Geomagnetic storms and associated scintillation on VHF signals

Sushil Kumar, V Ramachandran, Amol Kishore
Department of Physics, The University of the South Pacific, Suva, Fiji

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1 INTRODUCTION

Geomagnetic storms are prevalent during high solar activity periods and are characterized by prolonged depression of the horizontal component (H) of the Earth's magnetic field. The depression in H is characterized by the geomagnetic index D_{st} which lies between -100 to -200 nT for intense and <- 200 nT for very intense storms. The long period of interconnection of the southward interplanetary magnetic field (IMF B_S) with the Earth's magnetic field transports solar wind energy into the Earth's magnetosphere. This is the primary cause for the formation of geomagnetic storms (Allen *et al*. 1989; Tsurutani *et al*. 1992; Gonzalez *et al*. 1999).

Intense and very intense storms cause ionospheric scintillations which can in turn adversely affect communication systems by disrupting VHF-UHF satellite links (Lastovicka, 2002). Ionospheric scintillation is defined as the fluctuation in the intensity of the signal as it passes through the irregularities present in the ionosphere. It has been reported from the low latitude station at Ahmedabad (23.01^{o}N, 71.23^{o}E), India (Chandra, 2002), that during intense magnetic storm of 22 September 1999, strong ionospheric scintillations, exceeding 20 dB, were recorded on the 244 MHz radio beacon signal from the geostationary satellite FLEETSAT. This scintillation is reported to have lasted several hours starting from post-midnight and extending to early hours after sunrise. Researchers have not analyzed the cause of this observation. Many diverse effects of geomagnetic storms during previous solar cycles are being analysed continuously by researchers (e.g., Basu and Basu, 2002; Kelly *et al*., 2003). The present communication analyses, in detail, the interplanetary magnetic field (IMF) and solar wind plasma data during the above scintillation activity period. Storm parameters obtained by international agencies during the storm on 22 September 1999 were used in the analysis. Records of scintillations during three other intense storms during the last solar activity period were also analyzed in this work to establish the consistency of prediction of scintillation. Fiji islands being in similar low latitude belt (0-30^o around the magnetic equator), may also experience similar scintillations and fade effects in its VHF satellite communication links.

2 RESULTS AND DISCUSSION

The scintillation data obtained at the Physical Research Laboratory, Ahmedabad, revealed unusual post-midnight strong scintillation on VHF beacon from the FLEETSAT satellite on 22 September 1999 (Chandra, 2002). To examine the correlation between scintillations and magnetic storms, hourly values of D_{st} were downloaded from World Data Centre for Geomagnetism (KUJ, 2003). One minute average values of interplanetary magnetic field and solar wind plasma data from Wind-spacecraft were downloaded from Space Science Data Centre, (CDA Web, 2003). Figure 1 shows the variations of the proton bulk velocity (p^+V), solar wind thermal velocity (SW, V_{th}), ion density (N), dynamic pressure (DP), total IMF (B), Z component of IMF (B_z), and D_{st} index for the magnetic storm event of 22-24 September 1999. The Sudden Storm Commencement (SSC) occurred at 12:42 universal time (UT) on 22 September and the minimum D_{st} (maximum storm strength) occurred at 00:30 UT on 23 September. It is evident that the magnitude of IMF B increased rapidly and the enhancement of B_z at first turned northward (+), later southward (–), and remained so for approximately four hours. The negative B_Z, called IMF B_S, interconnects with the Earth's magnetic field and allows transportation of solar wind energy into magnetosphere causing a magnetic storm. The storms can be driven by shock compression mechanism. B_Z fluctuated in the beginning of the first shock, but it generally had a northward component. It then turned southward during the second shock which resulted in an abrupt increase in N from 10 cm^{-3} to over 60 cm^{-3}. A change in proton bulk velocity p^+V from 350 km s^{-1} to more than 600 km s^{-1} was also observed, which gave an increase in DP from 2 nPa to over 35 nPa. The sharp increase in DP indicates a strong magnetospheric compression leading to the formation of this storm event. The bottom panel in Figure 1 shows the plot of D_{st} index and the duration of scintillation (>20 dB) occurrence (solid straight line). The scintillation was completely suppressed in the pre-midnight period, but was enhanced in the post-midnight period and extended to beyond sunrise hours. The very strong and long duration VHF scintillation observed during the minimum D_{st} on this storm day suggests that it is a direct consequence of storm time dynamics. It also indicates the generation of new and intense ionospheric irregularities causing the strong and fast fading on 244 MHz beacon.

Three other storm events were also analyzed for the causative interplanetary parameters and to verify the correlation with scintillation. The data are summarized in Table 1. The times indicated are UT (LT = UT + 5.5 hrs). Rows 4-10 indicate the peak values. The "x" and "O" in the last two rows indicate no occurrence and occurrence of scintillation in the pre-and post-midnight periods. For the first two storms, strong scintillation (>20 dB) with higher fading rate (20-25 fades/min) started in the post-midnight and lasted several hours while for the latter two storms they started in the pre-midnight period and lasted only for few minutes after midnight.

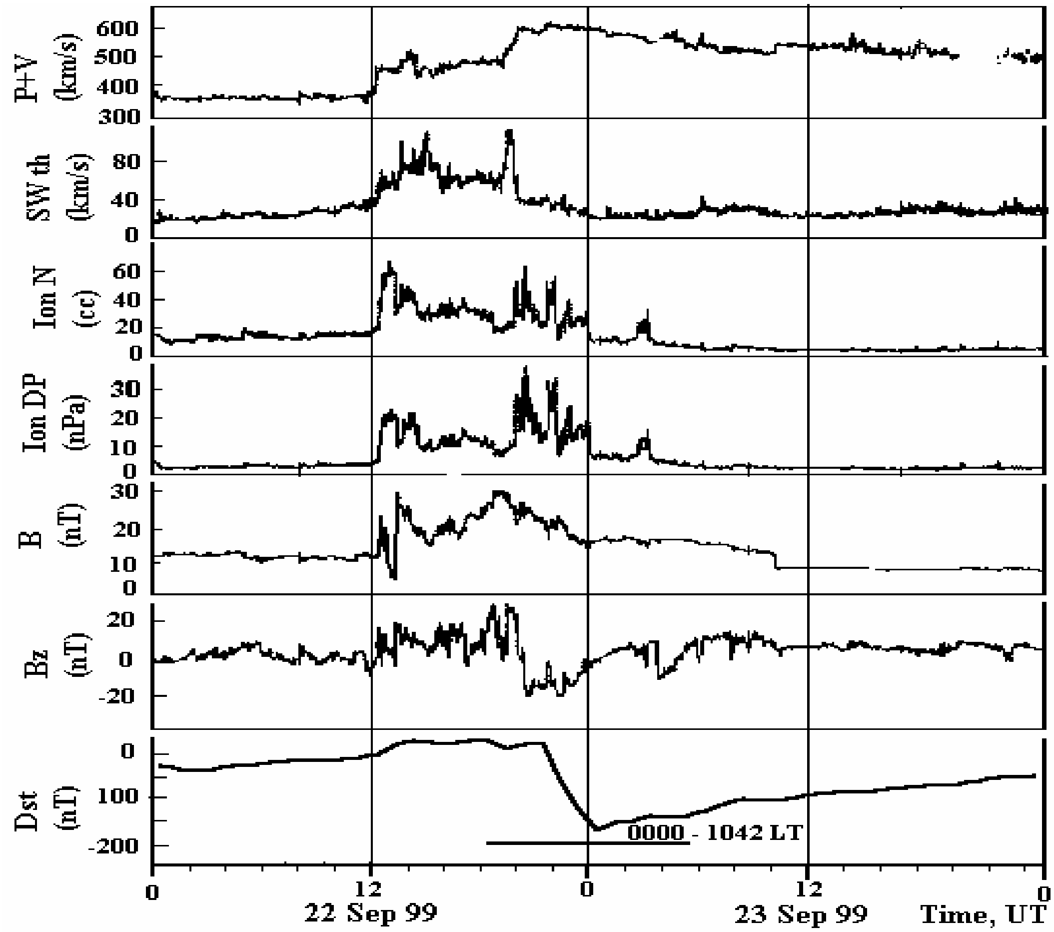

Figure 1 The variations of Wind spacecraft data, D_{st} index and scintillation activity

From Table 1 it can be seen that for all the storms the B_Z ranges from –10 to –20 nT. The storms were associated with IMF intensities in the range of 20 to 35 nT. The p^+V, *N* and associated *DP* were enhanced during these storms. For the first two storms, maximum strength (minimum D_{st}) occurred in post-midnight period and scintillation occurrence was completely inhibited in the pre-midnight period but enhanced greatly in the post-midnight period. The data show that the time of maximum storm strength occurrence determines the strength, time and duration of scintillation occurrence.

One of the necessary conditions for the generation of F-region irregularities in the night time equatorial ionosphere is that the F-layer should be lifted to a higher region, forming plasma bubbles, where the Rayleigh-Taylor instability sets in and recombination process is negligible. Nighttime F-layer drifts are normally downward because of the westward electric field, hence for an upward drift to occur, the electric fields should change to an eastward direction. Thus, during magnetic storms, the reversal of the equatorial ionospheric electric fields to an eastward direction seems to be a plausible explanation of intense post-midnight scintillation extending up to morning or daytime.

Table 1. Summary of interplanetary magnetic field, solar wind and scintillation data during the storms.

SSC day		22 Sept.99	13 Nov.99	14 Oct.00	10 Nov.00
D_{st} min)	Day	22 Sept.99	13 Nov.99	14 Oct.00	10 Nov.00
	Time	2400	2300	1500	1300
D_{st} (nT)		– 194	– 100	– 109	– 104
SWV_{th}(km s^{-1})		110	100	90	300
IMF *B* (nT)		32	35	20	30
B_z (nT)		– 20	– 18	– 10	– 15
N(cm^{-3})		60	40	55	30
DP(nPa)		35	60	20	40
p^+V (km^{-1})		620	500	450	950
Scint. Occur.	Pre	x	x	O	O
	Post	O	O	O	O

There are two important and related sources of storm time low latitude electric fields: i) the magnetospheric and high-latitude electric fields, and ii) the disturbance dynamo electric field. Rastogi and Woodman (1978) have shown that electric field reversals in the post-midnight period to be associated with southward turning of the IMF. From the correlation between the anomalous changes in equatorial electric fields and IMF, Fejer *et al.* (1979) concluded that changes in the magnetospheric electric fields and the auroral zone electric fields alter world wide ionospheric current flow and electric field patterns. From the observations of the Earth's magnetic field at Alibag (19.0°N, 73.0°E) and Trivendrum (8.3°N, 76.9°E), India, for the storm of November 11, 1991, Chandra *et al.* (1995) reported that during intense magnetic storms, the high latitude electric field penetrates into low and equatorial latitudes leading to the generation of new F-region irregularities.

During the magnetic storm of 22 September 1999, B_Z turned southwards during the main phase (min D_{st}). As a result the penetrating eastward electric fields associated with increase in high convection would have apparently occurred at this time and enhanced the equatorial vertical drifts that generate the irregularities associated with spread-F. The post-midnight scintillations extending into daytime may be due to the penetration of high latitude electric fields to low and equatorial latitudes. The magnetospheric electric field and the electric fields generated by disturbance dynamo may have further contributed towards the generation of F-region irregularities. At local sunrise, large conductivity of the E-region prevents the growth of plasma bubble by short circuiting the electric field but at times it takes several hours for the bubbles to decay thereby extending scintillations after sunrise or in the daytime.

3 CONCLUSIONS

The southward interplanetary magnetic field and solar ion dynamic pressure are the primary causes of the intense magnetic storms that can generate strong and long duration scintillation with higher fading rates on VHF signals. Ionospheric scintillation should also be taken into account while designing, satellite communication systems.

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