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Short Communication

Analysis of solar EUV and X-ray flux enhancements during intense solar flare events and the concomitant response of equatorial and low latitude upper atmosphere

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ABSTRACT

We investigate the X ray and UV flux changes during flare events and the corresponding ionospheric response. The study reveals that UV flux enhancement depends on both flare intensity and position on solar disk while X-ray flux enhancement depends only on the former. The study brings out a new result that the E region response to flares directly relates to the X-ray flux enhancement and that it does not exhibit limb effect. Further, the F region response shows limb effect indicating the UV flux control on the same and it also shows seasonal variability due to solar zenith angle variability.

1. Introduction

A solar flare presents a rapid sudden energy release in the upper chromosphere or lower corona usually over active regions with developed sunspot groups. This process leads to a localized heating (thermal flare) and acceleration of electrons, protons, and heavy ions up to energies from 20 keV to 1 GeV (Leonovich and Tashchilin, 2007). A solar flare generates the short period electromagnetic radiation in a broad range of wavelengths from hard X rays with a wavelength $\lambda \sim 10^{-2}$ nm (and sometimes from the gamma radiation ($\lambda \sim 10^{-4}$ nm) to kilometer radio-waves ($\lambda \sim 10^{4}$ m). In powerful flares, an energy about 10^{23}–10^{25} J is released in the form of radiation (Leonovich and Tashchilin, 2007). The frequency of occurrence of solar flares varies, from several per day when the sun is particularly active to less than one every week when the sun is quiet.

Studies on space weather are topical because of their importance to space based communication and navigation. Solar extreme ultraviolet (EUV) and X-ray photons are responsible for ionizing the terrestrial ionosphere. Electromagnetic radiation with wavelengths ranging from about 25 nm to 91 nm (UV), creates the F region of the ionosphere while wavelengths less than 15 nm (soft X-rays) creates the E region, and the Lyman-a radiation creates the D region (Rishbeth and Garriott, 1969). During solar flares, solar emissions in the X ray and EUV regions get enhanced and induce sudden and intense ionization at various altitude regions in the Earth's ionosphere.

Incoherent scatter radar observations of increase in E and F region electron densities, are reported by Thome and Wagner (1971). Their study brought out strong electron density enhancement in the E region of the order 100% and moderate enhancement in the F region. Early reports of TEC enhancements during flare events were given by Garriott et al. (1967), Mendillo et al. (1974), and Sato (1975). The limb effect of the UV flux enhancement and TEC response to flares have been reported by Afraimovich et al. (2002), Liu et al. (2006), Leonovich et al. (2010) and, Mahajan et al. (2010). Le et al. (2011) have shown using statistical analysis that limb effect decreases as the flare class decreases. Le et al. (2012) have shown in their recent analysis of thermospheric density response to solar flares that the thermospheric density enhancement has significant limb effect, which is also attributed to the limb effect of the EUV flux. The relationship between TEC enhancement and the EUV flux increases in 26–34 nm EUV flux during a flare which is reported to be more correlative than that in 0.1–0.8 nm soft X-ray flux (Zhang et al., 2011). Geomagnetic field response to solar flare events has been examined by many workers (Rastogi et al., 1999; Manju and Viswanathan, 2005; Manju et al., 2009). VHF radar

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observations of backscattered power and vertical polarization electric field at equatorial electrojet location of Trivandrum are reported by Manju and Viswanathan (2005).

In the present study, three different aspects pertaining to solar flares are investigated. They are Limb effect on X-ray and EUV fluxes, Limb effect and seasonal variation of F region response to solar flares and response of E region to solar flares.

2. Data and method of analysis

In our study we have made use of the following data: (1) EUV fluxes obtained from the Solar EUV Monitor (SEM) on the Solar Heliospheric Observatory (SOHO), (2) Xray flux from Geosynchronous Operational Environmental Satellite, GOES, (3) GPSTEC data over Indian longitudes, and (4) Geomagnetic field data over Indian longitudes.

2.1. *UV and X-ray flux data*

We have used the 15s average SEM/SOHO fluxes downloaded from the SOHO website. The SEMSOHO experiment is described by Ogawa et al. (1993).

The solar Xray fluxes used are obtained GOES series of satellites. In this study, we have used the 1min averaged Xray data observed by GOES-8/GOES10 in the wavelength band 0.1–0.8 nm NOAA website.

2.2. *GPSTEC data*

GPSTEC data from the stations of Trivandrum (TRV) (8.5°N, 77°E), Hyderabad (HYD) (17.5°N, 78°E), Raipur (RAI) (21°N, 81°E) and Delhi (DEL) (28°N, 77°E) are used in this study. Carrier phase delays and pseudo ranges of the GPS signals at L1 and L2 frequencies are used to obtain the Absolute Slant GPSTEC (STEC). The STEC are then converted to Absolute Vertical TEC (VTEC) using the mapping function given below.

$$VTEC = STEC\ cos\ (\chi), \quad (1)$$

where χ is the zenith angle at ionospheric pierce point (IPP) which is estimated from the satellite elevation angle. The shell height is taken as 350 km. Ramarao et al. (2006) have shown that an elevation angle cut off of $>50^\circ$ is ideally suited to represent the TEC over the Indian sector and hence the present analysis is based on this criterion.

2.3. *Magnetic field data*

The magnetic field (H) data is acquired from the magnetometer at the Alibag (8°39′N, 72°55′E).

3. Results

3.1. *Variability of solar EUV and X ray flux enhancements during solar flare events originating from different locations of solar disk*

Fig. 1a represents the variations of EUV ratio (EUV flux at peak/EUV flux just before flare start) with position on the solar disk for X class flares. We have included all the flares in this class for which we had both flux and CMD information. It is clear from the figure that the EUV flux is higher for flares occurring in the CMD region ($<40^\circ$) while it is lower for flares occurring in the limb region ($>40^\circ$). In this figure points are available in all regions of solar disk. Of course if we are considering only location as factor controlling the UV enhancement then this figure can be misleading as some cases with large CMD are showing relatively high increase compared to cases with low CMD due to the flare being of higher class. Nevertheless an examination of several flares occuring in the limb and central meridian reveals that it is the combined effect of location and central meridian that determines the enhancement. For example the flare of 4 November is a limb flare (rank X28) but relatively higher enhancement of 1.77 is seen. At the same time the X17 flare on 28 October near central meridian shows much higher enhancement of 2.3 although the rank is lower. Hence we are concluding that net effect of the location and rank of the flare will determine the enhancement thus pointing out that limb effect is also very important in controlling the flare increase. Mahajan et al. (2010) have reported a limb effect for UV flux emissions for X class flares. This is confirmed by Le et al. (2011). Our observation shown in Fig. 1a, is also on similar lines and brings out limb effect for UV emissions in the case of X class flares. Le et al. (2011) further examined the presence of CMD effect for M and C class flares also and noted that the effect is progressively reduced as the class of the flare decreases. They have further shown that for these weaker flares the CMD effect is weak because active regions spread all over the solar disk also contribute to the EUV flux for such flares.

The variation of X ratio (X ray flux at peak/X ray flux just before flare start) with CMD is examined for several X (left panel), M (middle panel) and C (right panel) class flares and these are depicted in Fig. 1b. No limb effect is discernible in X ray flux for any of the three classes of flares. Similar result is already reported by Mahajan et al. (2010) and Le et al. (2011) for X class flares. In this study we report the absence of limb effect even in the case of M and C class flares thus clearly showing that the intensity of a flare is the only factor that determines the *X* ratio for all classes of flares.

3.2. *E region response*

The seasonal variation of the response of the E region to X and M class flare events is examined using magnetometer data at the station of Alibag in the Indian longitude sector. The geomagnetic field variation is taken as a proxy for the E region response to solar flares.

3.2.1. *Dependence of H ratio on UV ratio for X and M class flares*

The scatter plot of H ratio and UV ratio for X and M class flares during the period 1998–2003 is shown in Fig. 2 (left panel). There is no significant correlation between the two parameters. This shows that increased enhancement in UV flux is not proportionately reflected in the enhancement in geomagnetic field represented by *H* ratio. It therefore seems that the E region response is not dominated by UV flux enhancements during flare events.

3.2.2. *Dependence of H ratio on UV ratio for X and M class flares*

The variation of *H* ratio as a function of *X* ratio is examined for X and M class flares during the period 1998–2003 [Fig. 2 (right panel)]. It is evident from the figure that as X ratio increases H ratio also increases. The correlation coefficient between the two parameters is 0.67, which is more than 95% significant. Thus the E region geomagnetic field variations are significantly controlled by the X ray flux enhancements during flares.

3.2.3. *Variability of geomagnetic field response to flare events located at different locations on solar disk*

The variation of *H* ratio as a function of CMD is examined and depicted in Fig. 3. It is obvious from the figure that there is no significant limb effect for the geomagnetic field response to