Indian Journal of Radio & Space Physics
Vol. 46, June 2017, pp. 37-45

A study on the response of Indian dip and low latitude ionospheric regions to a limb centred X9.0 class solar flare

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Received 22 June 2016; revised received 18 November 2016; accepted 2 January 2017

In this paper, we present how Indian dip equatorial and low latitude ionospheric system responded to a limb centred X9.0 class of solar flare event using GPS-TEC, Ionosonde and magnetometer measurements. The limb centred X9.0 solar flare was materialise on 05 December 2006 at the heliography coordinate S07E68 and NOAA 10930 active region, started at 10:18 UT (15:48 IST), peaked at 10:35 UT (16:05 IST), and decayed by 10:45 UT (16:15 IST). The measurements of the total electron content (TEC) of 30 s time resolutions from a series of GPS receivers installed near the dip and low latitude regions does not show TEC enhancement during peak flare hours, 10:35 UT (16:05 IST). An appreciable enhancement in the TEC units (~5 TEC units) is noticeable during post flare hours, 13:00 UT (18:30 IST) which is high at dip equatorial compare to low latitude regions. The Ionosonde measurement of 15 min time resolution at dip equatorial station shows an increase in the plasma density at the F-region while the E-region did not show any impact during peak flare hours, 10:35 UT (16:05 IST). The analysis of horizontal component of geomagnetic field (H) of 1 min time resolution data obtained from the INTERMAGNET shows sudden rise in electron density in the E-region of the ionosphere and intensification in the ionospheric current system in eastward direction at the dip equatorial and reverse in direction at low latitude regions at 10:35 UT (16:05 IST). Present analyses contribute our understanding about plasma dynamics during flare and post flare hours in the E and F-regions of Indian dip and low latitude Ionosphere.

Keywords: Solar flare, Ionosphere, SID, GPS-TEC, Ionosonde

1 Introduction

A solar flare is a diverse dynamical process in the solar atmosphere which is normally associated with a rapid and transient release of energy in the solar corona (~ 10^{27} J), local plasma heating to tens of Millions Kelvin (MK), particles acceleration to ultra relativistic speeds, violent mass of plasma motions, shock waves and release of electromagnetic radiations from radio to gamma rays[1,2]. The Earth's ionosphere, a shell of free electrons, namely NO^+, O_2^+, and O^+ ions, neutrals which surround Earth from ~50 km onward, which is normally formed by the photo ionization process through the ultra violate (UV), extreme ultra violate (EUV) and X-ray emission from the Sun and their interaction with the ionosphere neutrals, is known to get influenced by the solar flares[3-5]. During solar flare the enhanced emissions in X-rays and EUV flux cause extra ionization in the Earth ionosphere. The extra ionization causes increase in electron density in the D, E and F layers of the ionosphere[3-5]. Tsurutani *et al*.[6] and Xiong *et al.*[7] studied that the EUV emissions lead to increase in the electron density in the E and F layers. Sripathi *et al*.[8] studied for an intense X class flare that the X-ray emissions penetrate deeply to the low latitudes and lead to an increase the electron density in the D-region. The increase in the electron density at different altitudes is known as sudden ionosphere disturbances (SID)[9]. SID is recorded as a sudden cosmic noise absorption (SCNA), sudden enhancement of atmospheric (SEA), sudden phase anomaly (SPA), short wave fadeout (SWF), sudden frequency deviation (SFD), and sudden increase of total electron content (SITEC)[10-18] . However during a solar flare event, most of the increase in the electron density is associated with the F-region of the ionosphere. Thus, the SITEC mainly associated with the F-region plasma.

In recent years, there has been an increased interest in studies related to the sudden increase in the total electron content of the ionosphere (SITEC) in response to the solar flare events[7,19,18]. This is because of the increasing utility of services from the Global Positioning Satellite (GPS) system in our day to day life. As events like geomagnetic storms or solar flares can cause appreciable changes in the

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ionospheric system, several studies have been carried out to quantify their impact. Using measurements from a dual-frequency GPS receiver, Wan *et al.*[7] studied 14 July 2000 solar flare event and found that both the magnitude and variations in the TEC were proportional to the flare radiation and inversely proportional to the Chapman function. Afraimovich *et al.*[20] noted that the SITEC can be observed at the day side of the Earth's ionosphere and the temporal profile of the hard X-ray emissions from the solar flare can be well correlated to the temporal variations in the TEC. Moving a step further, Liu *et al.*[21] suggested that the TEC can be a suitable parameter for monitoring the overall variations of the flare radiations as the variations in the rate of change of the TEC is capable of detecting sudden changes in the flare radiations. Leonovich *et al.*[22] reported that the ionospheric TEC response amplitude decreases with increasing central meridian distance (CMD). Liu *et al.*[23] suggested that the variations in the TEC of the ionosphere are affected by flare locations in the Sun and can be described by the CMD with a factor of cos(CMD). Le *et al.*[24] in a statistical study show that a limb flare has less effect on the ionosphere than a central disc flare because the main ionization source of the ionosphere, the solar EUV radiations, can be absorbed by thick solar gas due to large CMD, which is called the CMD effect. Furthermore, the CMD effect decreases with decreasing flare X-ray class.

We noted, though the response of ionosphere to a solar flare event has been studied since 1960 using several instruments and theoretical models, the topic remains enigmatic as a consensus view is yet to emerge on how the Earth's ionosphere evolves in response to a solar flare event. Studies have shown that a solar flare event presents a picture which remains unique only to that event[4,7,20,25-28]. Measurement of the TEC of the ionosphere provides a reliable method to study how the ionosphere interacts with the solar flare. According to Liu *et al.*[23] The TEC measurement from the GPS receivers, therefore, is turning out to be an effective tool to study the solar flare effect on the Earth ionosphere.

In continuation of the ionospheres study, here we present a piece of work that how Indian dip and low latitude ionospheric region responded to an X class (X9.0) of solar flare event of 05 December 2006. We analyze the mean vertical total electron content (VTEC) measurements from GPS receivers located at Hyderabad (17.4°N, 78.5°E), Bangalore (12.9°N, 77.7°E) and Port-Blair (11.7°N, 92.3°E) in India, installed as a part of the GAGAN network. Further we used measurements of Ionosonde located at Trivandrum (8.4° N, 76.9° E) and horizontal component of geomagnetic field (H) from the International Real Time Observatory Network (INTERMAGNET) of Alibag (India) (18.6° N, 72.9° E) and Addis Ababa (Ethiopia) (09.0° N, 38.7° E) magnetometer stations. It may be noted that the variation in the H component shows the ionospheric E-region disturbance, solar quite (Sq) current and equatorial electro jet (EEJ) intensifications.

2 Methodology

In the present analysis we employed GPS-TEC, Ionosonde and horizontal component of geomagnetic field (H) measurements. The detail methodology of the measurements is as follows;

2.1 GPS-TEC measurements

Mitra[4] has established that the change in electron density of the ionosphere is the prime index to monitor the effect of solar flare on the Earth ionosphere. Taking the concept of change in electron density, here the mean VTEC measurements (30 s time resolutions) are employed of 04 and 05 December 2006 from the GPS receivers at Hyderabad (17.4°N, 78.5°E), Bangalore (12.9°N, 77.7°E) and Port-Blair (11.7°N, 92.3°E) stations installed under GAGAN project of India. These stations are representatives of different geophysical conditions in Indian ionospheric region, namely (i) a station at the dip-equator (Port-Blair), (ii) a station which is near to the equator, but away from the electro jet belt (Bangalore), and (iii) a station which is at the anomaly crest (Hyderabad).

GPS receivers provide the frequency measurement data to assess the TEC measurements over Indian stations. We know that GPS provide the position of the objects using dual frequency measurements (L1 and L2) between receiver and satellite. The source of error in the measurement arises because of ionosphere electron density. The delay characterized by a measurement of the TEC between GPS receiver and satellite. A general methodology of the TEC measurements could be understood from the ionosphere model equations. According to Davies[29], the rate of change of electron density N can be described by the continuity equation

$$\frac{\partial N}{\partial t} = Q - L - \nabla .(Nv) \quad \ldots (1)$$

Here, Q and L represent the rate of the electron production and recombination rate during photochemical processes. v represents the electron velocity and divergence in v represents transport of electron. The rate of electron production is described as:

$$L = \alpha N^2 + \beta N \quad \text{... (2)}$$

In Eq. (2), α and β are the recombination constants in the ionosphere E and F region respectively. It is known that the photochemical processes are faster during solar flares because of increased X-ray and EUV radiations. Changes in electron density at certain altitude are described by Eq. (3).

... (3)

Where, t_0 denote a certain time before the solar flare[30]. In this study we have used the TEC, derived from ground based GPS receivers, to estimate the change in electron density (N) during solar flare. According to Smith *et al.*[31] the TEC is a measure of the total electron content in a column of the unit cross-section along the path of the electromagnetic wave between the receiver and transmitter. Its unit is defined as 1 TEC unit=10^{16} electrons/m^2. The TEC between a GPS satellite (Tx) and a receiver (Rx) is expressed as;

... (4)

Where, s denotes the integration path along the electromagnetic ray. Change in the TEC can be described by Eq. (5);

$$\Delta STEC = \int_{T_x}^{R_x} \Delta N ds \quad \text{... (5)}$$

The STEC is known as slant total electron content of the ionosphere. In practice, the vertical TEC is used in the analysis. The STEC can be converted into VTEC using a standard mapping function as given by Smith *et al.*[31]. Further ΔTEC (t) can be used for detecting the solar flare.

2.2 Ionosonde measurements

In this analysis, we employed Ionosonde measurement (15 min time resolution) of 05 December 2006 located at Trivandrum (8.4° N, 76.9° E) to study how the ionosphere over the dip-equator responded. The Ionosonde at Trivadrum operate continuously (0.5-30 MHz) to derive F and E-region ionosphere parameters at equatorial region. Bilitza[32] shows that measurements from Ionosonde are usually used to infer the electron density of the ionosphere up to the peak of the F-region plasma density. Here in the present analysis, we used Ionosonde derived peak density of the F-region (foF_2) and E-region (foE) of 15 min time resolution to access the impact of solar flare on the ionospheric plasma density, particularly at the F-region altitudes at the dip-equator. The maximum frequency reflected from the F-region (foF_2) usually represents the peak density of the F-region (NmF_2) with (NmF_2) = $(foF_2)^2/80.3$ and the density in m^{-3}. The ionograms obtained from the Trivandrum Ionosonde were manually scaled using the DIGION code according to Titheridge[33] procedure which uses an empirical model proposed by Shimazaki[34] and later modified by Bilitza[32] to estimate the altitude of F-region peak (hmF_2).

2.3 Measurement of horizontal component of geomagnetic field (H)

In addition to the above measurements we also employed the 1 min time resolution data of H component of geomagnetic field during X9.0 flare (05 December 2006) and non flare (04 December 2006) days over dip equatorial and low latitudes regions. We took Alibagh (18.6° N, 72.9° E) magnetometer station data of low latitude ionosphere region in India and Addis Ababa (Ethiopia) (09.0° N, 38.7° E) of dip equatorial region in Ethiopia. The geomagnetic field H component data is obtained from the International Real Time Observatory Network (INTERMAGNET) of magnetometer stations. It is known that the magnetometer is used to obtain geomagnetic field components. The data are further plotted and utilised for the study of H component variations[8].

3 Results and Discussion

The top left panel of Fig. 1 shows the 3 day X-ray flux profile of the solar flares observed by the Geostationary Operational Environmental Satellite (GOES 12). The red curve in the middle region of this figure clearly shows the intensity of the X-ray flux of the X9.0 solar flare which erupted on the 5 Dec. 2006. The top right panel of Fig. 1 shows the X-ray images of the flare during the pre phase 10:17 UT of the flare observed by GOES 13 satellite. The images show the X-ray intensity and flare location. The flare is found to be located at the eastern limb of the Sun. The flare is located by its CMD. The bottom left panel of Fig. 1 shows the peak duration of the flare, 10:35 UT.

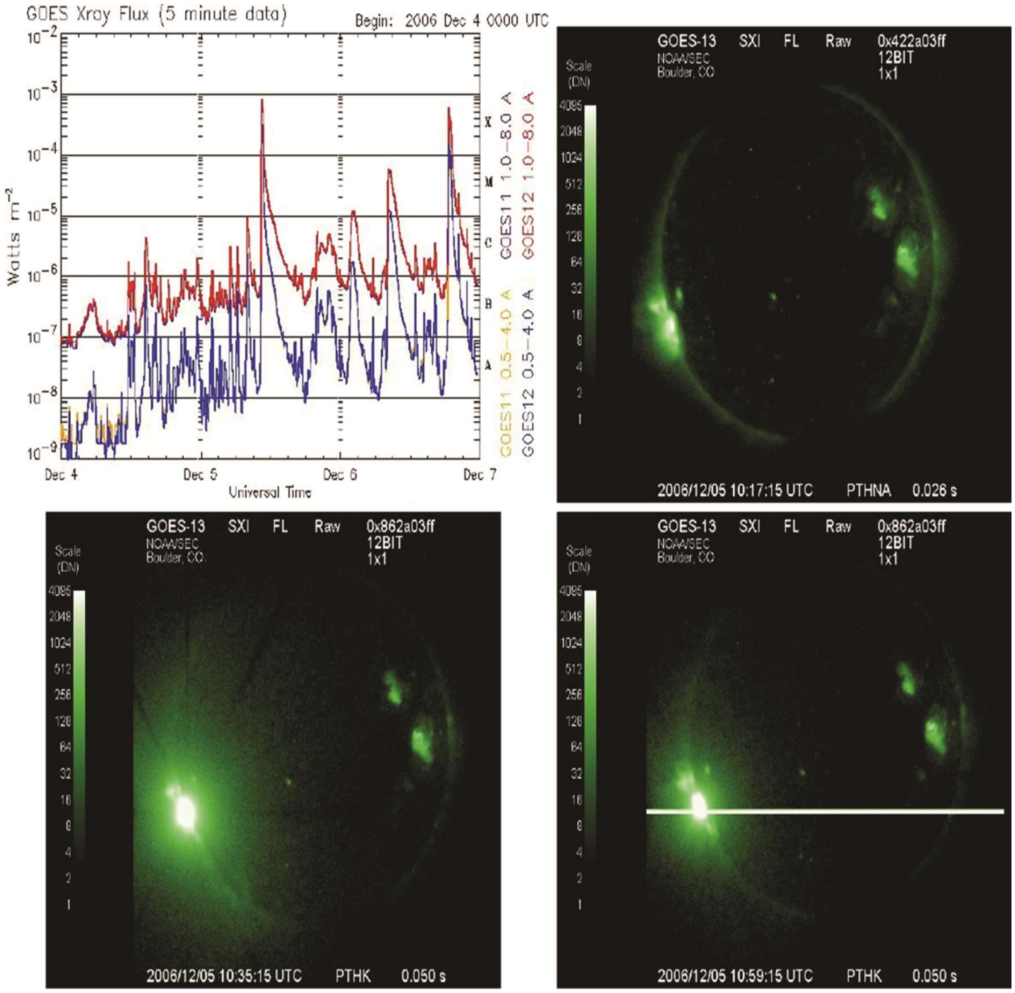

Fig. 1 — Top left panel show the 3 day X-ray profile of the Sun observed by the GOES satellite. The middle region spotted the X9.0 solar flare on 5 December 2006. Top right panel show the X-ray image of the X9.0 solar flare during the pre phase. Bottom left and right panel show the X-ray images of the solar flare during its peak and decay phases

The bottom right panel shows the image of the flare captured at 11:00 UT, the time when the flare finally subsided. It may be concluded from the X-ray images that the flare lasted for a long duration during its gradual phase of waxing and waning.

Figure 2 shows how the mean VTEC varied due to the solar flare as a function of Universal time (UT) over the three stations of interest in the Indian ionospheric sector. The Indian Standard Time (IST) leads the UT by 05:30 hrs (i.e. IST = UT+05:30). The mean VTEC was estimated from GPS measurements using a standard technique described in Smith *et al.*[30]. To generate mean VTEC statistics, we only considered measurements at any receiving station within ±1.5° latitude/longitude of the station, assuming standard ionospheric altitudes. While the station Port-Blair (magnetic latitude 8.8°N) is located at the dip-equator, Bangalore (magnetic latitude 8.8°N), being at the magnetic latitudes of 4.1°N, is considered close to the magnetic equator. Other station at Hyderabad (magnetic latitude 8.8°N) is located in the vicinity of the EIA crest. The left panel of Fig. 2 shows variations in the mean VTEC with respect to time on the 4, and 5 December 2006 at Port-Blair. The middle panel of the figure is for Bangalore, and the right panel shows data for Hyderabad (bottom panel). 04 December has been considered as a control day in the analysis as other nearby date (06 December) in this month was geomagnetically disturbed. In addition, since day to day variations in the TEC of the ionosphere in the equatorial region can be large, sometime larger than expected from the solar flare, we do not consider a control day which is too far from the solar flare event date of December 05, 2006.

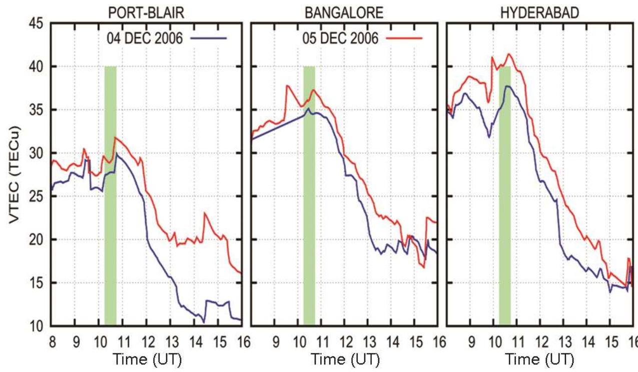

Fig. 2 — Left panel show the temporal variation (30s resolution) of the average VTEC over Port-Blair. The middle panel show the temporal variation of average VTEC over Bangalore and right panel show the variation of average VTEC over Hyderabad corresponding on 4 and 5 December 2006. Blue and red curves show the average VTEC response of Ionosphere on 4 and 5 December 2006 correspondingly

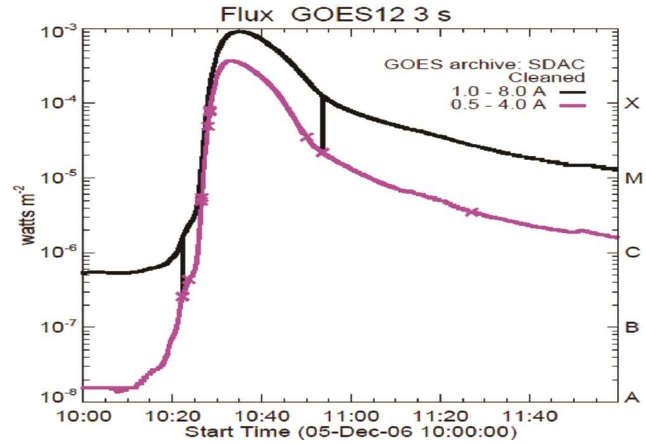

Fig. 3 — Figure show the X-ray flux profile of the X9.0 solar flare observed by the GOES12 satellite on 05 December 2006 between 10:00 -12:00 UT

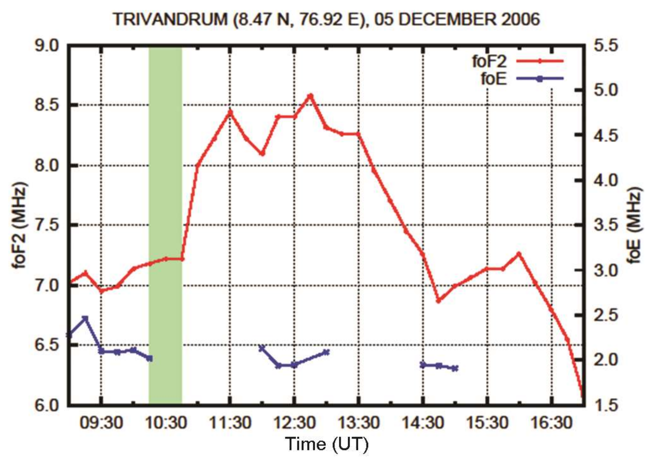

Fig. 4 — Figure show the response of foF2 (MHz) and foE (MHz) during flare hours on E and F layers of the ionosphere measured by the Ionosonde (15 min time resolution) located at the Trivandrum station

As one can note, there was a noticeable increase in the TEC on 05 December compared to the control day on 04 December, particularly after the solar flare event, the duration of which is marked as a vertical green bar in Fig. 2. There is clear indication of TEC rise at all the stations, though with a time lag. Immediately following the solar flare (11:00 UT), there is an identifiable rise in the TEC, which gradually becomes prominent and by 14:00 IST it becomes maximum. While at Port-Blair this rise (from ~ 10 TEC on December 4, to ~ 20 TEC on December 5, is quite glaring, a similar rise in the TEC is noted at Bangalore, and Hyderabad as well, albeit of lesser magnitude. The TEC at all the stations becomes normal after 16:00 UT. In general solar flares are associated with a rise in X-ray and EUV fluxes. In Fig. 3, we showed how the X-ray flux evolved during the flare hour (10:15 UT to 11:00 UT). There was a sudden rise in X-ray flux noticeable in the pre and impulsive phases of the flare which attained its peak approximately at 10:40 UT and decayed gradually during the later phase of the flare. The evolution profile of X-ray and EUV during flare is important to study the ionosphere response during flare and these radiations are known to produce ionization in the ionosphere.

Figure 4 shows the time evolution of foF_2 and foE before, during and after the solar flare event between 09:00 and 17:00 UT on 5 December 2006 over Trivandrum (8.4° N, 76.9° E). The green colour shaded bar in this plot represents the period of active solar flare. As one can note, immediately following the flare at 10:45 UT (16:15 IST), there is a steep increase in the peak density of the F-region, reaches a value close to 8.6 MHz by 12:30 UT (18:00 IST), and returns back to normal by 14:30 UT (20:00 IST). The increase in the peak density of the F-region during the period between 16:15 and 20:00 IST is conspicuous as the photo-production of fresh ionization in the Earth's ionosphere decreases due to the progressive increase in the solar zenith angle leading to the Sunset conditions. The density of plasma at the E-region (foE), on the other hand, does not show any real modifications. As a matter of fact, the E-region trace between 10:30 and 12:00 UT is so low that tracing the ionograms for E-region signals become difficult. It shows that it is the F-region at the dip-equator which shows the direct impact of the solar flare while the E-regions show not any effect.

Figure 5 shows the temporal variation of geomagnetic field component H(nT) of the magnetometer station installed at Alibagh (India) of 04 and 05 December 2006 respectively. Alibagh is the low latitude ionosphere region in India. The upper panel shows the variation on 04 December while lower panel on 05 December during 09:00 to 16:00 UT. It is clear from the Fig. 5 (lower panel) that on 05 December there is a gradual decrease to negative ~ 10 nT in the H component of the geomagnetic field during peak flare hours (10:35 UT). The H component further increased gradually to positive ~7 nT at 13:00 UT. Figure 6 is the representative of H component variation at the Addis Ababa (Ethiopia) geomagnetic

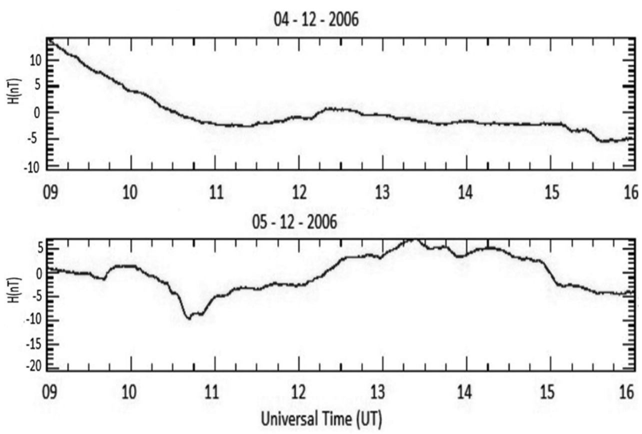

Fig. 5 — Upper and lower figure show the temporal variation of horizontal component H(nT) of geomagnetic field between 09:00 and 16:00 UT on 04 and 05 December 2006 respectively at the Alibagh, (India) (18.6° N, 72.9° E) magnetometer station. Fluctuation in the magnetic field component on 05 December is visible during flare onset (~10:15 UT) and flare peak hours (~ 10:35 UT)

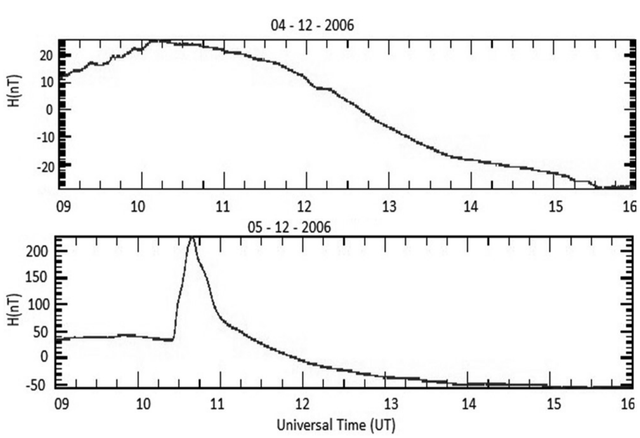

Fig. 6 — Upper and lower figure show the temporal variation of horizontal component H(nT) of geomagnetic field at the Addis Ababa (Ethiopia) (9.0° N, 38.7° E) in the Sunlit hemisphere on 04 and 05 December 2006 respectively during 09:00-16:00 UT. The Addis Ababa station lies at the dip equator in Ethiopia

station. Addis Ababa (Ethiopia) station lies on the dip equatorial and on 05 December 2006 during flare during 10:30 UT, it was Sun lit as of Indian equatorial geomagnetic station Tirunelveli (8.7° N, 77.8° E, dip latitude: 0.4° N). Figure 6 shows a sharp increase in H component to positive ~200 nT at 10:35 UT and sudden decreased to positive ~50 nT at 11:00 UT. The value further gradually decreases to negative ~50 nT around 13:00 UT.

On 05 December 2006, the parameters (limb centred, NOAA 10930, along the eastern side, S07E68, of the solar disc started at 10:18 UT peaked at 10:35 and decayed by 10:45 UT) of X9.0 solar flare were found favourable to study the interaction of solar flare over Indian regions due to the sunlit conditions over India. It is known from the earlier studies that its effect should be nominal on the Earth ionosphere due to limb centred compared to a disc flare event[23]. This is because those in a limb cantered solar flare most of EUV are absorbed by the thick gas of the solar atmosphere due to CMD effect[24] and X-ray remains the prime candidate to ionise the Earth ionosphere which ionises mainly D region[8]. It has also been studied by Le *et al.*[24] that there are several factors such as local time, season, size of flare, location of flare, and the time of flare control the response of the Earth's ionosphere to a solar flare. We noted being the X9.0 solar flare also late in the afternoon (between 15:48 and 16:15 IST) the impact was less glaring as the increasing solar zenith was reducing the photo-production of ions.

On the other side, the ionosphere over Indian region is known to be highly complex because of several factors, important among which is the zonal electric field which controls the distribution of plasma. Because of an almost horizontal alignment of magnetic field at the dip-equator, the eastward zonal electric field during the day time produces an upward vertical plasma E × B drift. If the upward drift is substantial enough, it diffuses plasma horizontally away from equatorial latitudes owing to the combined action of diffusion and gravity. The process is knows as fountain effect as proposed by Hanson and Mofett[35] in 1966. It simultaneously depletes the plasma column density at the equator and enhances the plasma density in regions away from the geomagnetic equator between 300 and 600 km altitudes, to the point that the equatorial column density becomes considerably smaller than its counterpart at latitudes away from it.

As the day to day variation in the zonal electric field is complex, so it is the day to day variations in the plasma density in the equatorial region.

Notwithstanding the complexities in the day to day variations in the plasma density at a location in the Indian dip and low latitude ionospheric region, we first noted an appreciable increase in the TEC of the ionosphere (~5 TEC units) during ~13:00 UT (Fig. 2). We notice that though the local time at different stations is different (difference in the local time at Bangalore (12.9° N, 77.6° E) and Port-Blair (11.7° N, 92.3° E) is approximately 1 h), the post flare increase in the TEC at these stations was almost of the same magnitude (~ 5 TECu). Additional increase in the TEC at Port-Blair could be noted after 13:00 UT. TEC increase at low latitude and dip equatorial station, however, may not be due to a direct impact of the solar flare. Reasons for this increase could be either pure local, or may be associated with the extra ionisation in the E-region due to the X9.0 solar flare on 05 December 2006. This could be understood by the plasma dynamics at the equatorial and low latitudes regions during day time and post sunset duration. It is known that during day time, because of eastward flow of electric field causes equatorial plasma to get pushed toward magnetic field lines and produced enhanced ionisation density at off-equatorial latitudes and an ionisation trough right over the dip-equator. During post sunset period zonal electric field developed due to thermospheric wind and sharp conductivity gradient in the E-region causes vertical plasma drift at the equatorial F-region while at the dip-equator, the plasma to get pushed down low in altitude to effect their recombination and decrease in the TEC[36]. Port-Blair (11.7° N, 92.3° E) which lies within the EEJ region contains more electron density. In this analysis, the additional increase in the TEC at the Port Blair could be understood that zonal electric field causes vertical drift of plasma at the equatorial regions during post sunset period this further results additional increased electron density over Port Blair.

Figure 4 shows the Ionosonde response over the dip equatorial latitude, Trivandrum (8.4° N, 76.9° E). We, however, note that the F-region of the ionosphere contribute more to this nominal increase in the TEC compared to the E-region (Fig. 4). As the solar EUV radiations control the photo chemistry of the F-region, it only goes to suggest that the X-ray effect is nominal compared to UV radiations from the solar flare. In addition, the flare interaction depends upon the time and location of the flare on the Sun. Disappearance of E-region echo at the equatorial latitude station, Tirunelveli, was also notice by the Sripathi *et al.*[8] for the X7 class of solar flare occurred on 09 august 2011. In Fig. 4 we also notice disappearance of E-region echo due to absorption of EUV emissions and sudden rise in electron density in the E-region at the Trivandrum equatorial ionospheric region.

Figures 5 and 6 show the variation of geomagnetic field component H(nT) during non flare and flare hours on 04 and 05 December 2006. The variation is occurred both at the dip equatorial and low latitudes magnetometer stations, Addis Ababa (Ethiopia) (09.0° N, 38.7° E) and Alibagh (18.6° N, 72.9° E) respectively. It has been established that during solar flare a geomagnetic storm is known to cause severe impacts on the distribution of plasma in the Earth's ionosphere[37-42]. The Earth ionosphere plasma dynamics is controlled by the magnetic field at the dip equatorial and low latitudes. The sudden decrease and increase in the ΔH value occurs because of sudden induction of flare related ionospheric current in the E-region during solar flare. A study carried out by the Manju *et al.*[43] inferred sudden depression in ΔH over Trivandrum and sudden enhancement of TEC of ~10 TECu. An analysis carried out by the Sripathi *et al.*[8] during an intense solar flare over several longitudes at Asian, European, and African longitudes in the Sunlit hemisphere shows a reverse trend in the H component variations. It have been suggested that ΔH at different longitudes also varies quite similarly to that of EUV flux variation and also further suggested that flare-related density enhancements in different longitude sectors in the magnetic equator can produce positive and negative variations in the electro jet (EJ) due to the presence of varying current systems at different longitudes.

Rastogi *et al.*[44] suggested about the ionospheric current system which does not extend to low latitude regions and remains toward the eastward direction. During this process the solar flare produces positive impulse in the H component. During X9.0 solar flare on 05 December 2006, we have obtained that H component sharply increased positive (~200 nT) at the dip equatorial and gradually decreased negative (~10 nT) at the low latitude ionosphere regions at

10:35 UT. The H component further gradually decreased negative (~50 nT) at dip equatorial and increased positive (~7 nT) at low latitude at 13:00 UT. The variations in the H component show the positive impulse at the dip equatorial region and negative impulse at the low latitude regions during flare hours (Figs 5 and 6 respectively). The analysis of H component clear indicate that there was a sudden rise in electron density in the E-region during 10:35 UT and intensification of Sq current occurred at the equatorial and dip latitude regions. The direction of ionospheric current systems remains as usual to eastward during peak flare hours (10:35 UT) which established in reverse direction during post sunset duration (13:00 UT).

5 Conclusions

In this analysis we studied the response of Earth's ionosphere over Indian region due to a limb centred X9.0 class of solar flare occurred on 05 December 2006. From the above analysis, we find major results those are summarised as follows.

(i) We find that following the onset of the solar flare (at 10:18 UT); there was no enhancement in the TEC observed at the dip equatorial region, Port-Blair, and low latitude regions, Bangalore and Hyderabad, respectively. We know that increase in TEC is mainly associated with the E and F layers[6,7]. Therefore from the analysis we inferred that the X9.0 solar flare being a limb centred (CMD effect) and its high zenith angle causes less photo ionization in the F-region during flare hours and it was not observed by the TEC measurements. However, the minor TEC enhancement in the F-region could not able to be detected due to 30 s time resolution of the TEC measurements.

(ii) We find appreciable increases in the TEC at all the three stations during 13:00 UT (18:30 IST). The TEC enhancement at the dip-equatorial station, Port-Blair, was found to maximum while at the low equatorial Bangalore and Hyderabad, it was less. The TEC enhancement during 13:00 UT at all the stations could be understood from vertical drift of movement of plasma to F-region during post sunset period. Additional vertical drift of plasma from the E-region to F-region was found to be primary cause of increased electron density over the low latitudes and dip equatorial region during 13:00 UT. However, it is known that Port-Blair already consisting additional plasma due to EEJ.

(iii) The Ionosonde measurement of ionospheric parameters (like foF_2 and foE) at equatorial latitude, Trivandrum, showed an increase in the plasma density at the F-region while the E-region did not show any impact. The absorption of echo from the E-region is attributed with the completely absorption of EUV emissions and deep penetration of the X-ray flux into D and E-regions which results increase ionisation in the E-region.

(iv) We obtained sudden increase and decrease in the geomagnetic field component H(nT) at the dip equatorial and low latitude regions. The H component shows the variation on 05 December 2006 at both the Alibagh (India) and Addis Ababa (Ethiopia) stations those were the representative of low and dip equatorial latitude. The H component sharply increased positive ~200 nT at the dip equatorial and gradually decreased negative ~ 10 nT at the low latitude ionosphere regions during 10:35 UT and further established gradually during post flare hours. This attributed to intensification of Sq current and EEJ toward the eastward direction at the equatorial region and westward direction over low latitude region during flare hours. This intensification of Sq current clearly shows the increase in electron density at the E-region of ionosphere during 10:35 UT. The downward vertical drift of the plasma from E-region occurs which could be primary reason for not enhancing electron density in the F-region during peak flare, 10:35 UT. However, the vertical upward drift of plasma could be the reason of increase in electron density at dip equatorial and low latitudes at 13:00 UT.

Acknowledgments

One of the authors (P Kumar) is very much thankful to Dr. Anil Bhardwaj (Director, M/s SPL, VSSC Trivandrum, ISRO, India) for providing the opportunity to carry out research on response of Earth ionosphere during a intense X9.0 solar flare using GPS-TEC and IONOSONDE observations at SPL, VSSC Trivandrum. Use of global observations of geomagnetic “H” component data as obtained from INTERMAGNET network is highly acknowledged.

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