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Ionospheric response to major storm of 17th March 2015 using multi-instrument data over low latitude station Kolhapur (16.8°N, 74.2°E, 10.6°dip. Lat.)

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Abstract

The optical observations of ionospheric and mesospheric OI 630.0 nm, OI 557.7 nm along with OH emission carried out from low latitude Indian station, Kolhapur (16.8°N, 74.2°E) using CCD based all-sky camera system. The features of night airglow variations observed during the period of a strong geomagnetic storm, which commenced on March 17, 2015, at ~04:30 UT (10:00 IST (Indian Standard Time = UT + 5.5 h)). Dst of ~−222 nT was seen in this storm suggest that this is among the strongest. The OI 630.0 nm images on 16, 17 and 18 March show the development of Equatorial Plasma Bubbles (EPBs) and bright intensity regions in OI 630.0 nm emission. Generally, EPBs move from west to east direction but it moved in reverse direction on the strong magnetically disturbed night. The EPBs drift velocity was less by ~100 m/s than the velocity measured on magnetically quite night 16–17 March 2015. The bright intensity regions are also observed in OI 557.7 nm airglow, but there is no intensity enhancement seen in OH emission. It is also observed that the OI 630.0 nm intensity variation well matches with the GPS VTEC variation for PRN-2. The reversal in EPBs drift velocity and the nightglow intensity variations due to the strong magnetic storm are discussed.

Keywords: Magnetic storm; Ionosphere; EPB; Reverse zonal drift velocity

1. Introduction

Geomagnetic storms are the most important Space Weather phenomena as far as the impact on the global magnetosphere-thermosphere-ionosphere system is concerned. The storm caused by the solar wind energy, captured by the magnetosphere, and transformed, dissipated in the high latitude upper atmosphere through Joule heating/particle precipitation. It affects the composite morphology of the auroral currents, winds, temperature and neutral composition. Subsequently, it causes changes in the mid and low latitudes. The response of the equatorial ionosphere during geomagnetic storms is one of the significant issue related to space weather studies. How geomagnetic storms affect the characteristics of equatorial spread-F and Plasma bubble is an important aspect and has more significance for trans-ionospheric communications. Somewhat large sets of literature now exist to show that at the time of geomagnetic storms and substorms, the ionospheric electric fields, currents and plasma density in the dip equatorial region depart quite significantly on different time-scales from the geo-magnetically quiet time patterns

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(Fejer, 1991; Reddy and Nishida, 1992; Sastri et al., 1992a, b; Abdu et al., 1993, 1995; Fejer and Scherliess, 1995). Geomagnetic activity is found to influence preferentially within the zonal, rather than the meridional component of the ionospheric electric field at dip equatorial locations (e.g. Gonzales et al., 1983; Fejer et al., 1985).

The ground-based optical measurements of various F-region and mesospheric night airglow emissions (OI 630.0 nm, 557.7 nm and OH emission) which provide the important information on the response of the ionosphere-thermosphere during the different phases of a geomagnetic storm. Several researchers have brought out the salient features of the F region storm effects by multi-spectral optical observations at equatorial and low latitude stations. Optical and particle measurements made from the ISIS-II spacecraft during August 1972 geomagnetic storm have been reported by Shepherd et al. (1976). They found strong enhancement of thermally produced OI 630.0 nm emission due to plasma heating over two different regions in the magnetosphere during a major storm.

Based on numerous studies, using data from space borne and ground based techniques, it is widely accepted that the OI 630 nm emissions are generated at low latitude F-region heights (~250–300 km). The OI 630 nm emission is closely related to the F- region electron density (Link and Cogger, 1989; Ghodpage et al. 2012) by the following mechanism:

$$O^{+} + O_2 \rightarrow O_2{}^{+} + O \quad (1)$$

$$O_2{}^{+} + e^{-} \rightarrow O\,(^1D) + O \quad (2)$$

$$O\,(^1D) \rightarrow O\,(^3P) + hv\,(630\text{ nm}) \quad (3)$$

Because reaction Eq. (1) dominates the whole process, the production of the OI 630 nm emission is proportional to the molecular oxygen density $[O_2]$ and the oxygen ion density $[O^+]$. The oxygen ion density $[O^+]$ is almost equal to the electron density Ne in the F-layer. Thus, the OI 630 nm emission is a sensitive indicator of the electron density in the bottom side of the F-layer.

However, the major portion of OI 557.7 nm emission comes from the recombination of oxygen atoms in the mesopause region (80–100 km). Some of the studies have focused on the evolution of EPB irregularities under storm-time conditions (Basu et al., 2001; Lee et al., 2002; Su et al., 2002; Kil et al., 2006). For example, Abdu et al. (2003) studied the evolution of equatorial EPBs and found that the disturbed dynamo plays an important role in bubble development during the storm of 26 August 1998 in the Brazilian sector. The westward EPB irregularity could arise from prompt penetration electric field (PPE) in the course of a disturbance sequence lasting several hours. Ma and Maruyama (2006), presented the observations of EPB at mid-latitude detected by a dense GPS (Global Position System) TEC (Total Electron Content) network in Japan and suggested that a prompt penetrating magnetospheric electric field helped to trigger the super bubble. On the basis of multi-instrument observations at middle latitude in the Japanese sector. Sahai et al. (2001) found the small scale intensity depletion structures (with scale size of 30 to 50 km) are caused by possible nonlinear interaction between the medium scale traveling ionospheric disturbances (TIDs) and enhanced regions of the equatorial ionospheric anomaly where, the enhanced ionospheric disturbances were confined at middle latitude during the storm of 12 February 2000. Kiyama et al. (1996); Sahai et al. (2001) have found unusual enhancement of the OI 630.0 nm emission during different phases of magnetic storms at low and mid-latitude stations. In addition, Patra et al. (2016) showed that the generation of EPBs during this period was confined to a narrow longitudinal region between 69° E and 98°E in the Asian sector. Rajesh et al. (2017) studied the all sky camera observations carried out over Taiwan which show the intense EPBs in 630.0 nm airglow images on successive nights of 13–16 March 2015, but the EPBs were absent in the night of 17 March when St. Patrick's Day magnetic storm occurred. Their results show that on the night of the magnetic storm, pre-reversal enhancement of zonal electric field over Taiwan was weaker when compared to that over India. On the other hand, the American sector exhibits a notable increase in Vertical Total Electron Content (VTEC) while in the Asian sector, the largest decrease in VTEC (signatures of EPB structures) is observed (Nava et al., 2016). During storms, the low-latitude ionospheric electric fields can be promptly disturbed by penetrating electric fields. Past studies have shown that average empirical equatorial prompt penetration electric fields are in good agreement with the predictions from global convection models (Fejer and Scherliess, 1997; Fejer and Emmert, 2003). On the other hand, the large variability of these electric fields with different magnitudes and lifetimes is not well understood (Huang et al., 2005). Sahai et al. (1990), presented the first simultaneous optical measurements of the OI 777.4 nm, 630.0 nm and 557.7 nm emissions from Cachoeira Paulista (22.7°S, 45.0°W), Brazil, an equatorial low latitude station and from Fortaleza (3.9°S, 38.4°W), Brazil, an equatorial station, during magnetic disturbances. They found that the dynamic variations in the F region ionospheric parameters were well correlated with the non-diurnal variations observed in the atomic oxygen airglow emissions at both equatorial and low latitudes. Sau et al. (2017) studied the characteristics of equatorial plasma bubbles (EPBs), using OI 630.0 nm emission such as their zonal drift and tilt, from the low-latitude during the main phase of the 17–18 March 2015 storm and observed that the EPBs drifted eastward during 1430 to 1630 UT between 3°S and 15°N dip latitudes.

The motivation to understand the ionospheric responses to geomagnetic disturbances has greatly evolved from academic to practical interests, whereby dedicated government agencies are actively involved in planning and developing strategies to mitigate potential hazards related to intense space weather events (Hapgood, 2012). The aim of the present study is to understand the effect of the storm on ionospheric processes such as F-region airglow emission,