Flare Induced Changes in Electrodynamics: An Investigation Using Radio and Optical Techniques

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***Abstract*— This paper deals with the response of equatorial ionosphere-thermosphere system to the X3.8 solar flare of January 17, 2005 using the co-ordinated measurements of GPS derived Total Electron Content (TEC), OI 630.0 nm dayglow and magnetic field measurements over a dip equatorial station Trivandrum (8.5° N, 77°E, dip 0.5°N), in India.**

***Index Terms*- GPS, Equatorial Ionosphere, dayglow, solar flare**

I. INTRODUCTION

Recent studies have indicated that solar flare alters not only the photochemistry of the ionosphere, but also the electrodynamical and neutral dynamical processes through the ionosphere-thermosphere coupling. Globally considerable efforts had been made to glean out the neutral dynamical response of the upper atmosphere to the solar flare. Recent observations using the satellites like CHAllenging Mini satellite Payload (CHAMP) and Gravity Recovery And Climate Experiment (GRACE) provided a renaissance in this regard [1]. Although its effects at ionosphere, in general had been studied extensively, there is a glaring dearth of information on the effect of such events on various processes in the dip equatorial upper atmosphere. In this context, an attempt has been made in this work to investigate the neutral and electrodynamical processes in the equatorial upper atmosphere during X3.8 solar flare of January 17, 2005. For the analysis of ionospheric response of solar flares, Total Electron Content (TEC) measurements using the GPS receivers and Equatorial Electrojet (EEJ) measurements from ground based magnetometers are used. The thermospheric response is studied using the unique data set of the neutral OI 630.0 nm dayglow. The EEJ and TEC measurements revealed prompt enhancements during the peak flare. Interestingly, the temporal evolution of GPS derived TEC at different latitudes showed that, the X3.8 class flare produced significant weakening of the plasma fountain and hence in the Equatorial Ionization Anomaly (EIA). Further, the response of OI 630.0 nm dayglow during the flare is found to be strongly affected by the prevailing electrodynamics. The results are presented in detail.

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II. DATA

The OI 630.0 nm dayglow has been obtained from a unique Multiwavelength Dayglow Photometer (MWDPM), over a magnetic dip equatorial station Trivandrum (8.5° N, 77°E, dip 0.5°N), in India. For the ionospheric information, the Total Electron Content (TEC) data measured using GPS receivers at different stations in the EIA region over the Indian longitudinal sector are used. Further, one minute values of the strength of the EEJ (i.e., $\Delta H_{TVL} - \Delta H_{ABG}$) using the magnetometer observations from an equatorial station Tirunelveli (TVL) and an off-equatorial station Alibag (ABG) are used for studying the response of the flare in the dynamo region, where ΔH stands for the difference in the instantaneous values of horizontal component of magnetic field from its nighttime mean value. For the Flare characterization, high cadence measurements of the X ray (1-8 Å) flux obtained using GOES-10 (Geostationary Operational Environmental Satellite) and EUV flux (26-34 nm) obtained from the SEM (Solar EUV Monitor) onboard SOHO (Solar Heliophysical Observatory) are used.

III. RESULTS AND DISCUSSIONS

Fig. 1 shows the time evolution of X-ray (1-8 Å) and EUV (26-34 nm) flux on 17 January 2005. As is clear from the Fig., an abrupt, but a small enhancement in X-ray followed by EUV occurred at ~13:25 IST. Thereafter, both showed a steep enhancement at ~15:15 IST reaching a maximum at 15:20 IST. It is long duration flare (~4 hour), which continued till ~17:30 IST. It is interesting to note that though the X-ray showed a single peak, a double peak has been observed in the EUV flux.

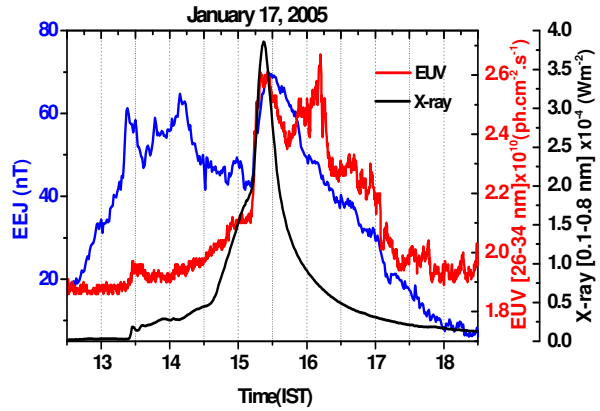

Fig. 1. The time evolution of X-ray and EUV flux along with EEJ on the flare day.

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A. *Response of Equatorial Ionosphere.*

The response of E and F region of the equatorial ionosphere has been found to be prompt as is inferred from the concomitant enhancement in the EEJ (shown in Fig. 1) and TEC (not shown here). This is expected due to the increased production of ionization during the flare period. In order to investigate how flare effects manifested in the evolution of EIA, the latitudinal distribution of TEC at every 30 minutes during the period 12:00-17:00 IST is shown in Fig. 2 (top panels). For comparison, the same for the control day (13th February 2005) is also shown in the bottom panels. A clear-cut development of anomaly has been observed on the control day. However, on January 17, 2005 anomaly development is found to be inhibited. This strongly corroborates the flare associated weakening of the EIA as reported in a recent study [1].

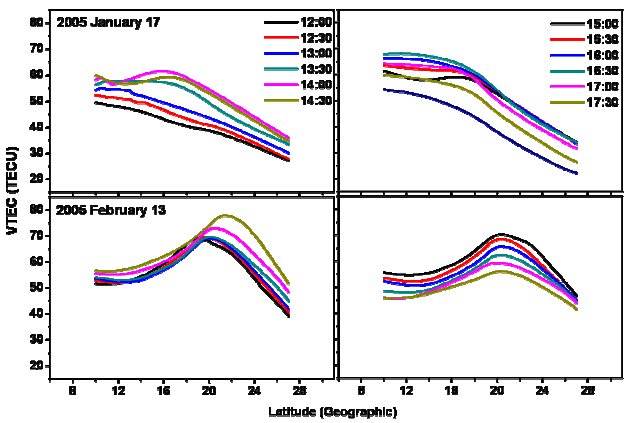

Fig. 2. The Latitudinal variation of VTEC during 12:00-17:30 IST on flare and control days.

This weakening of EIA is believed to be associated with the reduction in the eastward electric field due to the flare. As is well known, the flare is expected to cause the rapid change in the conductivity in the vertical direction. This in turn affect the ratio of Hall to Pedersen conductivity, which is a crucial factor in regulating the dynamo electric field and hence the EIA. However a complete explanation to this effect is yet to evolve.

B. *Response of Equatorial Thermosphere.*

To further investigate the thermospheric response, the time variation of the OI 630.0 nm dayglow on this day during the period 12:00-18:00 IST is plotted in Fig. 3 along with that on a control day (January 25, 2005). Three distinct signatures (highlighted using circles) can be observed during the flare period. These signatures are attributable to the combination of the flare induced changes and electrodynamics as described below

The eastward electric field increased at ~13:20 IST as is evdient from the EEJ in Fig. 1. This results in the pumping of more ionization over the equator due to the upward ***E×B*** drift. This inturn increases the airglow intensity over Trivandrum as seen in the present case.

This increase in dayglow continued till ~14:30 IST, and showed an abrupt decrease at ~14:45 IST, which persisted till ~15:00 IST. The reduction in the dayglow intensity during the period 14:30-15:00 IST can be attributed to the decrease in the effective recombination at the emission altitudes due to the transport of more ionization density from equator to off-equatorial latitudes due to the prevailing eastward electric field. Further increase in dayglow, which showed a peak at ~15:30 IST is attributed to the increased O(^{1}D) production during the flare time due to all the three production mechanisms, *viz*, photo electron impact of O, Photodissociation of O_2 and Dissociative recombination of O_2^+.

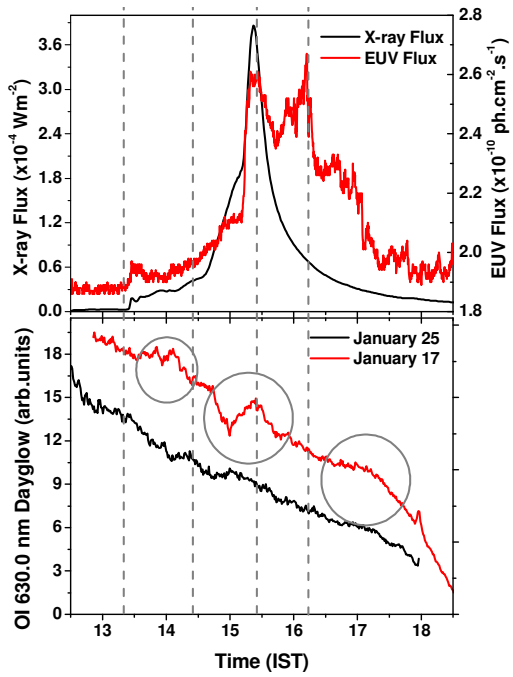

Fig. 3. The The time variation of OI 630.0 nm dayglow on flare and control days along with the flare radiations.

However, the dayglow did not show any appreciable signature associated with the secondary peak in the EUV flux. This is due to the fact that, during this period, the EEJ started to recover and flare associated westward electric field, started dominating.. The further enhancement in the dayglow intensity during the period 16:30-17:30 IST can be attributed to the subsequent weakening of plasma fountain. However, the delayed enhancement in the dayglow due to the time delay in the charge exchange of O_2+O^+ reaction, as well as the delayed response of neutral density during the flare cannot be precluded in this context.

IV. Conclusions

We have studied the response of equatorial ionosphere-thermosphere system during the X3.8 class solar flare event of January 17, 2005. The important conclusions are (i) The E and F region of the equatorial ionosphere responded promptly to the flare (ii) Significant weakening of the EIA has been noticed during the X3.8 Flare (iii) The dayglow response is found to be modulated by the ongoing electrodynamics.

REFERENCES

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