Study of equatorial low-latitude ionospheric irregularities during a recent geomagnetic storm of 03 August 2010 using GPS Receiver

S. Priyadarshi and A. K. Singh

Atmospheric research Laboratory, Department of Physics, Banaras Hindu University Varanasi 221005
Email:spshishir@gmail.com

Abstract

In the past decade there has been growing interest in the investigation of plasma bubble (PB), associated irregularities, which often profoundly impact satellite communication and navigation systems and produce ionospheric scintillations. The basic mechanism of generation and development of equatorial spread F (ESF) is the gravitational Rayleigh-Taylor instability. The trans-ionospheric signal scintillation causes considerable communication hazards at a wide range of frequencies and hence is of much practical interest. In the present study we have investigated the effect of geomagnetic storm on the low latitude ionospheric scintillation for the 03 August 2010 storm at Varanasi (25.30^0 N, 82.99^0 E), India.

1. Introduction

Ionospheric irregularities are formed in the post-sunset period due to the gravitational Rayleigh–Taylor instability processes operating on the steep upward gradient in the bottomside F-region. They produce amplitude and phase scintillations on trans-ionospheric satellite signals from VHF to L band mainly near the geomagnetic equator. The strongest L band scintillations, with signal fades of about 20 dB, often occur during solar maximum years, in the equatorial anomaly regions during the post-sunset period [1-2]. With the increasing reliance on satellite-based positioning systems in critical applications, the impact of scintillation on GPS communications has generated a new impetus. Since scintillation prediction can help to avoid blackouts and distortions in GPS communications due to ionospheric irregularities, it also can help to advance the understanding of the nature of scintillations. The prediction of the scintillation during geomagnetic storms, and how geomagnetic storms affect the occurrence of scintillation, as one of the prominent issues related to space weather studies, is very important for radio communications.

During periods of geomagnetic storms, the equatorial electric fields could be affected by two main high-latitude sources, namely the solar wind– magnetosphere dynamo (direct or prompt penetration of the magnetospheric convection electric field) and the ionospheric disturbance dynamo. The equatorial zonal electric field affects the growth rate of the Rayleigh–Taylor instability through the gravitational and electrodynamic drift terms and by controlling the electron density gradient in the bottomside of the F layer after dusk. Therefore, the equatorial post-sunset electric field should play a dominant role in the variability of ESF [3]. Kelley and Maruyama [4] presented case studies of storm-time electric field effects on the generation of ESF over Jicamarca during post-midnight hours and tested the assumption that the penetration of eastward plasmaspheric electric fields initiates the generation of these irregularities. However, Fejer [5] presented that prompt penetration electric fields alone cannot explain the complex dependence of ESF on magnetic activity. In addition, Fejer et al. [6] explained the dependence of spread-F occurrence on magnetic activity as due mostly to the corresponding variability of the equatorial vertical plasma drifts, and reported a threshold level of ~50 m/s (~0 m/s) $\mathbf{E} \times \mathbf{B}$ drift velocity at solar maximum (solar minimum).

The effects of geomagnetic storm of 3-5 August 2010 on ionospheric irregularities are studied here using GPS scintillation data recorded at Varanasi (25.30^0 N, 82.99^0 E). We have used the variation of scintillation index S4 as well as Dst index and kp index to study the effect of geomagnetic storm on ionospheric irregularities.

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

2. Experimental Observation and Data Analysis

We are using here a GSV 4004 Novatel receiver. The amplitude scintillation is monitored by computing the S4 index, which is the standard deviation of the received power normalized by its mean value. For the cases presented in this paper, only the signals coming from satellites with an elevation angle higher than 15^0 and with a time of lock longer than 180 s were taken into account. Geomagnetic storms are characterized by a prolonged depression of the horizontal component (H) of the Earth's magnetic field. The depression in **H** is characterized by the geomagnetic index Dst, obtained from the Space Physics Interactive Data Resource. The southward turning of the interplanetary magnetic field (IMF) Bz ensures the transportation of solar wind energy into the Earth's magnetosphere, which is the primary cause for the formation of geomagnetic storms [7-8]. Here, IMF Bz, and Dst indices are used to classify the storms. IMF Bz and Kp data are obtained from Coordinated Data Analysis Web. We have used here the term ionospheric scintillation for that time at which amplitude scintillation (S4) index is greater than 0.2.

3. Results and Discussions

3.1. S4 Vs Kp index from 03-05 August 2010

The correlation between geomagnetic activity based on Kp index and occurrence of scintillation has been investigated. As shown in Fig. 1, the 3-h Kp values are plotted versus the amplitude scintillation index (S4) observed at Varanasi for 03 to 05 August 2010. The red line parallel to abscissa shows the threshold value of amplitude scintillation (S4) index to be considered as ionospheric scintillation. From the figure we can see that the scintillation occurrence is mainly confined to periods of lower Kp values, and for periods with higher Kp values (Kp > 5), there are nearly no scintillation occurrences. The results indicate that scintillation may easily occur during geomagnetic quiet days at Varanasi, and geomagnetic disturbance may not trigger the scintillation occurrence. Since ionospheric irregularities producing scintillation were generated a few hours after the beginning of the disturbance, in order to make the correlation between Kp and scintillation occurrence more realistic, here, the used Kp value is the maximum Kp value for the previous and current 3 h.

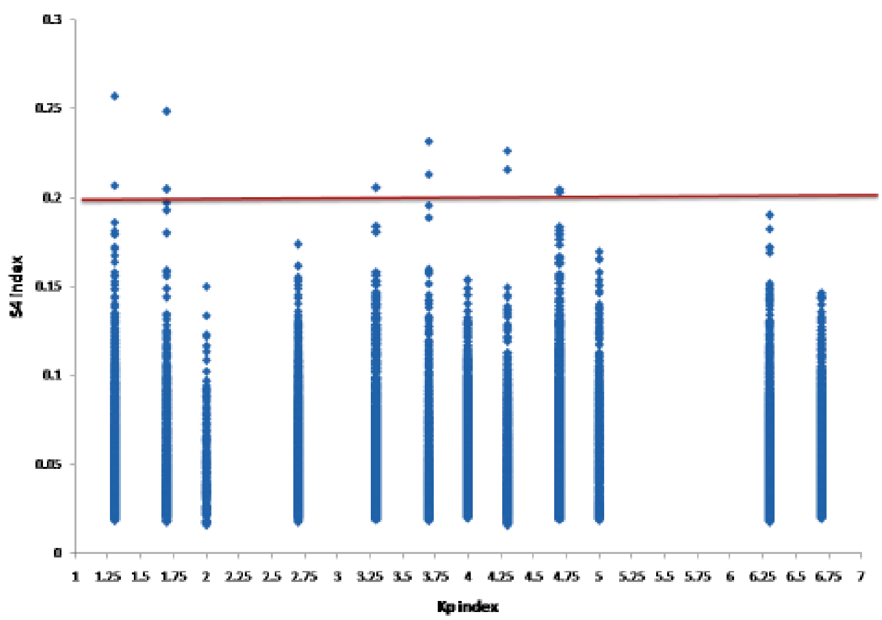

Fig.1: Three-hour Kp index versus amplitude scintillation index (S4) observed at Varanasi during the period 03-05 Aug. 2010.

3.2. Study of inter-Planetary magnetic field Bz (nT), Kp and Dst indices from 03-05 August 2010

The variation of IMF Bz, Kp and Dst index for 3-6 August, 2010 are shown in the three upper panels of Figure 2. As shown, IMF Bz turned southward at around 18:00 UT on 3 August 2010 and reached the maximum value -65 nT. Except for several northward excursions, it remained negative for several hours until 03:00 UT on 4 May 2010. And then, IMF Bz again turned southward at around 07:00 UT. The Dst index shows two maximum negative excursions -62 and -65 nT at about 11:00 and 04:00 UT. The top panel shows two sudden increases in Bz near 19:00 and 07:00 UT on 3 August and 04 August respectively.

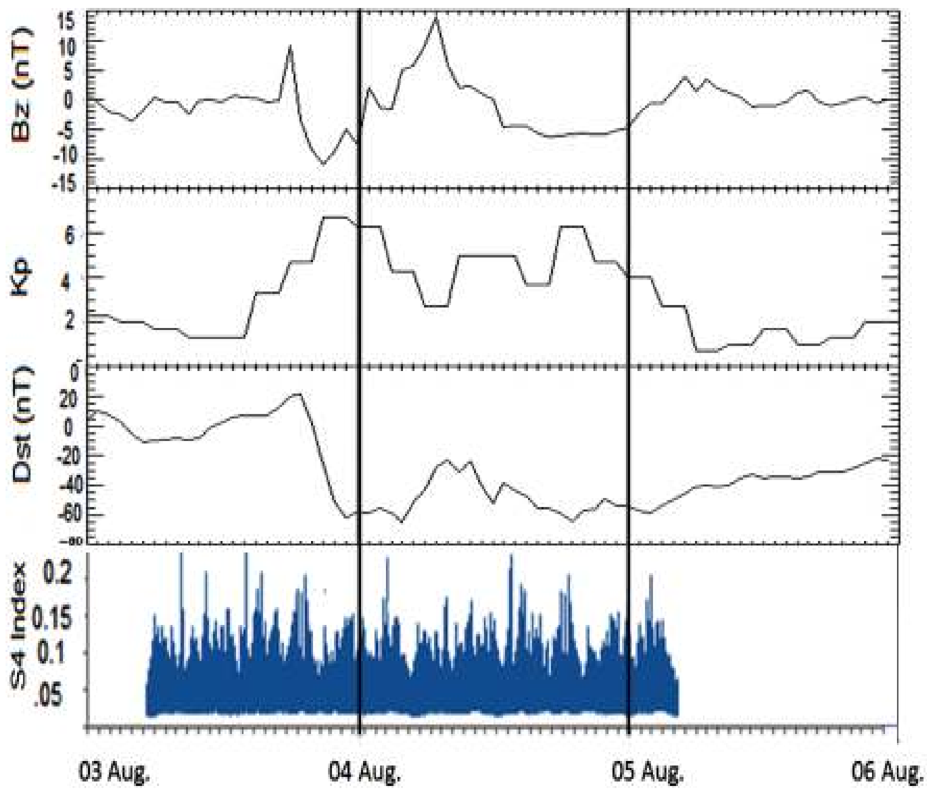

Figure 2: Variation of Dst-Index, Kp index, IMF Bz and S4 index during the period 03-05 Aug. 2010.

3.3. Storm on 03-05 August 2010

The variation of scintillation S4 index observed at Varanasi during the above period is shown in lower panel of figure 2 (blue plot) which showed that in general during the main phase of storm there is suppression of GPS scintillation. Although we have observed a significant GPS scintillation in this duration but, we are strict in commenting that at the time of reversal of IMF there is suppression in the value of scintillation index as can be seen in lower panel at around 18:00:00 UT to 02:00:00 UT on 3-4 August 2010. This process of suppression is continuing up to 04:00:00 UT to 13:00:00 UT on 04 August 2010 and from 19:00:00 UT to 02:00:00 UT on 04-05 August 2010. This behavior is most likely associated with the effect due to the prompt penetration of an eastward electric field into the equatorial ionosphere.

4. Conclusions

Based on the present study the following points emerge:

(i) At low latitude, in general, the effect of geomagnetic activity is suppressive to GPS scintillation.

(ii) During geomagnetic storm periods we have observed suppression in amplitude scintillation index S4.
(iii) The same characteristic is observed in statistical study of S4 to the 03 hourly averaged Kp index at Varanasi.
(iv) For the values of the Kp index greater than 5 we have observed almost no scintillation.
(v) The geomagnetic activity does not trigger the equatorial ionospheric scintillations or if they trigger its effect is observed few hours after the sudden commencement.

5. Acknowledgements

The work is partially supported by DST, New Delhi under SERC project and partially by ISRO, Bangalore.

6. References

1. J. Aarons, “Global morphology of ionospheric scintillations”. *Proceedings of the IEEE,* **70**, 1982, pp. 360.

2. S. Basu, E. Mackenzie, S. Basu, “Ionospheric constraints on VHF/UHF communication links during solar maximum and minimum periods” *Radio Science,* **23**, 1988, pp. 363.

3. Farley, D.T., Balsley, B.B., Woodman, R.F., McClure, J.P., 1970. Equatorial spread F: implications of VHF radio observations. Journal of Geophysical Research 75, 7199–7216.

4. M. C. Kelley, T. Maruyama, “A diagnostic method for equatorial spread F, 2, the effect of magnetic activity” *Journal of Geophysical Research,* **97**, 1992, pp. 1271.

5. B. G. Fejer, “Natural ionospheric plasma waves. In: Kohl, H., Ruster, R., Schelegel, K. (Eds.)” *Modern Ionospheric Science. Max-Planck Institute For Aeronomy, Lindau, Germany*, 1996, pp. 217.

6. B. G. Fejer, L. Scherliess, E.R. de Paula, “Effects of the vertical plasma drift velocity on the generation and evolution of equatorial spread F” *Journal of Geophysical Research,* **104 (A9)**, 1999, pp.19859.

7. J. Allen, L. Frank, H. Sauer, P. Reiff, “Effects of the March, 1989 solar activity” *EOS Transactions of the American Geophysical Union,* **70**, 1989, pp. 1479.

8. B. T. Tsurutani, W. D. Gonzalez, F. Tang, Y. T. Lee, “Great magnetic storms” *Geophysical Research Letters,* **19**, 1992, pp. 73.