Behaviour of ionosphere in the morning and night-time sectors during an x-ray and EUV solar flare

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Abstract

The effects of x-ray flare also known as extreme space weather events is of practical importance, being a cause of deleterious effect on the wireless, HF and GNSS communications and other radio systems respectively. As the solar flare effects during dusk to dawn regions have not yet been explored much previously, we have investigated the ionospheric response of a gradual X-class flare which occurred on 5 March 2012 (X1.1, onset: 0215 UT, end: 0950 UT). This flare is visible also in EUV (0.1-50 nm) as observed by SOHO-SEM instrument and is associated with an intense solar radio bursts as observed by Nobeyama observatory (1 GHz, 501812 sfu). The preliminary results of ionospheric parameter, TEC (total electron content) obtained by using satellite measurements: JASON showed modifications in the daytime equatorial ionization anomaly (EIA) during the flare which recovers sometime after the end of flare (in ~6 hours). The nighttime sectors show an increase in TEC whereas not much change is observed in the morning sector. The behavior of the bottom and upper ionosphere will be investigated in detail by multitechnique observations of space based and ground-based observations respectively. The detailed results of the investigations will be presented.

1. Introduction

Solar flare (SF) is a transient phenomena occurring in the chromosphere and lower corona of Sun emitting huge amount of energy (~10^{27} ergs or even more), in the form of radiation and matter into the interplanetary medium in a very short duration. The sudden increase of XUV and EUV irradiance at Sun during SF enhances the ionization in the Earth's upper atmosphere and is termed as "crochets" or Solar Flare Effects (SFE) or Sudden Ionospheric Disturbances (SID). The excess amount of energy triggers various geophysical processes in the ionosphere like radio propagations as they can lead to sudden onset of short-wave fade out, phase anomaly, shift in the radio frequency, cosmic noise absorption, changes in atmospherics etc. [1-3]. Together with coronal mass ejections (CMEs), a flare is an explosive event that releases high energy protons and electrons, including intense radiation in all wavelengths and can affect the Earth's atmosphere. Many a times, the x-ray flares are also associated with solar radio-bursts (SRBs, intense radio emissions from the Sun) which affects severely the GPS performance when solar flux is sufficiently high (40,000 sfu) as proposed by [4] in the L-band frequency and also when its right-handed circularly polarized (RHCP) - the polarization to which GPS antennas are also receptive. The GPS signal losses of lock has been re-evaluated and found that the threat threshold of SRBs is 4000-12,000 sfu at 1.415 GHz [5]. As the GPS performance gets highly disturbed/failed by SRBs during the X-class flare of 6 and 13 December 2006 respectively when the signal was partially disrupted for more than 10–15 minutes as reported by [6]. Hence considering the importance of such flares, we investigated the effect of an x-ray flare associated also with SRBs on the Earth's ionosphere. As the recent studies shows that the SF effects can be observed from pre-dawn to post-dusk regions, with most pronounced signatures in the noon region, where the solar zenith angle is close to zero [7-12]. Here, we considered in our study the effects of an X-class solar flare which occurred on 5 March 2012 (X1.1) in the daytime and nighttime sectors as observed by Jason-2 satellite and ground based measurements respectively.

2. Data used

The X-ray and EUV photons are the major wavelengths which are responsible for the ionization in the earth's upper ionosphere (e.g., [13]. The x-ray flare intensity is obtained by the GOES (0.05-0.3 nm and 0.1-0.8 nm) and XUV and EUV fluxes (0.1-50 nm and 26-34 nm) by the SEM instrument onboard SOHO respectively. The x-ray flare

information like onset-time, peak-time and peak flux is obtained by the GOES website. The end time is obtained when the x-ray flux has returned to pre-flare values. This flare is also found to be associated with an intense solar radio burst as observed by Nobeyama observatory. The radio flux is observed at 1GHz and it peaked to 501812 sfu during the flare-time. The various details of x-ray and EUV flare are represented in Table 1.

TABLE 1. Description of the timing and flux of x-ray and EUV flare respectively.

Wavelength (nm)	Start time (UT)	Peak time (UT)	End-time	Peak-flux
x-ray (0.1-0.8)	0215	0355	0950	1.1×10^{-4} W/m^2
EUV (0.1-50)	0325	0415	0700	4.99×10^{10} ph/cm^2/s

To investigate the response of this flare on the earth's ionosphere in daytime and nighttime sectors, the dual-frequency satellite altimeters: Jason-2 operated at 5.3 and 13.6 GHz performing 1-sec ionospheric range delay measurements is used which can be converted to vertical TEC beneath the satellites, i.e., between the water surface and the orbit altitude of about 1336 km (http://www.aviso.oceanobs.com/). The orbit inclination of JASON-2 is 66^0 and an orbital period of 112 minutes with a repeat cycle of 9.91 days. The TEC measurements were obtained almost every second and the data set used in our analysis has a time resolution of 18-s or about 1^0 of orbit. The scatter of 1-s TEC values about the 18-s averaged mean shows fairly constant spreads of about ±4-5 TECU for different seasons, local times, and hemispheres [14].

3. Results and Discussion

The Figure 1 here represents the time profile of x-ray (0.1-0.8 and 0.05-0.3 nm) and EUV (0.1-50 and 26-34 nm) flare respectively as obtained on 5 March 2012 by GOES and SOHO-SEM instrument in 1-min resolution during 0000-1200 UT. The gradual x-ray flare was erupted from the sunspot region AR#11429 around 17^0N, 41^0E on Sun's disk. The background geomagnetic conditions were quiet during the flare-occurrence time (Kp~3, Sym-H~-5 nT). The gradual increase in flux in x-ray started around 0215 UT but the flaring in EUV wavebands is delayed and started around 0325 UT when the x-ray shows a sudden rise in the rate of flux.

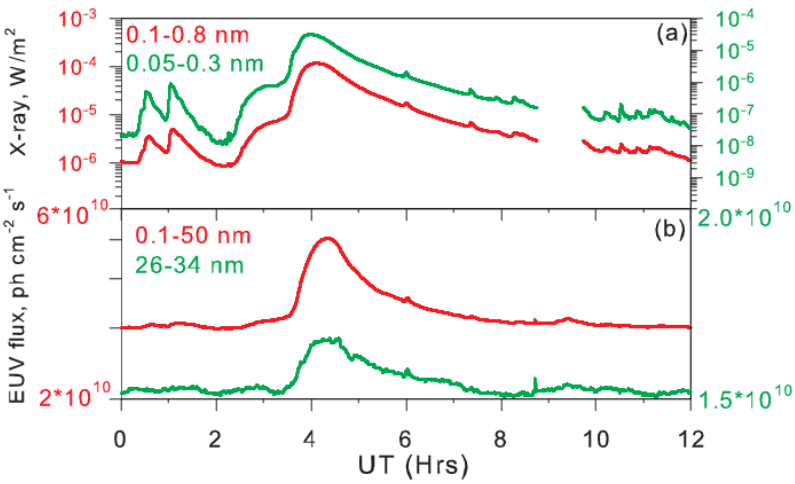

Figure 1. Light-curves of (a) X-ray flare (0.05–0.4 nm and 0.1–0.8 nm energy bands) as obtained by GOES-15 and (b) EUV flare (26–34 nm and 0.1-50 nm bands) using SOHO-SEM satellite on 05 March 2012 during 0000-1200 UT.

To investigate the disturbances in the earth's ionosphere which may be produced due to this solar flare, the observations of JASON-2 is analyzed. Here Figure 2 represents the changes in the VTEC (vertical total electron content) before (0154-0236), during (0546-0816 UT) and after (1107-2313 UT) the flare occurrence in the earth's ionosphere in daytime sectors. The nighttime sectors are also investigated before (0044-0126 UT), during (0429-0851 UT) and after (1008-2357 UT) the flare respectively. The JASON-2 passes over the equator around ~1200 LT in daytime and ~0000 LT (midnight) in nighttime sectors respectively.

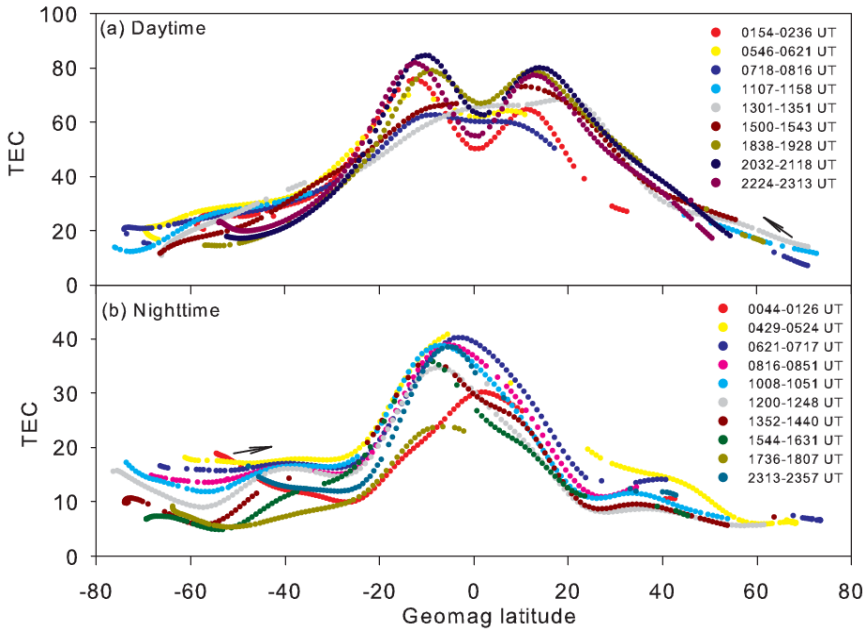

Figure 2. Variation of TEC with geomagnetic latitude during the passes of JASON-2 before, during and after flare during (a) local daytime (0700-1800 LT) and (b) local nighttime to morning-time (1800-0600 LT) sectors respectively. The arrow shows the direction of descending (daytime) and ascending (nighttime to morning) passes of JASON-2 respectively.

A well-known daytime phenomenon in ionosphere is the equatorial ionization anomaly (EIA) in the equatorial and low latitudes which is higher density of electrons or TEC observed at +/- 10^0 geomagnetic latitudes (crest) than at the equator (trough). This phenomenon is dependent on the solar-flux, equatorial electrojet, neutral-winds and neutral composition. The latitudinal variation of TEC is represented in FIGURE 2 during the (a) daytime and (b) nighttime respectively. The latitudinal observations of TEC during the daytime in FIGURE. 2 (a), before the flare shows a well developed EIA with a crest of 75 TECU at northern and 65 TECU at the southern hemisphere with a trough at the equator (51 TECU). During the flare duration, the EIA gets weakened modifying the anomaly with higher TEC observed over the equatorial region and a decrease in anomaly regions. The EIA starts appearing again after ~6 hours of the end of the solar flare (after 1500 UT). The sectors which are in dark (FIGURE. 2(b)) during the flare duration show a clear sharp increase in TEC when the flare is around its peak in x-ray and EUV flare, which then decreases in the evening and postmidnight sectors (1800-0200 LT) in high and low latitude respectively. Whereas no clear effect of flare is observed in the morning sectors (0200-0600 LT). Such a modification in EIA during flare has also recently been reported observationally and theoretically by [8, 11]. The possible additional contributions from electrodynamics has been suggested by [11] and found that the vertical E X B drift in the magnetic equatorial region plays a significant role in the ionosphere response to solar flares.

The detailed analysis of this event will be presented based on multi-technique observations to understand the peculiarities of this strong solar-flare.

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