# Effect of Magnetic activity on scintillation at Equatorial Region during Low Solar Activity

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**Abstract**
Single and dual frequency GPS receivers used in low-latitude regions can suffer from rapid amplitude and phase fluctuations known as scintillation. Intense signal fluctuations cause GPS receivers to stop tracking the signals from GPS satellites in a process sometimes called "loss of lock". This may increase navigation errors or, in some cases, cause navigation failure. Data recorded from ground-based GPS scintillation monitors (GSV 4004A GPS receiver) installed at the Space Science Laboratory, Department of Physics, Barkatullah University, Bhopal (23.2ºN, 77.4ºE; Geomagnetic 14.2ºN) are used. Different phases of geomagnetic storms affect the generation and development of ionospheric irregularities differently. Results shows that occurrence of scintillation observed during summer months are relatively weak as compared to those recorded during winter and equinox months. The enhancement in magnetic activity leads to a suppression of pre-midnight scintillations during the equinox and during the winter, whereas as enhancement is observed in summer months. The generation or inhibition of irregularities during the main phase/recovery phase of a magnetic storm depends upon the location of the station and local time.

**Keywords**: Scintillation, Geomagnetic storms, Magnetic activity

## 1 Introduction

The ionosphere is a region of the atmosphere at an altitude of several hundred kilometers whose defining feature is the presence of free electrons stripped from atoms by solar ultraviolet radiation. One of the first known effects of space weather was fluctuations in the amplitude and phase of radio signals that transit the ionosphere. The fluctuations are called scintillations, if it is sufficiently intense, degrade the signal quality, reduce information content, or failure of the signal reception. With increasing interest in understanding the behavior of ionospheric irregularities near the magnetic equator, efforts have been made to examine the influence of solar and magnetic activity over the occurrence of scintillations associated with ionospheric irregularities (Aarons et al., 1980; DasGupta et al., 1985; Dabas et al., 1989; Pathak et al., 1995; Bhattacharya et al., 2000 and Basu et al., 2001).

Single and dual frequency GPS receivers used in low-latitude regions can suffer from rapid amplitude and phase fluctuations known as scintillation. Intense signal fluctuations cause GPS receivers to stop tracking the signals from GPS satellites in a process sometimes called ‘‘loss of lock’’. This may increase navigation errors or, in some cases, cause navigation failure. Scintillation occurs when the GPS satellite signal travels through small-scale irregularities in electron density in the ionosphere, typically in the evening and nighttime in equatorial regions. Amplitude scintillation can be severe enough that the received GPS signal intensity drops below a receiver’s lock threshold, forcing the receiver to reacquire the signal. Another form of scintillation, known as phase scintillation, occurs from rapid phase variations in the signal after traveling through these same small-scale ionospheric irregularities. Phase scintillation may lead to cycle slips and loss of lock for receivers as they track the signal.

During geomagnetic storms, the equatorial electric fields can be affected primarily by strong magnetospheric convection electric fields that penetrate promptly to equatorial latitudes. Relevant studies on the generation and evolution of ionospheric irregularities, and/or of the equatorial ionosphere–thermosphere system under geomagnetically disturbed conditions may be found in the works of Aarons (1991).

Different phases of geomagnetic storms affect the generation and development of ionospheric irregularities differently. The classical storm may be considered as having three phases, the initial, main and recovery phases. The initial phase consists of a shock wave preceded by the arrival of enhanced solar activity. The main phase is the decrease in the H (horizontal) component of the earth’s magnetic field due to the increase in the trapped magnetospheric particle population. Equatorial and low latitude F region ionosphere modified drastically during geomagnetic storms as compared to the quiet days, are mostly due to the combined effects of relatively short lived prompt penetration electric field (PPE) (Sastri et al., 2000) and long lasting ionospheric disturbance dynamo electric field (DDE). The experimental technique employing spaced GPS receivers have been extensively used in recent years to study the dynamics of the ionospheric irregularities.

## 2 Data and Methodology

Data recorded from ground-based GPS scintillation monitors (GSV 4004A GPS receiver) installed at the Space

Science Laboratory, Department of Physics, Barkatullah University, Bhopal (23.2ºN, 77.4ºE; Geomagnetic 14.2ºN) are used to analyze the behavior of the ionospheric irregularities from Jan 2005 to Dec 2006. GISTM system consists of NovAteL OEM4 dual frequency GPS receiver and a low phase noise oven controlled crystal oscillator (OCXO) that is required for phase scintillation. This system is capable of tracking up to 11 GPS satellites at the L1 frequency (1575.42 MHz) and the L2 frequency (1227.6MHz). It computes TEC from combined L1 and L2 pseudorange and carrier phase measurements. For the data to be useful the receiver must maintain lock for more than 240 seconds. This is the time required for the detrending High Pass Filter (HPF) to re- initialize lock with the carrier phase signal. In our study, the signals coming from satellite with an elevation angle greater than 30º were taken into account.

To study the effect of geomagnetic activity with scintillation we use geomagnetic indices SYM-H, similar to the Dst index, the SYM-H index may also serve as an indicator of magnetic storm intensity, but having distinct advantage of high time resolution and Kp, the global measure of magnetic disturbance, the ionospheric parameter, Bz component of the Interplanetary magnetic field (IMF).

### *2.1 Amplitude Scintillation*

Amplitude scintillation (S4) is derived from detrended signal intensity of signals received from satellites. The S4 index, which includes the effects due to ambient noise, is recorded by GISTM as S4T.

$$S_{4T} = \sqrt{\frac{\langle P^2\rangle - \langle P\rangle^2}{\langle P^2\rangle^2}}$$

Where ‹ › represents the average values over a 60-second interval.

#### *2.1.1 Removal of Ambient Noise*

The total $S_4$ ($S_{4t}$) defined in above equation has significant amount of ambient noise associated with it, which has to be removed before further analysis. This is achieved by estimating the average signal-to-noise density (S/N) over a 60-second interval. This estimate is then used to determine the expected $S_4$ due to ambient noise (also known as S4 correction) as follows:

$$S_{4N_0} = \sqrt{\frac{100}{S/N_0}\left[1+\frac{500}{19S/N_0}\right]}$$

Replacing the $S/N_o$ with the 60-second estimates, $S/N_o$, gives the S4 due to noise. The corrected $S_4$ (ambient noise free) is then calculated in post processing as follows:

$$(S_4) = \sqrt{(S_4)^2_{tot} - (S_4)^2_{cor}}$$

## 3 Results

Scintillation has a significant impact on radio communications, navigation and radar systems. It has been reported by many workers in Indian sector that the scintillation at low latitude can be either inhibited or triggered during storms, depending on the phase of the storm and its local time of occurrence (Kumar and Gwal,2000; Banola et al., 2001; Kumar et al., 2005) Equatorial scintillation has greater impact on receiver tracking performance during the period of strong scintillation activity. We have considered the S4 index >0.25 for our analysis. Amplitude scintillation index is categorized in four distinct levels similar to Gwal et al., (2004) is presented in Table 1.

### *3.1 Effect of magnetic activity*

The effect of magnetic activity was analyzed by comparing scintillation occurrence rates on five (international) quiet (Q) and five disturbed (D) days in each month. Percentage occurrence of scintillation during quiet and disturbed days, derived from our data, is shown in figure 1, 2, 3 and 4 for 1800-0500 hours. On disturbed days in winter and equinoxes scintillations are seen to be inhibited during the pre-midnight period and increased during the post mid-night period. During summer season scintillation on disturbed days are more pronounced before mid-night and are suppressed after midnight. On an annual basis a clear suppression of scintillation on disturbed days both during pre-midnight and post-midnight period is seen in Figure 4. This suppression is more significant during high solar activity years (Singh and Singh 2004).

The suppression and enhancement of the irregularities during geomagnetic disturbances can be attributed to changes in the ring current (Aarons, 1991). During the pre-sunset period, the eastward electric field is increased, causing an increase in F-layer height. A negative excursion of ring current during this period would lower the local eastward electric field and reduce the F-layer height. This effect may sometimes be large enough to reverse the upward movement of F-layer during the post-sunset period, thereby inhibiting the creation of irregularities. This may result in a suppression of pre-midnight scintillations over most longitudes during periods of intense magnetic activity. However, scintillations may continue to appear at some longitudes. At midnight and during the post-midnight period when the electric field is westward and the F-layer height is falling, the ring current may create a short-lived eastward electric field. This may cause the F-layer height to rise momentarily before falling again. Such a situation may create irregularities and this might be the cause of scintillations during midnight and post-midnight periods. Figure 5 shows the percentage occurrence of losses of lock occurred during quiet and disturbed days for the year 2005-06. It is seen from the Figure that maximum number of losses of lock were observed in the month of January during quiet days whereas it is minimum in April and May. No losses of lock were observed during the month of August and November. Percentage of occurrence of losses of lock is more pronounced during the disturbed days. During the occurrence of strong irregularities there are large phase and amplitude scintillation (called fades) in the GPS signal and when the fades are deep enough and long enough there are possibilities of occurrence of loss of lock or lengthening of acquisition times.

### *3.3 Effect of storms on scintillations*

Different phases of geomagnetic storms affect the generation and development of ionospheric irregularities differently. In this section the association of magnetic storms with the occurrence of scintillations at Bhopal is examined. The events were classified into three different types by using a method close to that suggested by Aarons (1991). Here, the Type-I geomagnetic storms are those with maximum negative value of SYM-H index occurring after sunset and before midnight. The Type II geomagnetic storms are those with maximum negative value of SYM-H in the midnight and post midnight hours and the type III geomagnetic storms refers to that when the maximum negative value of SYM-H takes place during day time hours. The Aarons (1991) criteria use the 1-h time resolution magnetic Dst index to classify into these three types of storms. According to Aarons (1991) the ring current (as seen by the Dst index) may be a controlling factor in the generation of F-region irregularities. Recent studies have followed the Aarons method to study geomagnetic storm effects on the generation or inhibition of F-layer irregularities such as Singh et al. (2004). The advantage in the use of the SYM-H index is its 1-min time resolution which provides more precisely the time occurrence of the SCs, the maximum negative value of the horizontal component of geomagnetic field and the initial-to-main and recovery phase duration of the storms.

#### *3.3.1 Type-I storms*

It can be seen for the type I storms that the post-midnight period of the main phase night follows that time when the large negative SYM-H takes place (in the pre-midnight period). It means for this type of storm, the enhancement in the eastward electric fields at the equator due to prompt penetration electric field and, consequently, the uplift of the F-layer, could favor the intensification and/or generation of ionospheric irregularities. So, during type-I storms scintillations might occur in the post midnight hours of the main phase and mainly during the recovery phase. Figure 6 shows an example of type-I storm. The top panel shows the Bz component from Interplanetary magnetic field (IMF), the middle panel shows the SYM-H and the bottom panel presents the GPS amplitude scintillation index (S4).The SSC occurred at 11:25 LT on 24 August 2005. After the SSC, IMF Bz fluctuate in the southward and northward direction and turned strongly southward reaches to its lowest value of ~-45nT. The SYM-H index reached to its minimum value -179nT at 1151 UT. The Sudden decrease in SYM-H might be due to the prompt penetration of electric field. Since the prompt penetration of electric field was during the local post-noon hours, its eastward polarity uplifts more plasma from dip equator by enhanced EXB drift. During the main phase of storm, before the maximum value of SYM-H, weak scintillations were observed at Bhopal.

#### *3.3.2 Type-II storms*

According to Aarons (1991) we should expect in a similar way, for the SYM-H index with large excursion in the midnight and post-midnight hours (type-II), the triggering of scintillations in the post-midnight main phase. This might occur due to momentary creation of eastward electric field opposing the normal nighttime zonal westward electric fields. Figure 7 shows an example of type-II storm that occurred on 8 May 2005. The top panel shows the Bz component from Interplanetary magnetic field (IMF), the middle panel shows the SYM-H and the bottom panel presents the GPS amplitude scintillation index (S4). The SSC occurred at 16:00 LT on 7 May 2005 and the SYM-H index reached -117 nT. Previous studies have shown occurrence of post-midnight scintillation activity when the maximum of main phase of storm begins at midnight to dawn local time sector.

When the maximum negative value of SYM-H takes place, the sharp decrease in SYM-H and the associated prompt penetration electric field into the equatorial ionosphere is not efficient enough to trigger the irregularities and to overcome the factors that may be acting to suppress the generation of irregularities in the post-midnight main phase. For the cases in which the SYM-H index is above -100 nT (weak-to-moderate storms), the intensification in the ring current and the changes in the magnetospheric electric fields may not be sufficient to cause scintillations in the post-midnight main phase.

#### *3.3.3 Type-III storms*

Figure 8 shows an example of type-III storm that occurred on 15 May 2005. The top panel shows the Bz component from Interplanetary magnetic field (IMF), the middle panel shows the SYM-H and the bottom panel presents the GPS amplitude scintillation index (S4). The SC occurred at 0808 LT on May 15, 2005 It is observed that after the SSC, IMF Bz fluctuates between southward and northward and turned strongly and steeply southward at 1040 LT. It reached to the lowest value of ~ 45nT. The sudden decrease in IMF Bz causes the decrease in Sym-H, which results in the beginning of the main phase of the geomagnetic storm. On May 15, 2005, the value of Sym-H reached to minimum -305nT at 1351 LT. This suggests that sharp decrease in IMF Bz created the under-shielding condition and the prompt penetration electric fields occurs at low latitudes around 1135 LT.

In this storm the large excursion of SYM-H occurs during day time and the scintillations are inhibited during the following recovery phase night. Singh et al. (2004) explain that in the occurrence of type-III storms, the normal uplift of the ionosphere at F-layer heights as seen from the height parameters scaled from ionograms are disturbed and, as consequence, the generation of the irregularities is suppressed. According to Abdu (1997) we may attribute to disturbance dynamo effects as the main cause for the inhibition of irregularities during type-III storms.

## 4 Discussion

The observation of GPS signal scintillation from the northern crest of the equatorial anomaly in the Indian zone reveal two distinct regions of very intense scintillations (1) near the crest of the equatorial anomaly and (2) in the southern sky. The first one is attributed to irregularities in an environment of high ambient electron density near the crest (Aarons et al., 1981) and the later is attributed to the propagation geometry with respect to the magnetic field lines. The morphology of equatorial scintillations during solar maximum and minimum is well established (Aarons, 1982; Basu et al., 1988).

Scintillation studies using GPS has been carried out by many groups (Bhattacharyya et al., 2000; Gwal et al., 2004; DasGupta et al., 2004; Dubey et al., 2006 and Gwal et al., 2006) for low latitude and equatorial region. Weak and strong level of scintillation can produce disruption of the communication and navigation links that use low or high altitude orbiting satellites.

During low solar activity years, the height of the F-region decreases results a sparse scintillation occurrence. The irregularities at low latitude are observed at irregular intervals and their duration increases as one move closer to the geomagnetic equator. The occurrence of scintillation observed during summer months are relatively weak as compared to those recorded during winter and equinox months Figure (1, 2, and 3). The enhancement in magnetic activity leads to a suppression of pre-midnight scintillations during the equinox and during the winter, whereas as enhancement is observed in summer months. The generation or inhibition of irregularities during the main phase/recovery phase of a magnetic storm depends upon the location of the station and local time. If the storm occurs post-midnight, then scintillations are observed during main and recovery phase. On the other hand, when a storm occurs during the day time no scintillation is observed during the night of the recovery phase. Weak scintillations observed during the recovery phase in some magnetic storm are attributed to freshly generated irregularities caused by disturbance dynamo electric field (Basu et al., 2001). In the third case when a storm occurs after sunset and before mid-night, the F-layer is disturbed but scintillations are observed only during the undisturbed nights.

## 5 Conclusions

The main outcomes of the present work are summarized as follows-

- On an annual basis the results showed here show that the magnetic activity effect over Bhopal leads to a suppression of L-band. The percentage occurrence of loss of lock is maximum in the month of January during quiet days whereas it is minimum in April and May. Percentage of occurrence of loss of lock is more pronounced during the disturbed days. Due to strong scintillation activity the loss of GPS signal may occur.
- Whether the minimum value of SYM-H takes place after sunset and before mid-night, then scintillation might be observed in the pre-midnight main phase and/or in the post-midnight main phase. When the maximum negative value of SYM-H occurs after mid-night and before sunrise then scintillation are observed only during the recovery phase. On the other hand, when a storm occurs during the day time, there are no scintillations during the first recovery phase night.

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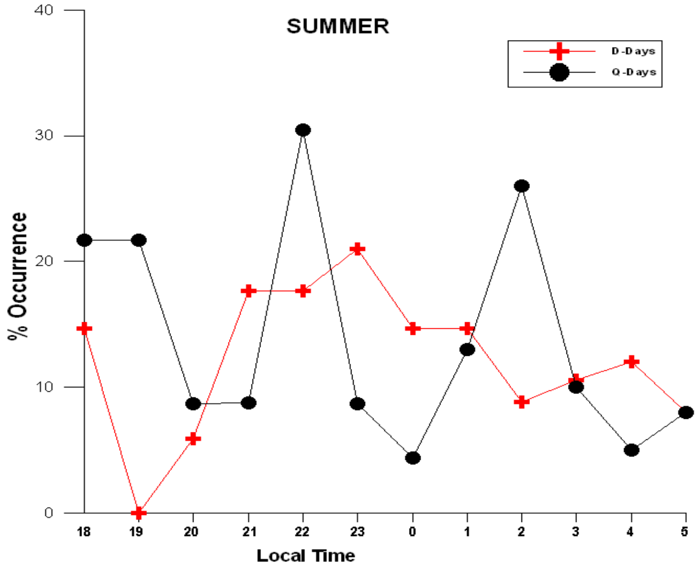

Figure 1 Seasonal variation of the percentage occurrence of amplitude scintillation for summer months during 2005-06

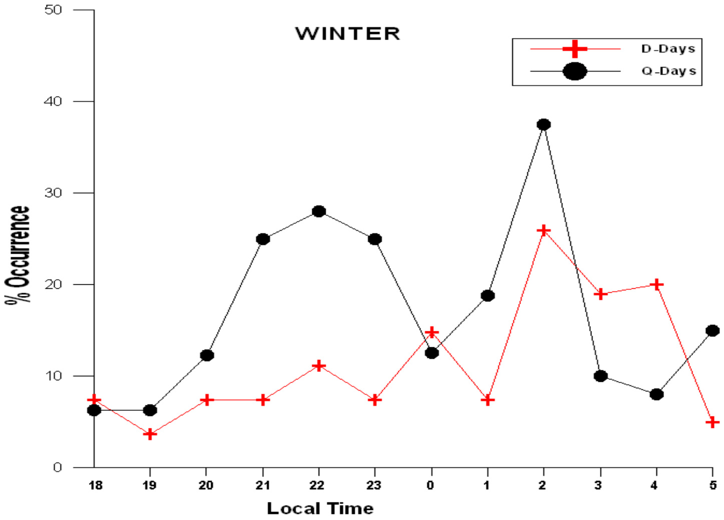

Figure 2 Seasonal variation of the percentage occurrence of amplitude scintillation for winter months during 2005-06

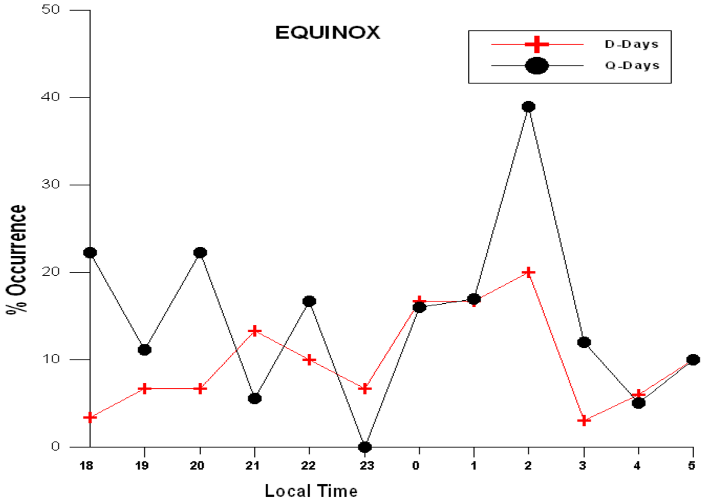

Figure 3 Seasonal variation of the percentage occurrence of amplitude scintillation for Equinox months during 2005-06

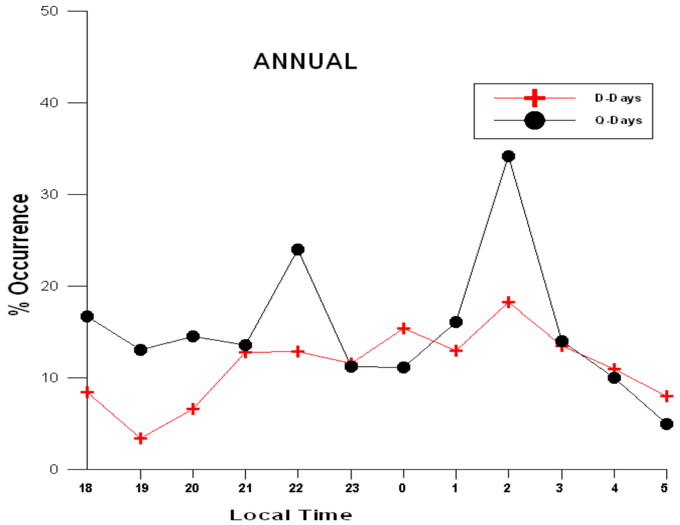

Figure 4 Annual variation of percentage occurrence of scintillation with local time for the year 2005-06

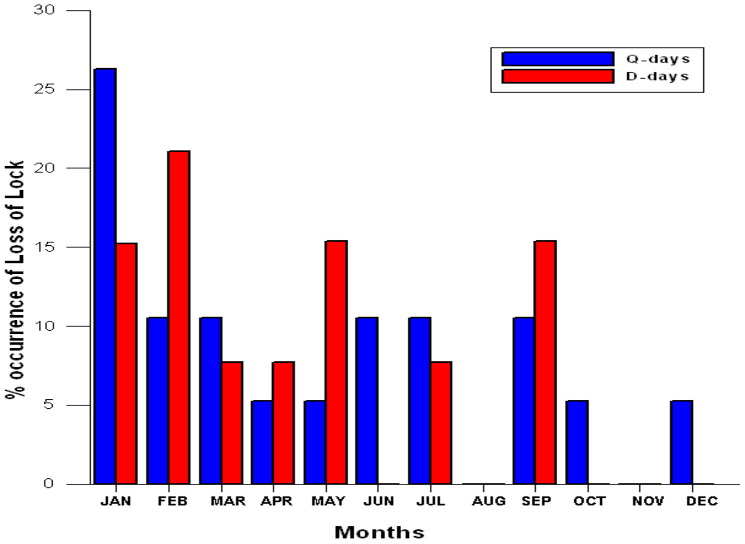

Figure 5 Percentage occurrence of Losses of lock occurred during 2005-06

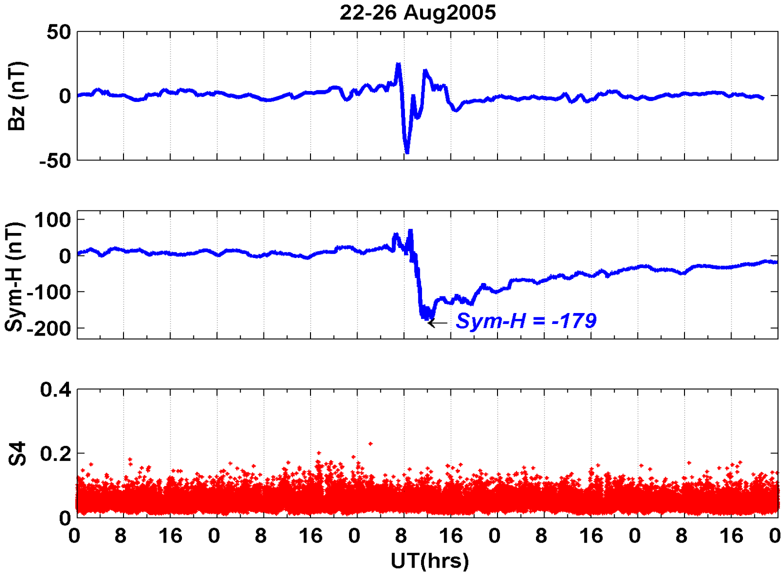

Figure 6 Example of type-I magnetic storm that occurred during 22-26 August 2005

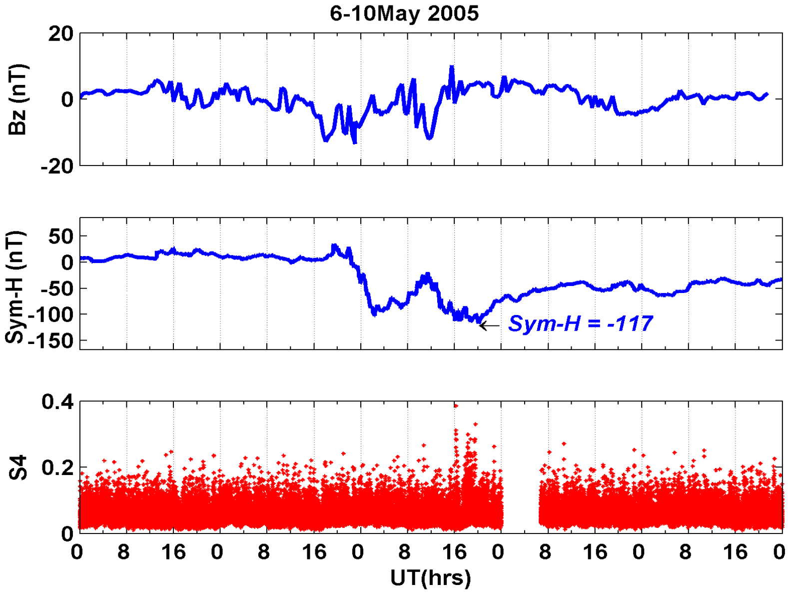

Figure 7 Example of type-II magnetic storm that occurred during 6-10 May 2005

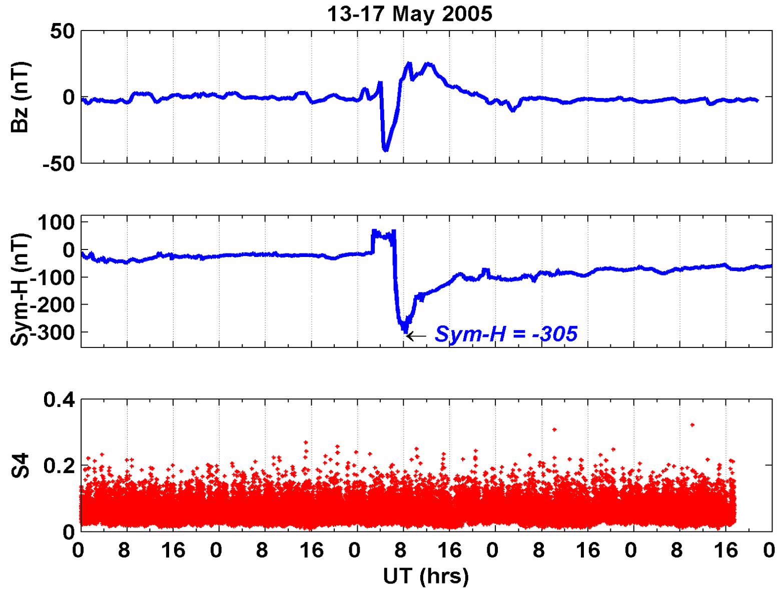

Figure 8 Example of type-III magnetic storm that occurred during 13-17 May 2005

**TABLE-1**

The classification of weak, moderate and strong scintillation

| S. No | Level of Scintillation | Scintillation Index |
|---|---|---|
| 1. | Weak | >0.25 and <=0.4 |
| 2. | Moderate | >0.4 and <=0.6 |
| 3. | Strong | >0.6 and <=1.0 |
| 4. | Very Strong | >1.0 and <=1.4 |

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