAtel dual frequency GPS receiver GSV4004A GISTM receivers installed and operated at Department of Physics and Electronics, Barkatullah University, Bhopal, India (23.2°N , 77.6°E).

3. Results and discussions

To evaluate the performance of GPS under disturbed geomagnetic condition we have selected 31 geomagnetic storms that were observed during 2004 and 2005. As these years correspond to the high solar activity phase of the solar cycle 23, the geomagnetic activity during these years also remained high. The distribution of weak, moderate and weak geomagnetic storms is shown in Figure 1. From the Figure we find that among 31 storms, 11 belonged to the weak category, 13 storms were moderate and 07 intense storms were also observed.

We then identified the scintillations observed during all the three categories of geomagnetic storms viz. Weak, moderate and intense, separately for each category. The scintillations observed during a particular category e.g weak storm were then categorized into weak scintillation, moderate scintillation and strong scintillations. The Figure 2 shows the percentage occurrence of weak, moderate and strong scintillation during three different categories of geomagnetic storms separately. From the Figure during all three types of storms weak, moderate and intense the maximum percentage occurrence is that of weak scintillation followed by moderate scintillations and the least is that of strong scintillation. This shows that irrespective of the intensity of a geomagnetic storm, the highest percentage of scintillation observed during geomagnetic storms is those of weak scintillation while the lowest percentage is those of intense scintillation. The intensity of geomagnetic storm seems to have no association with the intensity of scintillation. To further investigate this we took the storm intensity index Dst and the scintillation index S4 and derived the correlation between them to access the magnitude of association between the two.

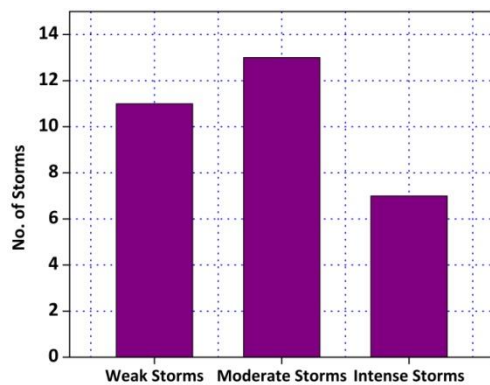


Figure 1. Distribution of geomagnetic storms into weak, moderate and intense storms observed during 2004 and 2005.

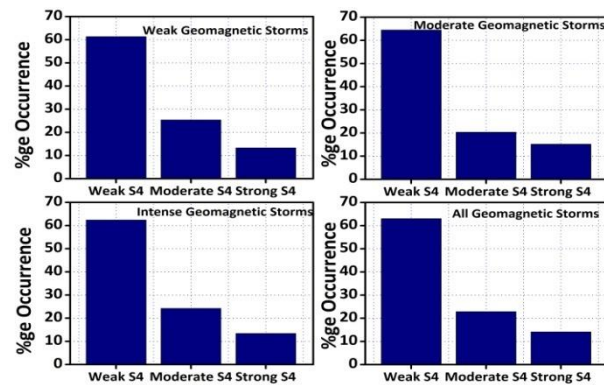


Figure 2. Percentage occurrence of weak, moderate and strong scintillations during three categories of geomagnetic storms.

The correlation analysis was performed separately for weak, moderate and intense storms. In each category of storms, we derived the correlation between the Dst index and no. of S4 occurrences separately for weak, moderate, strong and all scintillations. The scatter plot between the Dst index and no. of S4 occurrences separately for weak, moderate, strong and all scintillations observed during all the selected weak, moderate and intense geomagnetic storms separately is shown in Figure 3 to 5. To construct these plots we have taken the peak values or minimum values of the Dst index during each selected weak storms. From the Figure 3 we find that no. of S4 occurrences do not exhibit a good correlation with weak, moderate and strong scintillation separately. However if we examine the correlation between the total no. of S4 occurrences and the Dst index, we find the correlation is good.

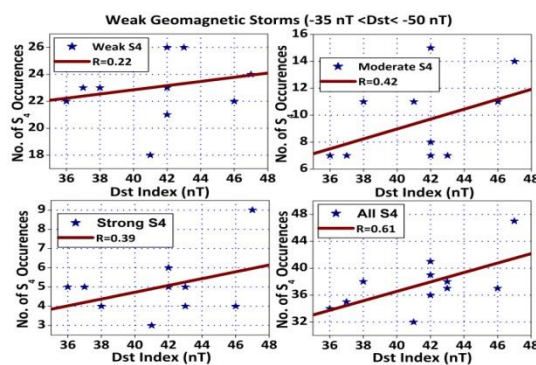


Figure 3. Scatter plot and correlation between the Peak Dst index and the No. of S4 occurrences for weak, moderate and strong scintillations during weak geomagnetic storms.

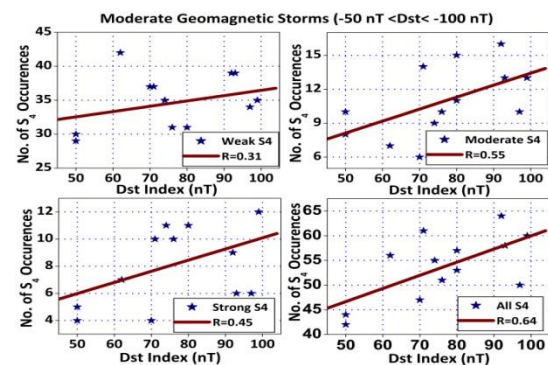


Figure 4. Scatter plot and correlation between the Peak Dst index and the No. of S4 occurrences for weak, moderate and strong scintillations during moderate geomagnetic storms.

From the figure 4 we find the no. of S4 occurrences exhibit a weak correlation with Dst index when examined separately for weak, moderate and strong scintillation. However, when the correlation between the total numbers of S4 occurrences is examined with the Dst index, the correlation is good. But the correlation is slightly better than observed between the same in case of weak geomagnetic storms.

From the figure 5 we find Dst index exhibits a good correlation with the no. of S4 occurrences for weak, moderate and strong scintillation. At the same time we also find that the total number of S4

occurrences exhibits a strong correlation with the Dst index. The correlation between the two is found to be much better than observed during the case of weak or moderate storms. The least correlation was observed during the case of weak geomagnetic storms while the strongest correlation was observed during the intense storms. Thus we find the number of S4 occurrences is highest during intense geomagnetic storms and least during weak geomagnetic storms showing that as the intensity of geomagnetic storm increases the number of scintillation occurrences increases.

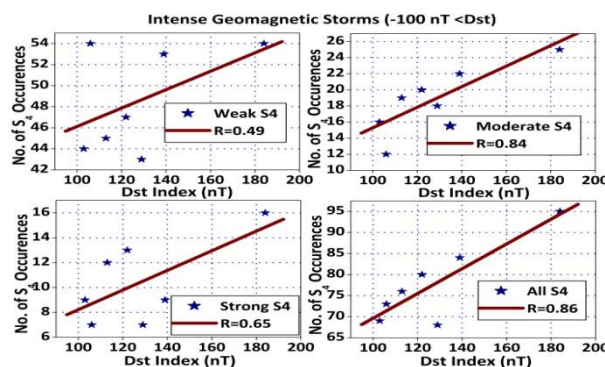


Figure 5. Scatter plot and correlation between the Peak Dst index and the No. of S4 occurrences for weak, moderate and strong scintillations during intense geomagnetic storms.

4. Conclusions

We summarize the main results of our investigation as follows:

- ★ During all types of storms the maximum percentage occurrence of scintillations was those of weakscintillations (60-70%), followed by moderate scintillations (20-30%) and the least was those of strongscintillations (10-20%).
- ★ A good correlation was observed between the number of S4 occurrences and Dst index during the moderate and intense storms for all the three types of scintillations weak, moderate and strong as well as the total number of scintillation occurrences.
- ★ A weak correlation exists between the Dst index and the number of S4 occurrences during the weak storms for all the three types of scintillations. However, a good correlation exists if the correlation is examined for total number of scintillation for the same category of storms.
- ★ The strongest correlation coefficients were found to exist for the intense storm category followed by moderate and least for weak storms for all three types of scintillation events.

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