J. Astrophys. Astr. (2018) 39:36
https://doi.org/10.1007/s12036-018-9529-2

Effect of geomagnetic storms on VHF scintillations observed at low latitude

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MS received 5 October 2017; accepted 9 May 2018; published online 7 June 2018

Abstract. A geomagnetic storm affects the dynamics and composition of the ionosphere and also offers an excellent opportunity to study the plasma dynamics. In the present study, we have used the VHF scintillations data recorded at low latitude Indian station Varanasi (Geomag. latitude = $14^{\circ}55'$N, long. = 154°E) which is radiated at 250 MHz from geostationary satellite UFO-02 during the period 2011–2012 to investigate the effects of geomagnetic storms on VHF scintillation. Various geomagnetic and solar indices such as Dst index, Kp index, IMF Bz and solar wind velocity (Vx) are used to describe the geomagnetic field variation observed during geomagnetic storm periods. These indices are very helpful to find out the proper investigation and possible interrelation between geomagnetic storms and observed VHF scintillation. The pre-midnight scintillation is sometimes observed when the main phase of geomagnetic storm corresponds to the pre-midnight period. It is observed that for geomagnetic storms for which the recovery phase starts post-midnight, the probability of occurrence of irregularities is enhanced during this time and extends to early morning hours.

Keywords. Geomagnetic storm—VHF scintillation—dst indices—ionospheric irregularities.

1. Introduction

Space weather activity causes geomagnetic disturbances, such as geomagnetic storms and substorms, due to which the energy inputs from the magnetosphere, render dramatic effects into the Earth's upper atmosphere. One of such effects is the change in ionospheric plasma density and formation of ionospheric irregularities, which perturbs communication and navigation systems (Basu *et al.* 2001b). The fluctuations in amplitude and phase of the radio signal passing through the irregular ionosphere is known as scintillation (Aarons *et al.* 1980). It is observed that the severe scintillation may lead to data loss and cycle slips in Global Positioning System (GPS) (Aarons and Basu 1994; Basu *et al.* 1996). During geomagnetic disturbance the low latitude ionosphere is prone to serious problems (Olatunbousun and Ariyibi 2015). Hence it is necessary to understand the effect of geomagnetic storm on the generation and inhibition of very high frequency (VHF) scintillations.

The variations of geomagnetic storms are controlled by the solar and magnetic sources such as simple coronal mass ejections (CMEs), magnetic cloud structures, multiple occurrences of CMEs, high–speed solar wind streams, etc. (Zhang *et al.* 2007). The geomagnetic storms are characterized by using various magnetic indices Kp, Ap and Dst index. The Dst index is the widely used index to characterize geomagnetic storm which represents the hourly measurement of the globally averaged horizontal component of the Earth's magnetic field at mid to low latitudes. A geomagnetic storm refers to a prolonged depression of the Dst index in the mid to low latitudes in the range of several tens to several hundred nT and occurrence time has few hours to several days (Gonzalez *et al.* 2002). The horizontal geomagnetic field component has its different degree of deperession and depends on the magnetic local time. Due to assymmetric flow of the ring current the maximum and minimum depression of the horizontal geomangetic field component is found on the night time to dusk time and day to dawn side respectively (Aarons 1991). Orientation and strength of the ionospheric electric fields gets modulated by the magnetic disturbance, however the effects can be highly localised and can vary from storm to storm (Nayak *et al.* 2017). These disturbances produce a problem to the scintillation in the ionosphere in trans-radio wave propagation, even GHz frequencies.

The study of the response of geomagnetic storms on the VHF scintillation's activity has been done by many decades by many authors for different altitudes and latitudes (Aarons *et al.* 1980; Aarons & Das Gupta 1984; DasGupta et al. 1985; Kumar and Gwal 2000; Bhattacharya *et al.* 2002; Kelley *et al.* 2003; Singh *et al.* 2004, 2017). The penetration electric field associated with the southward turning of the IMF *Bz* and the disturbance dynamo electric fields together play significant role in generation and development of ionospheric F-region irregularities (Fejer *et al.* 1999; Basu *et al.* 2001a; Basu *et al.* 2001b). However, during certain times of the geomagnetic storm, contributions due to protonspheric-fluxes and electric fields are also important, for example during the initial phase of a storm the magnetospheic electric field penetrates to mid and low latitudes. Aarons and Das Gupta (1984) has reported for most of the storms that the probability of occurrence of scintillation activity is enhanced during the post-midnight period for which the recovery phase starts after midnight. Using VHF scintillation and L-band data, Vijay Kumar *et al.* (1988) also reported that increased magnetic activity might inhibit in inhibition growth of Rayleigh–Taylor instability (RTI), hence results in inhibition of scintillation production, especially during high solar activity period. Banola *et al.* (2001) has reported occurrence of scintillations during high solar activity periods and the study during low solar activity period over low latitude region is lacking. To complete the study of effect of geomagnetic storms on VHF scintillation during comparatively low solar active period of 2011 (Rz = 55.6) and 2012 (Rz = 57.6) over low latitude region, the present study has been initiated.

This paper presents the detail study of the response of geomagnetic storms on VHF scintillations with the help of 250 MHz signal data recorded at our low latitude Indian station Varanasi (Geomag. latitude = $14^{\circ}55'$N, long. = 154°E, Dip angle = 37.3°, Sub-ionospheric dip = 34°) during 2011 to 2012. The diurnal, seasonal, annual, as well as effect of solar and geomagnetic activity on occurrence of scintillations have been carried out.

2. Data analysis

The VHF scintillation recording system is installed at Atmospheric Research Lab, Department of Physics, Banaras Hindu University, Varanasi, which consists of a super-heterodyne fixed frequency VHF Receiver "Akash", an 11-element Yagi-Uda antenna and a strip chart recorder (Singh *et al.* 2004). The amplitude scintillations of 250 MHz signal radiated from the geostationary satellite UFO-02 situated at 72°E longitude has been continuously recorded at Varanasi. The amplitude scintillations recoded on strip chart is calibrated as 1 cm equal to 2.54 dB by the method described by Basu and Basu (1989). This receiver has its dynamic range about 20 dB. Using the calibration and conversion chart (Whitney *et al.* 1969) the scintillation index in dB has been scaled manully with the interval of 20 min by measuring peak-to-peak $P_{max} - P_{min}$, where P_{max} presents the power amlpitude of the third peak down from the maximum excursion and P_{min} also represents the power amplitude of the third level up from the minimum excursion. The number of the occurrence of scintillation data is divided by the total number of days of scinitllation recorded and then multiplying by 100 to get the percentage occurece of scintillaion.

Typical examples of different types of amplitude scintillations recorded at Varanasi during 2011 to 2012 are shown in Fig. 1. The scintillation index of the recorded different amplitude fluctuations varies between 1.77 dB to 3.30 dB. The results of detailed analysis of variation of percentage occurrence of scintillations and effect of geomagnetic storms on scintillations at Varanasi during the period 2011–2012 are presented in Sect. 3. To investigation the response of the geomagnetic storm on the VHF scintillation occurrence, we have analyzed the data of Kp, Dst index, solar wind velocity (Vx) and interplanetary magnetic field (IMF) Bz downloaded from Goddard Space Flight Center, NASA, USA.

3. Results and discussions

The annual occurrence characteristics of VHF scintillations and the effect of geomagnetic storms on VHF scintillation during the years 2011 and 2012 have been carried out. The study considered different intense storms that occurred in 2011 and 2012. Comparative results of the occurrence of VHF scintillation and roles of storm events on the formation of such irregularities are presented. The effects of geomagnetic storm on VHF scintillation as well as the annual occurrence characteristics have been investigated with the help of the recorded data during the period 2011 to 2012 at the low latitude Indian station Varanasi.

3.1 *Annual occurrence*

The diurnal variations of the percentage occurrence of scintillations for the period of 2011 to 2012 have been shown in the Fig. 2. It is clear from the figure that

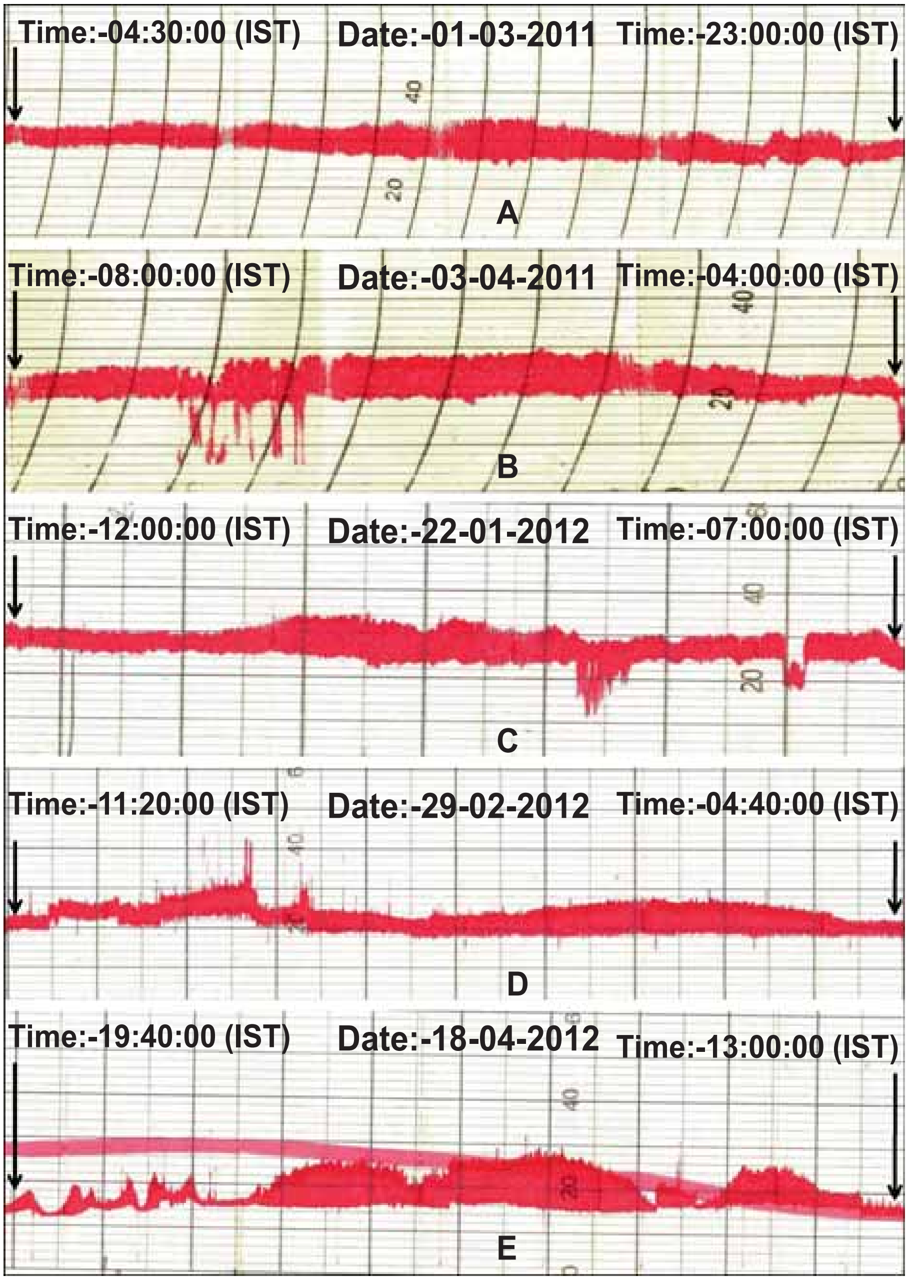

Figure 1. Typical examples of different types of scintillations observed at Varanasi during 2011–2012.

maximum percentage occurrence of scintillations was observed during pre-midnight periods between 18:00-20:00 hrs (IST). The percentage scintillation occurrence is higher during 2012 (Rz = 57.6) compared to during 2011 (Rz = 55.6), having peak occurrences 3.49% and 0.96% respectively.

At low latitude the scintillations occur in small patches and the time duration of patches vary from a few minutes to several hours. It is observed that the scintillation activity during night is higher by 25% than during day (Bhardwaj *et al.* 1983; Singh *et al.* 2004). Singh *et al.* (2006) and Singh *et al.* (2017) have reported that the percentage occurrence of VHF scintillation over Varanasi is higher during the high solar activity period than the low solar activity. The high electric field is enough to push the ionospheric plasma to higher altitudes over the magnetic equator, the plasma bubbles map to off equatorial latitudes along the magnetic field lines in the post-sunset hours (Brahmanandam *et al.* 2017). The irregularities generated by the post-sunset electrodynamics show solar activity dependence, seasonal-longitudinal variations as well as day-to-day

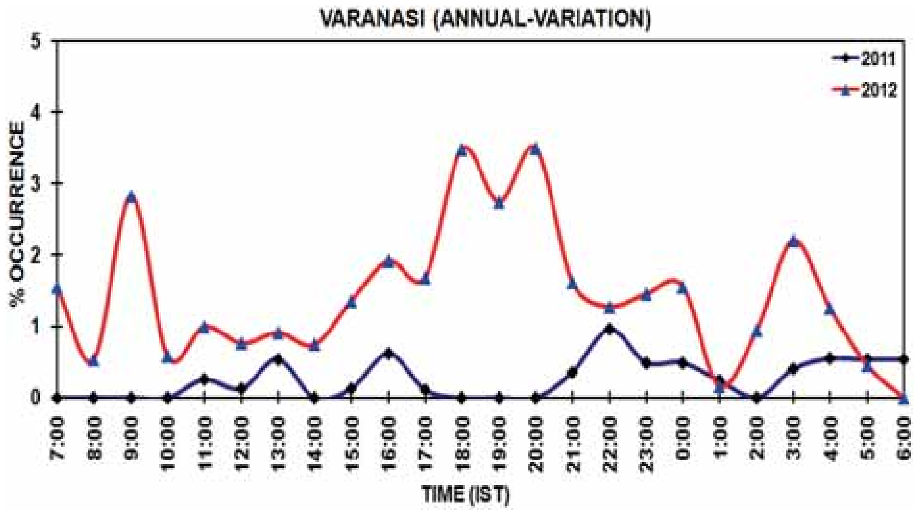

Figure 2. Percenatage scintillation occurrence rate during 2011–2012 at low latitude Indian station Varanasi.

variations at equatorial and low latitude (Yeh and Liu 1982; Tsynoda 1985; Srinivasu *et al.* 2017). Basu *et al.* (1977) have explained due to the varying thickness and horizontal extent of the layers of irregularities along the transionospheric propagation path of the signal and also due to the breaking up structures into smaller ones as they move away from the equator along and sometimes across (due to east-west drifts) the field lines are reasons for the observed continuous scintillation activity at equator and patchy activity at the off-equatorial stations (Singh *et al.* 2004).

3.2 *Effect of geomagnetic storms*

Ionosphere shows a variety of effects which may depend on geographic latitude, local time and time of onset of the storm during geomagnetic storm. The dynamical and electro change in the ionosphere are introduced by the geomagnetic storm (Aono & Suzuki 1949). Dynamic effects influence the ionosphere during geomagnetic disturbances to the upward or downward motions of the ionization caused either by electric fields or neutral winds and field-aligned flow of ions between the ionosphere and magnetosphere (Fejer 1997).

A geomagnetic storm has main phase and recovery phase and it is observed that different phases affects the generation of ionospheric irregularities differently (Singh *et al.* 2004). Studies on the generation of spread-F irregularities and VHF scintillation, during the post-midnight period when geomagnetic storms are active have been reported (Aarons 1991). To study the effect of geomagnetic storms on VHF scintillation a total 16 moderate and intense geomagnetic storms during the analysis period (2011–2012) for which the scintillation recording is available are included, and the results of these studies are presented in Table 1. We have tried to illustrate the results using some typical cases. The variation of Dst index, Kp index, interplanetary magnetic field (IMF) Bz, solar wind velocity (Vx km/s) and scintillation index of VHF scintillations for some of the selected cases are presented below.

3.2.1 Storm during 1–6 March, 2011 In Fig. 3, we have shown the variation of solar wind speed, Bz component of IMF, Dst and Kp index and scintillation index for the selected geomagnetic storm occurred during 1–6 March, 2011 for the study of response of geomagnetic storm on VHF scintillation. The top panel shows the variation of Dst-index during storm period having minimum Dst index value of -81 nT on 1 March 2011 at 15:00 UT then it starts to recover and recovery phase saturated on 5 March 2011 at 5:00 UT after 0110 h. The second panel shows the variation of Kp index during the storm having maximum value of 5.25 on 1 March 2011 at 18:00 UT. During these selected geomagnetic storm periods the solar wind speed was maximum with 687 km/sec on 2nd March, 2011 at 4:00 UT and minimum with 305 km/sec on 1st March, 2011 at 2:00 UT. The IMF Bz was northward having maximum value of 10.4 nT on 1st March, 2011 at 8:00 UT and suddenly goes to turn southward direction having minimum value of -11.1 nT after 4 hrs on same day at 12:00 UT. The Bz component of IMF fluctuates from 2nd to 6th March, 2011. Scintillations occurred, 1-3 UT on 2nd March, 2011 and during 9-10 UT on 3rd March, 2011. These events were intense with a fast fading rate and extending well into the recovery phase of the storm. The maximum

Table 1. Details of moderate and intense geomagnetic storms and scintillation activity during the years 2011 and 2012 for which the scintillation data is available.

S. No	Storm Day	SSC time (h)	Main Phase onset time (h)	Magnitude of storm (nT)	Main Phase duration (h)	Recovery Phase Duration (h)	Longevity of storm (h)	Scintillation Occurrence		
								Pre-Day	Occurrence Day	Post- Day
1.	06 January 2011	21	23	−38	9	33		No	No	No
2.	4 February 2011	17	19	−59	4	98	104	No	No	No
3.	01 March 2011	10	11	−81	5	109	115	Yes	No	Yes
4.	09 March 2011	23	23	−83	32	67	100	No	No	No
5.	06 April 2011	10	11	−65	9	44	54	No	No	No
6.	12 April 2011	5	6	−51	4	73	78	No	No	No
7.	27 May 2011	16	17	−91	20	88	108	No	No	No
8.	22 January 2012	11	12	−73	10	42	53	No	Yes	Yes
9.	24 January 2012	16	18	−80	18	126	145	Yes	No	No
10.	18 February 2012	20	24	−54	5	68	77	No	No	ND
11.	07 March 2012	1	3	−85	13	20	35	No	No	Yes
12.	08 March 2012	12	15	−143	18	73	94	No	No	Yes
13.	12 March 2012	11	12	−80	80	128	209	No	No	Yes
14.	27 March 2012	9	12	−55	17	27	47	No	No	No
15.	23 April 2012	16	19	−104	10	87	101	No	No	No
16.	17 June 2012	1	9	−86	6	87	101	No	No	No

Note: ‘No’: No Scintillation, ‘Yes’: Scintillation present; ‘ND’: No data

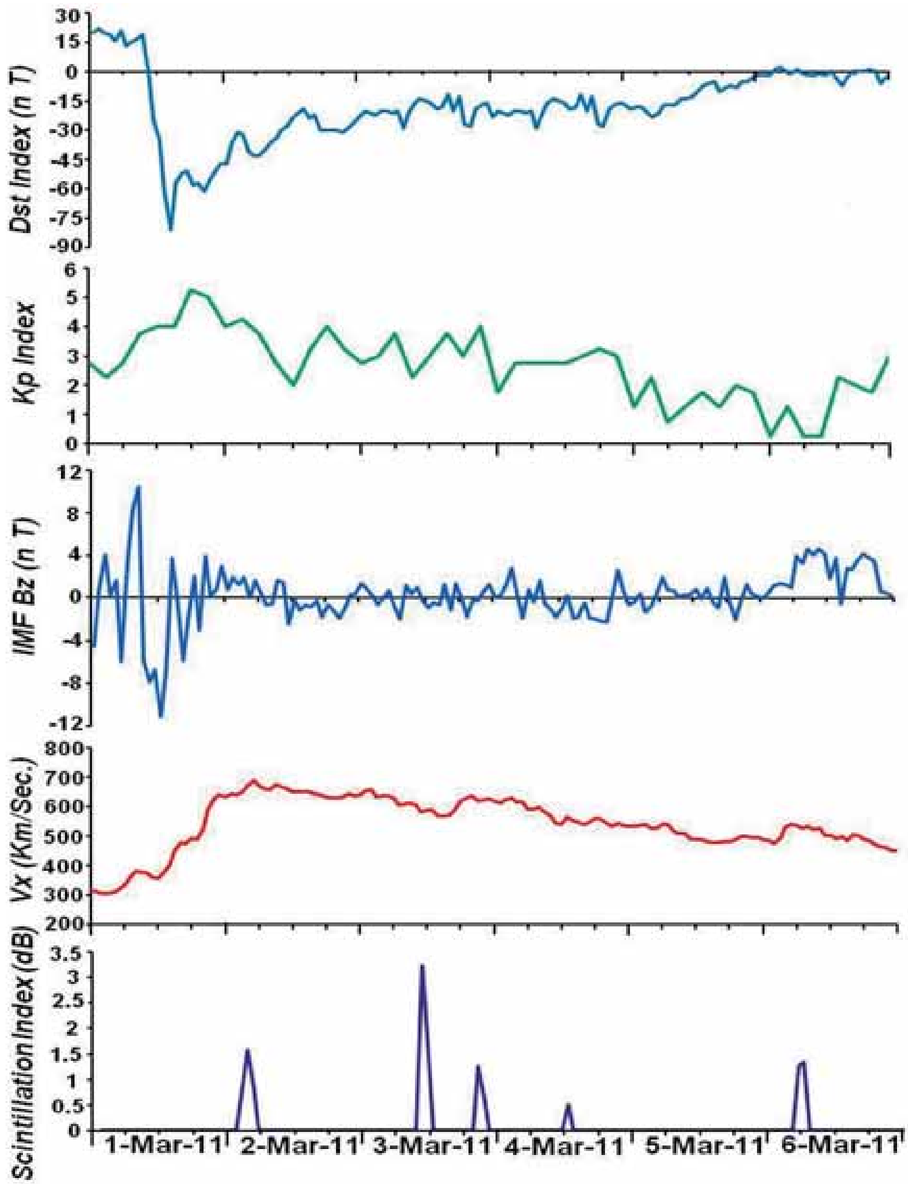

Figure 3. Variation of Dst index, Kp index, IMF Bz (nT), Vx (km/sec.) during geomagnetic storm period from 1–6 March 2011.

value of the scintillation index is found to be 3.3 dB on 3rd March, 2011.

Aarons (1991) has reported that enhancement of irregularties during geomagnetic storm are related with the change in ring current. The east ward electric field is increased due to an increase in the F-layer (Fejer *et al.* 1999) during the pre-sunset period. The geomagnetic storm process reduces the F-layer height because it would lower the eastward electric field. This effect may sometimes be large enough to reverse the upward movement of F-layer during the post-sunset, thereby inhibiting the creation of irregularities. This may result in a suppression of pre-midnight scintillations over most longitudes during period of intense magnetic activity.

3.2.2 Storm during 22–25 January, 2012: It is well known that solar wind has the association of geomagnetic storm with CME. Figure 4 also contains the variation of solar wind parameters, IMF Bz component, Dst index, Kp index and scintillation index of the selected geomagnetic storm occurred during 22 - 25 January, 2012. The top panel shows the variation of Dst-index during storm period having minimum Dst index value of -73 nT on 22 January 2012 at 21:00 UT. Then it starts to recover and become positive on 24 January 2012 at 15:00 UT. The value of Dst index again becomes negative to attain a minimum value of -80 nT on 25 January 2012 at 10:00 UT. The solar wind during this selected geomagnetic storm has maximum value of

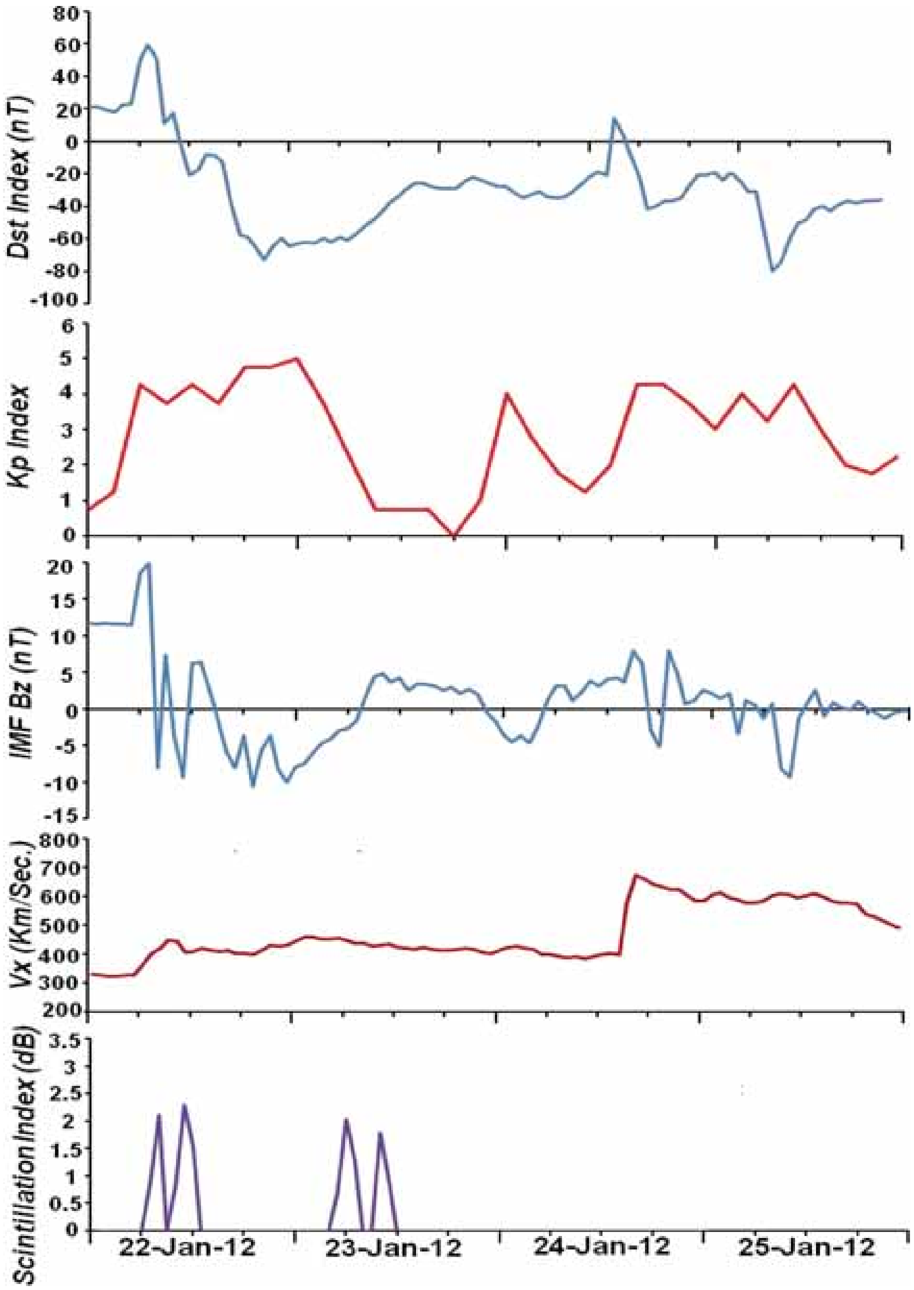

Figure 4. Variation of Dst index, Kp index, IMF Bz (nT), Vx (km/sec.) during geomagnetic storm period from 22–25 January 2012.

673 km/s on 24 January 2012 at 16:00 UT and minimum value of 331 km/s at 01:00 UT on 22 January 2012. It is clear from the figure that solar wind speed has initially average low value of about 400 km/s at 12:00 UT on 22 January to 14:00 UT 24 January 2012 and after that it suddenly increases and reaches to 673 km/s on 24 January at 16:00 UT. After reaching the maximum value it starts to decrease and goes to 491 km/s on 25 January 2012 at 23:00 UT. IMF- Bz has also maximum value 20 nT on 22 January 2012 at 07:00 UT and it suddenly goes to turn south ward direction and goes to the lowest value of -10.5 nT on 22 January 2012 at 19:00 UT. It is found that the maximum Kp value during the storm period is 5 on 23 January 2012. Scintillations are observed on 22 January 2012, during 6-11 UT and on 23 January 2012 during 4–6 UT and 9–10 UT. The maximum scintillation index of 2.2 dB is found on 22 January at 10 UT. It may be noted that the first event of scintillation started in the main phase of the storm, whereas the second event was in the recovery phase.

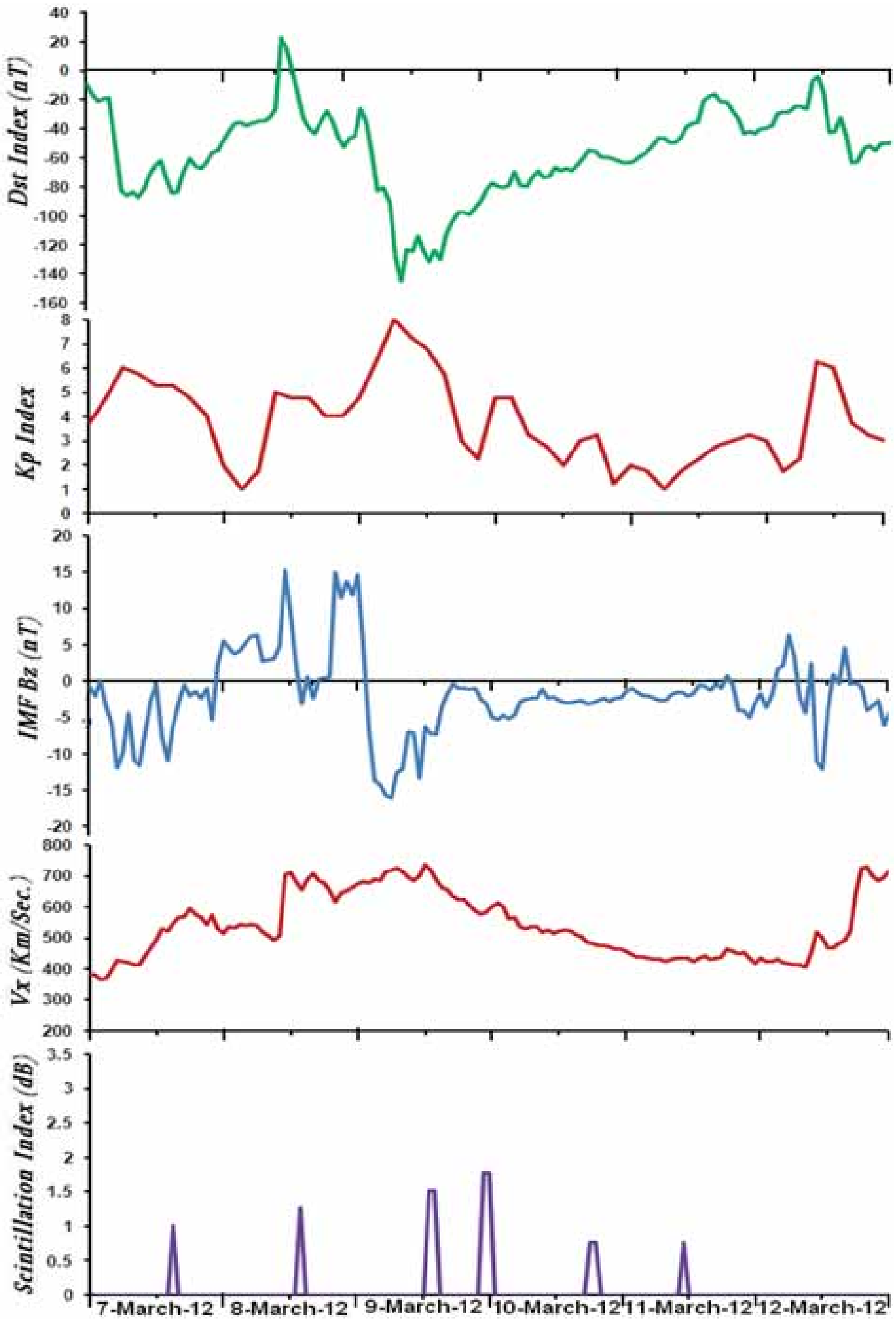

Figure 5. Variation of Dst index, Kp index, IMF Bz (nT), Vx (km/sec.) during geomagnetic storm period from 7–12 March 2012.

The first event of scintillation associated with a sharp decrease in Dst-index may be caused by a prompt penetration of the electric field into the equatorial ionosphere with a consequent sudden onset of irregularities (Basu *et al.* 2001a).

3.2.3 Storm during 7–12 March 2012 Two geomagnetic storm events occurred during the period 7–12 March 2012 as shown in the Fig. 5. The first event was occurred on 7 March, with minimum Dst index value -75 nT at 12 UT. The storm has fully recovered before the commencement of the second intense geomagnetic storm on 9 March 2012. This event started at about 02:00 UT and get minimum value about of -131 nT. The maximum value of Kp was found 8 during the storms on 9 March 2012. The IMF-Bz showed southward turning during the storm days and has highest value about–16 nT at 06:00 UT during the main phase of the storm on 9 March 2012. The plasma speed remained high from about 12:00 UT on 8 March to 12:00 UT on 9 March 2012 with maximum value 740 km/s. From the Fig. 5, it is clear that the Kp also started rising before the southward turning of IMF-Bz. It also remained high even when the IMF-Bz changed direction and it decayed more slowly that it rose. This is an evidence of correlation of Kp and IMF-Bz. Davis and Hartmann (1997) has reported that the Kp index is correlated with southward turning of the IMF-Bz to a large extent. During the storm on 9 March the prompt penetration of electric field operates about 6 h. It is observed that storms events on 7 March was moderate and on 9 March was intense. Scintillations are observed on 7 March, during 14:05–14:20 UT, on 8 March during 13:40–14:00 UT, on 9 March during 22:40–23:50 UT, on 10 March during 17:40–19:00 UT and on 11 March 2012 during 09:40–09:50 UT. The maximum scintillation index of 1.78 dB is found on 9 March 2012 at 23:00 UT.

Many workers (Singh *et al.* 2004; Prasad *et al.* 2005) have reported the effect of geomagnetic storms on the occurrence of VHF scintillations and related results are explained relating the short term (transients) and long term (recurrent) effects during individual storm events (Abdu *et al.* 1985). During the magnetospheric disturbances, coupling of the high latitude and the magnetospheric current systems with the equatorial electric fields possibly causes a direction reversal of the electric fields from westward to eastward (Gonzales *et al.* 1979). This plays a significant role in the generation and growth of F-region irregularities and explains the magnetic storm-induced post-midnight scintillations extending into the daytime (Chandra *et al.* 1995; Chakraborty *et al.* 1999; Basu *et al.* 2001a; Bhattacharya *et al.* 2002). The equatorial dynamo electric field is also disturbed during a geomagnetic storm and this also affects the generation and growth of ionospheric irregularities (Basu *et al.* 2001a; Bhattacharya *et al.* 2002). Kassa and Damtie (2017) have studied the effect of different cases of geomagnetic storms on the occurrence of GPS phase fluctuation based on ionospheric irregularities at low latitude station in the Ethiopian sector. They have found that in most cases, the irregularities have been suppressed as result of the observed storms but in some of the case, the irregularities develop in the evening sector during the early stages of high geomagnetic activity periods and latter suppressed. Recently, Nayak *et al.* (2017) have reported the absence of ionospheric VHF scintillations over Pingtung, Taiwan during the 17 March 2015 St. Patrick's day geomagnetic storm. He explained that the absence of scintillation was a reduced pre-reversal enhancement electric field caused due to eastward prompt-penetration electric field. An enhanced geomagnetic activity is not guaranteeing the formations of ionospheric scintillation but under certain conditions it can favor the formation of ionospheric scintillations at magnetic equator (Nayak *et al.* 2017). The scintillation occurrence during intense geomagnetic storms at low latitude stations reveled that scintillation can be inhibited or triggered during geomagnetic storm depending upon the phase of the storm and time of occurrence (Olatunbousun *et al.* 2017).

4. Conclusion

To study the response of geomagnetic storms on VHF scintillation we have analyzed the scintillation data recorded at Varanasi during 2011 to 2012. The diurnal variation of percentage occurences of scintillation having maximum percentage occurrence between 18:00–20:00 h IST in the year 2012 and in the year 2011 maximum percentage occurrence lie between 22:00–23:00 h IST. This diurnal variation shows the maximum occurrence during pre-midnight period having a small peak before noon hours. The peak occurrences are 3.49% during 2012 and 0.96% during 2011. The maximum scintillation indices of the selected geomagnetic storm periods during 1st - 5 March 2011, 22–25 January and 7–12 March 2012 are 3.3 dB, 2.2 dB and 1.78 dB respectively. The VHF scintillation occurrence during the moderate and intense geomagnetic storms (2011–2012) can be inhibited or triggered depending upon the phase of storm or local time of occurrence.

The occurrence of VHF scintillations at low latitude particularly in the late afternoon hours may be due to E-region irregularities and the nighttime scintillation may be due to the F-region irregularities. The role of the storm time electric field is very complex and it gives the informations that the magnetospheric electric field changes related to the ring current intensification are not sufficient to explain all of the observations of inhibition and the generation of low-latitude ionospheric irregularities during the night. There are several other factors which shape the development of irregularities, such as the ion-neutral collision frequency, neutral wind, large scale plasma density gradient, gravity wave, etc. A magnetic storm enhances the interplay of these parameters and hence their contributions should be considered separately.

Effect of magnetic and solar activities on ionospheric irregularities are studied so as to ascertain their role in the space weather of the near Earth environment in space. Solar and geomagnetic activity are linked to the upper atmosphere and constituted one of the important links in understanding the complex solar terrestrial relations. The study of solar-terrestrial relation ephemeris predictions is severally degraded during these activities.

Acknowledgements

The work is partially supported by ISRO, Bangalore, under ISRO-SSPS to BHU. The author (SBS) is thankful to the DST-PURSE (5050) grant for providing Research Associate. We are thankful to the reviewer for their valuable comments and suggestions to improve the quality of the manuscript.

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