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ORIGINAL ARTICLE

A multi-technique study of the 29–31 October 2003 geomagnetic storm effect on low latitude ionosphere over Indian region with magnetometer, ionosonde, and GPS observations

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Abstract The present study demonstrates the ionospheric response to the extreme geomagnetic storms during 29–31 Oct 2003 (the Halloween storm), in the low latitude anomaly Indian region, based on multi-instrument measurements namely magnetometer, ionosonde, and GPS observations. Unlike earlier reports, we have suitably chosen the best quiet days (CQ-Days) amongst 10 international quiet days (Q-Days), on the basis of equatorial electrojet strength and pattern, that drives the distribution of plasma over the low latitude. We stress that arbitrarily selecting the Control/Q-Days may lead to erroneous interpretations and will not yield a clearer understanding of the equatorial electrodynamics. Our analysis confirms the anomalous increase in TEC at all stations on 29 Oct 2003 and suppressed TEC across anomaly crest latitudes during 30–31 Oct 2003. The sharp transition in h'F is noticed during the progressive period of the storm, though it was relatively lower at the equator. The respective foF2 remained subordinate at Trivandrum. However, we did not notice such foF2 changes at Delhi. Observations at various latitudes confirm the maximum positive deviation of TEC at mid-latitude POL2 (140 %), followed by the low latitude Jodhpur (108 %), and the rest of the stations showing relatively lower enhancements with deviations ranging between 60–90 %. However, at Ahmedabad, the lowest divergence from the mean CQ-Days, attribute the typical quiet day formation of crest at this latitude. Although the results are well agreeing with earlier reports, miniature differences is noticeable due to our way of choosing the best reference days in the analysis.

Keywords Geomagnetic storm · Equatorial electrojet strength · Ionosphere · Total electron content · Equatorial ionization anomaly

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1 Introduction

Geomagnetic storms are temporary disturbances of the Earth's magnetosphere, associated with coronal mass ejections (CMEs), coronal holes, or solar flares, thereby changing the magnetosphere-ionosphere-thermosphere coupling processes. Major disturbances in the storm-time equatorial and low latitude ionosphere are caused by prompt penetration electric field (may last for short duration or few hours) and the disturbance dynamo electric field (may last for several hours) of magnetospheric origin (Nishida et al. 1966;

Fejer et al. 1979; Huang et al. 2005). However, recent studies demonstrate that during daytime penetration electric field (eastward), an equator-ward neutral wind is required to produce positive ionospheric storms, profoundly affecting the distribution of F-layer plasma in the equatorial low and mid-latitude ionosphere (Vijaya Lekshmi et al. 2008; Balan et al. 2010). Unlike the typical quiet days, the penetrating electric fields of magnetospheric origin intensifies the plasma fountain (super fountain) at the dip equator and develops the anomaly crest at relatively higher latitudes. Hence the quiet time distribution of plasma is totally disturbed in the low latitude equatorial ionization anomaly (EIA) region. However, Joule heating at the auroral zone may drive the equator-ward propagating acoustic gravity waves (AGWs), manifest in the ionosphere as traveling ionospheric disturbances (TIDs) (Richmond 1978; Ding et al. 2008).

Severe geomagnetic storms are well known to affect the propagation of trans-ionospheric radio signals and can severely impact satellite communications, navigation systems and electrical power grids. Ionospheric response to diverse geomagnetic storms have been extensively studied through theoretical, experimental and model predictions (Matsushita 1959; Mendillo et al. 1974; Huang 1985; Basu et al. 2005; Lin et al. 2005b; Abdu et al. 2007; Jakowski et al. 2008; de Abreu et al. 2010; Balan et al. 2012; Yao et al. 2013). In particular, the storm effects in the low latitude ionosphere across the Indian region have been vastly studied since last few decades. Revisions suggest that most of these studies are based on the comparison of ionospheric characteristics during the storm period with the preceding/succeeding control days (Lin et al. 2005b; Dashora and Pandey 2006; Perevalova et al. 2008; Manju et al. 2009; de Abreu et al. 2011; Balan et al. 2012), mean quiet days (Q-Days) (Sahai et al. 2005; Sharma et al. 2011; Uma et al. 2012), or monthly median values (Huang 1985; Maltseva et al. 2012). However, it has been proved that the dynamics of the equatorial ionosphere is greatly influenced by the generation of equatorial electrojet (EEJ), a daytime eastward electric current in the ionospheric E-layer, within a narrow belt of $\pm 3^\circ$ latitude over the dip equator. This manifests the $E \times B$ vertical drift of plasma (fountain effect) to F region, and then carry the plasma to relatively higher latitudes ($\pm 15^\circ$) developing the EIA (Appleton 1946; Chapman 1951). However, at time the EEJ current flows in the reverse (westward) direction referred to as counter electrojet (CEJ) inhibiting plasma transport process (Gouin and Mayaud 1967). The strength of EEJ is manifested in the magnetometer horizontal H variation, hence considered as a proxy index of the electric field over the equator. During severe geomagnetic disturbances, the EIA crest may shift towards (negative ionospheric storm) or away (positive ionospheric storm) from the geomagnetic equator (Deshpande et al. 1977). Studies reveal that the CEJ events may occur on the extremely quiet days due to localized changes in the driving electric field. Hence in this study we have carefully chosen the best quiet days (CQ-Days) amongst 10 international Q-Days which have very regular EEJ strength and normalcy in pattern peaking around the local noon.

The motivation behind the present research came up from the study of the enormous literatures portraying varied equatorial electrodynamics predominantly controlling the low latitude ionosphere during quiet/storm days, ideas of the electric field circulations, and an opportunity of the magnetometer, ionosonde, and GPS Aided GEO Augmented Navigation (GAGAN)/International GNSS Service (IGS)-Global Positioning System (GPS) observations across the Indian region. We carried out a multi-instrumental study of the extreme storm event of 29–31 Oct 2003 (popularly known as the Halloween storm) from the above observations, to investigate the ionospheric effects over the Indian sub-continental region. The magnetometer data is used to choose the best quiet days (CQ-Days) and to examine its storm-time variations. Similarly, the ionosonde parameters (h’F, foF2) and GPS derived total electron content (TEC) are studied for understanding equatorial electrodynamics driving the net distribution of plasma over the low latitude. The storm-time deviations of electron density/TEC are compared with the mean chosen CQ-Days and then evaluated through earlier reports of this event. We believe this careful selection of reference days in our studies would help in better understanding of equatorial electrodynamics and spatial distribution of plasma over low latitude Indian region.

2 Data, method of processing and analysis

For thorough understanding of the solar, interplanetary and geomagnetic conditions during the storm and selecting the quiet control days, we have used 1-min averaged symmetric disturbance index (SYM-H; equivalent to Dst) and estimated planetary K-index (Kp), the vertical component of interplanetary magnetic field (IMF-Bz), interplanetary electric field (IEF), plasma speed, and the auroral electrojet index (AE) sequentially arranged from bottom to top in Fig. 2. The parameter EEJ proxy index ($\Delta H_{\mathrm{TIR}} - \Delta H_{\mathrm{ABG}}$) is obtained by subtracting the nighttime baseline of magnetometer H variation from the daytime values at equatorial Tirunelveli and off-equatorial Alibag observatory, and then finding the difference between them, ensuring the removal of the core and large-scale magnetospheric fields. This method was initially suggested by Chandra et al. (1971) and later used by several workers (Bhargava et al. 1983; Rastogi and Klobuchar 1990; Alex and Mukherjee 2001; Jose et al. 2011; Sripathi and Bhattacharyya 2012) and many more.

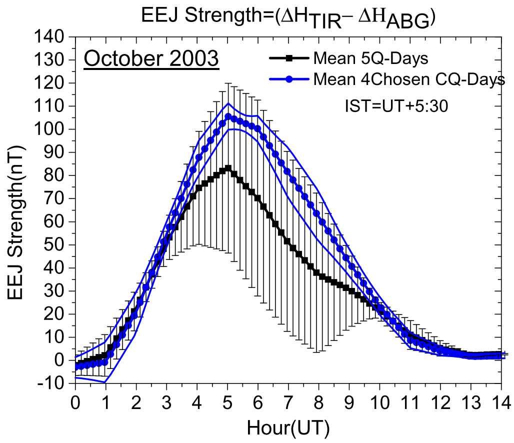

Fig. 1 Average EEJ strength of five international quiet days (Q-Days; *black curve* with SD *error bar*) and suitably chosen quiet days (CQ–Days; *blue curve* with SD error range)

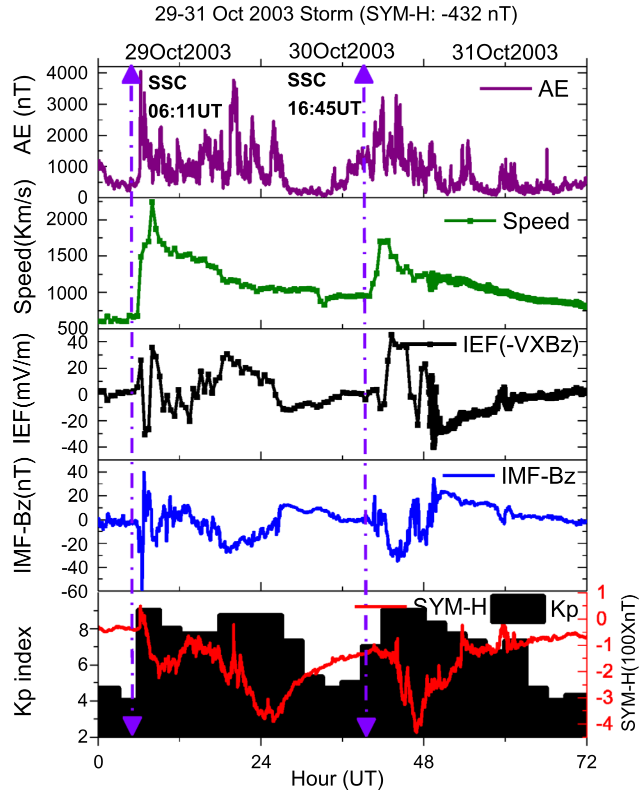

Fig. 2 1-Min averages of Geomagnetic Kp, SYM-H index (*bottom*), vertical component of interplanetary magnetic field (IMF-Bz; *second from bottom*), electric field ($-V \times Bz$) (*middle*), solar wind speed (*second from top*), and auroral electrojet (AE; *top*) during 29–31 Oct 2003 geomagnetic storm. The *vertical dashed line with the arrowhead* represents the instant of the storm sudden commencement (SSC)

The F2-layer parameters at Trivandrum and Delhi are examined in this study to realize the ionospheric behavior over equatorial and beyond EIA crest low latitudes respectively. It is known that the F-region electron density is the major contributor to the ionospheric TEC derived from GPS observables. However, studies also confirm that during geomagnetically disturbed conditions both the parameters (foF2 and TEC) behave differently, predominantly due to the neutral winds and electric fields controlling the storm-time electron density profile and thereby manifesting the distribution of plasma (Davies and Liu 1991; Stankov and Warnant 2009). The temporal variation of electron density in the low latitude region is the resultant effect of ionization, transport and recombination, hence consideration of these two widely separated stations would help in better understanding of the storm time ionosphere over the region.

The line-of-sight slant TEC (STEC) are obtained from dual frequency GPS observation stations established by the Indian GAGAN program and the International GNSS Service (IGS) across the Indian longitudes. The elevation angle of 30° is chosen to convert the STEC to its vertical equivalent (VTEC), at each location with suitable mapping function at the ionospheric piercing point (IPP) altitude of 350 km, for minimizing the change in satellite geometry, multipath and other lower atmospheric effects during the period (Adewale et al. 2012).

3 Results and discussions

3.1 Solar and geophysical parameters

The precursors responsible for 29–31 Oct 2003 extreme geomagnetic storm were the most energetic consecutive X-class solar flares on 28 (X17.2/4B) and 29 (X10) of Oct 2003, erupted from a giant sunspot (NOAA AR0486) which struck the Earth on 29 and 30 Oct 2003 respectively. The high-resolution storm time variation (1 min) of the planetary Kp index (interpolated), SYM-H index (equivalent to hourly Dst index), interplanetary magnetic field component (IMF-Bz), interplanetary electric field (IEF), solar wind speed, and the auroral electrojet index (AE) are shown in Fig. 2. It is clear from Fig. 2 that the storm consists of two major drops in SYM-H index with downward peaks of −391 nT (01:48 UT) and −432 nT (22:55 UT) on 30 October. The first shock of sudden storm commencement (SSC) was seen at 06:11 UT (11:41 IST) on 29 October with abrupt southward turning of the IMF-Bz (−59 nT), sudden flipping of IEF between −30 to 35 mV/m, and a massive intensification in AE index to a range of 4000 nT, followed by frequent fluctuations and recovery until the next day. The solar wind speed exceeded 1500 km/s for a period of more than 6-h reaching a value of 2241 km/s (08:00 UT). Soon before reaching its normal state, the second SSC occurred around 16:45 UT (22:15 IST) on 30 October with the renewed intensification of AE index (above 3000 nT), the southward turning of IMF-Bz (−34 nT), and the north-south flipped IEF (−40 to 40 mV/m). This resulted the sharp negative excursion of

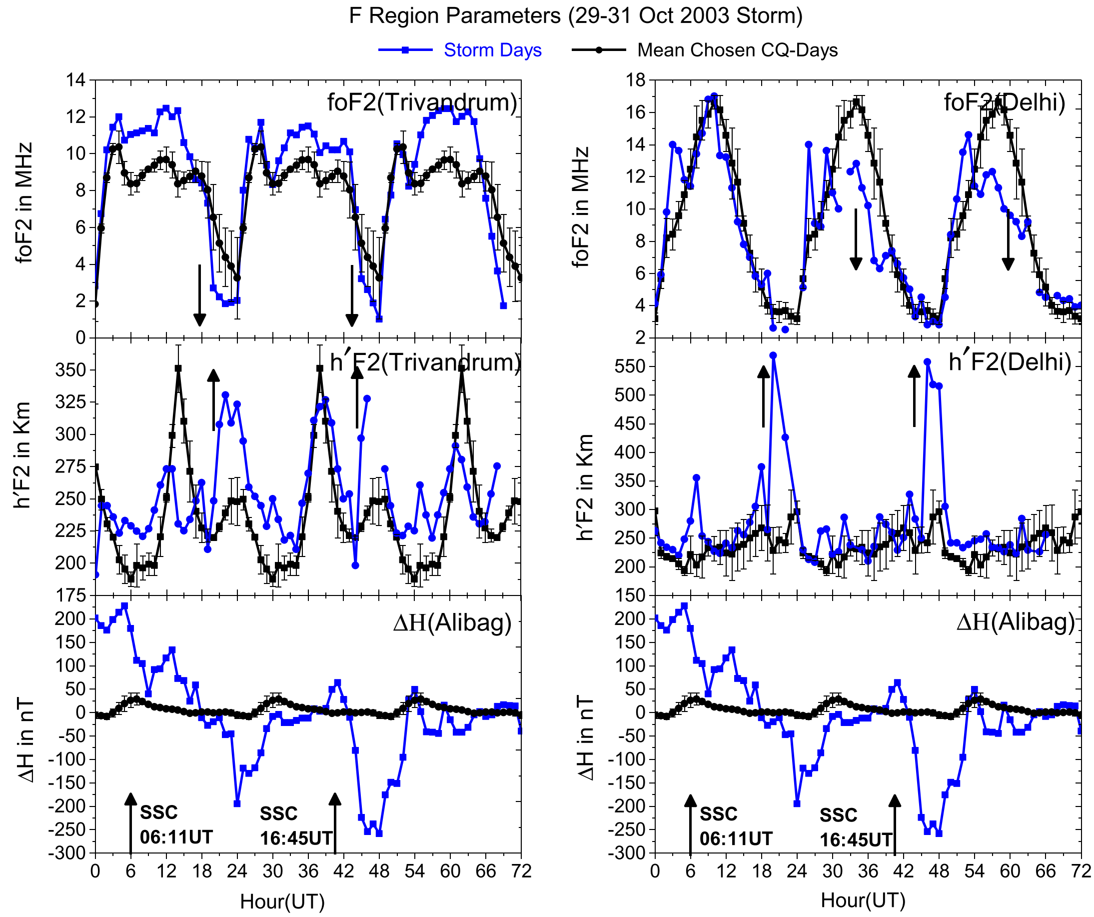

Fig. 3 Hourly variation of foF2 (*top*), h'F (*middle*) at Trivandrum (*left*) and Delhi (*right*) along with ΔH variation (*bottom*) at Alibag magnetic observatory during storm period (29–31 Oct 2003) and suitably chosen quiet days (CQ-Days)

SYM-H index that continued recovering until 16:00 UT of 31 October, but superposed with a series of small oscillations. The maximum solar wind speed on 30 October was around 1710 km/s (18:40 UT), exceeding the 1500 km/s for at least 1 h. Detailed documentation of extreme solar wind disturbances and magnetic field observations is given in Skoug et al. (2004). Moreover, the planetary Kp index remained in the severe storm levels during this event with a maximum limit of 8–9 units at least for a period of 24 h.

To understand the storm effect, we have picked up only the best quiet days (CQ-Days) amongst 10 international quiet days (Q-Days), on the basis of EEJ proxy index. It is clear from Fig. 1 that the usual choice of averaged first five Q-Days is showing wide range of standard deviation (SD) error. Conversely, by selecting the CQ-Days, the range of SD error is minimized, suggesting this method would give better understanding of any solar-terrestrial event on/over the low latitude EIA region. However, the regular EEJ ($\Delta H_{\mathrm{TIR}} - \Delta H_{\mathrm{ABG}}$) index gets corrupted during the storm time as many other current systems are in progress to disturb the magnetic H data over the equator; hence we chose the ΔH_{ABG} at Alibag (off-equator) for studying the storm time variations in our study.

3.2 F-Layer parameters

Figure 3 depicts magnetic ΔH_{ABG} variation at Alibag (bottom panel) and F-region parameters (h'F, foF2) at (a) equatorial Trivandrum (left), and (b) the beyond EIA crest station Delhi (right) during the storm period, and mean chosen quiet days (CQ-Days). It is clear from the figure that during the storm period, the foF2 and h'F at Trivandrum remained higher except the progressive hours of the storm, whereas at Delhi, although the overall h'F raised, lower foF2 was observed with exception to the morning hours that witnessed markedly raised foF2 values from the mean CQ-Days. The unusual features observed corresponding to the sudden negative excursion in ΔH_{ABG} (similar to SYM-H index) following both the storm sudden commencements (SSCs) are the sharp transition in h'F (75 km and 100 km) and decrease in foF2 (2–3 MHz) at Trivandrum. The relative upliftment in h'F at Delhi (300 km and 250 km) is more pronounced than

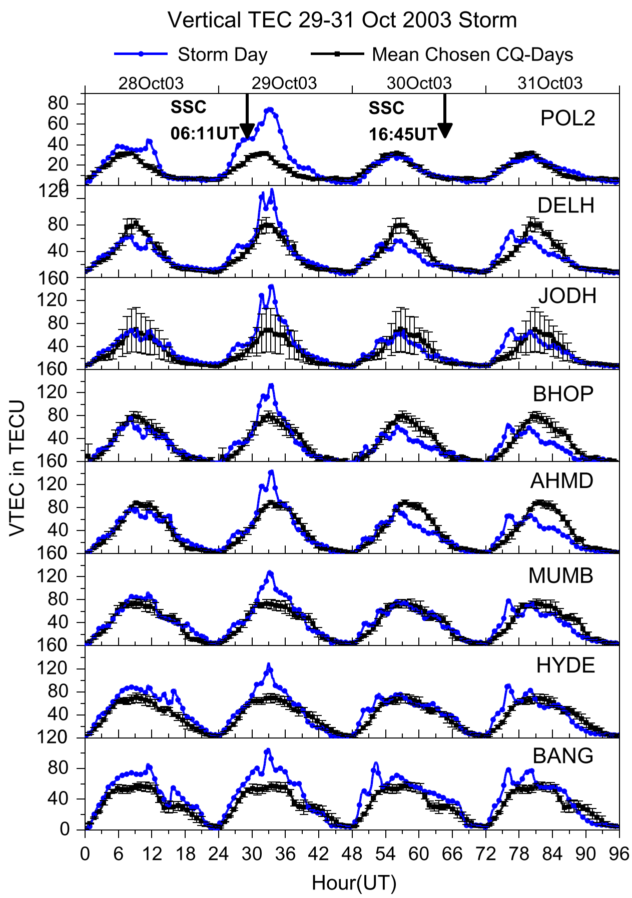

Fig. 4 Diurnal variation of TEC at different latitudes during storm period 29–31 Oct 2003 (*blue curve*), and suitably chosen quiet days (CQ-Days; *black curve* with SD *error bar*) on the basis of EEJ strength and pattern

the former, and essentially reduced foF2 is unnoticed during the main phase of the storm.

3.3 TEC from GPS observations

Figure 4 shows 5-min averaged TEC variation at different latitudes, during the storm period (29–31 Oct 2003) and mean chosen CQ-Days. It is clear from the figure that soon after the arrival of the SSC (6:11 UT), the first smaller enhancement in TEC occurred towards the equatorial stations (i.e., Bangalore) with a peak at about 6:45 UT, which decreased by 7:30 UT showing a clear depression. Similar feature was also seen in TEC data from low latitude Ahmedabad, Bhopal, Jodhpur, and Delhi as well as the foF2 plots at the equatorial Trivandrum station (Fig. 3). The second and most pronounced TEC enhancement attained its peak at 9:00 UT (14:30 IST, the regular peak hours) and later recovered to its normal value until 10:30 UT. Equatorial upward $E \times B$ drift of 75 m/s and 72 m/s as estimated from the passage of ROCSAT-1 around 07:12 UT and 08:54 UT across 120 E Geographic longitude in the Asian/Australian sector, and about 133 m/s around 20:00 UT across 70 W Geographic longitude in the American sector are corresponding to the increased electron density in the south equatorial anomaly region (Lin et al. 2005a). However, the development of these two peaks are prominently noticed at latitudes beyond Mumbai with a delay of about 30 min. We observed a small post sunset enhancement (around 13:00 UT) in TEC at Bangalore and to a very small extent at Hyderabad and Mumbai. Notable to say, all the stations from equator to anomaly crest latitude witnessed night-time depressions below mean CQ-Days level and this concur well with global ionospheric reports of Perevalova et al. (2008) pointing ↓50–100 % reduction at mid and low latitudes. It is to be mentioned that studies of Manju et al. (2009) on storm time excursion of plasma at the equatorial (Trivandrum) and off-equatorial (Sriharikota) ionosonde stations agrees well with the TEC developments in a range of GPS-TEC stations across Indian longitudes. However the storm time TEC at these stations (Fig. 4), demonstrates that highest TEC is witnessed at Jodhpur (148 TECU) but the highest TEC of averaged chosen CQ-Days falls around Ahmedabad (< 90 TECU), conforming the poleward movement of anomaly crest on the storm day. Perevalova et al. (2008), based on global ionosphere map (GIM), have also reported the northward shifting of anomaly crest up to 20–23° on the storm day as compared to their considered normal day (23 Oct 2003). They also noticed a significant enhancement of TEC (150–200 %) at the EIA crest region by comparing with the control day (23 Oct 2003). However, remarkable enhancement of night-time TEC (↑400 %) is reported by them at the high latitudes in contrast to the night ionosphere at the middle and low latitudes which witnessed essential reduction of TEC (↓50–100 %). Similar description was also given by Anderson et al. (2006) suggesting the regular crest at ±16° that shifted to ±20° dip latitude on the storm day.

Deviation of TEC at various locations as shown in Table 1 confirms that storm time positive deviation of TEC from the mean chosen CQ-Days is maximum at the mid-latitude station POL2 (140 %, Geographic 42.67 N, 74.68 E), followed by Jodhpur (108 %, Geographic 26.26 N, 73.05 E). Deviations at other stations are seen to be within the range of 60–90 %. However observations of Manju et al. (2009) report storm day diurnal peaks of 120 (↑50 %), 130 (↑85 %) and 115 (↑92 %) TECU by comparing with a single control day (5 Nov 2003) at Ahmedabad, Jodhpur, and Delhi respectively. These results certainly differ from our results due to our selectively chosen CQ-Days on the basis of EEJ strength and pattern. Similar studies have been conducted by Cander and Mihajlovic (2005) in the European sectors with a single control Q-Day (11 Oct 2003), reporting about 230 % increase in TEC at Matera (Geographic. 16.7 E, 40.6 N) and Noto (Geographic. 15.0 E, 36.9 N), and more than 130 % increase at Graz (Geographic.

Table 1 Geographic/Geomagnetic coordinates of magnetometer/ionosonde/GPS stations and deviations (%) of ionospheric electron density/TEC on the storm day.

Stations	Geographic		Geomagnetic		Observation type	↑Deviations (%)	
	Lat. (N)	Long. (E)	Lat. (N)	Long. (E)		Our	Others
POL2	42.7	74.7	33.7	150.7	GPS	140	230[b]
Delhi	28.7	77.2	19.6	151.3	GPS/ION	64	115[a]
Jodhpur	26.2	73.0	17.6	147.1	GPS	108	130[a]
Ahmedabad	23.0	72.5	14.4	146.3	GPS	63	120[a]
Bhopal	23.0	77.2	14.0	150.7	GPS	71	
Mumbai	18.5	72.5	10.0	145.8	GPS	79	101[d]
Hyderabad	17.5	78.5	08.4	151.5	GPS	86	95[d]
Bangalore	13.0	77.5	04.1	150.1	GPS	88	90[d]
Trivandrum	08.5	77.0	−0.3	149.2	ION	25	13[c]
Tirunelveli	08.7	77.8	−0.2	150.0	MAG	–	–
Alibag	18.6	72.9	10.2	146.5	MAG	–	–

ION—Ionosonde, MAG—Magnetometer, GPS—Global Positioning System

[a](Manju et al. 2009), [b](Cander and Mihajlovic 2005), [c](Tsurutani et al. 2005), [d](Panda and Gedam 2012)

15.5 E, 47.1 N) and Hailsham (Geographic. 0.3 E, 50.9 N). Studies of Lin et al. (2005a) in the Asian/Australian sector shows that on the prestorm day (28 Oct 2003) the northern/southern anomaly peak (81/89 TECU) was around Geographic 14.0 N/2.0 N (Geomagnetic 5.0 N/7.0 S) while on the storm day (29 Oct 2003) the northern/southern anomaly peak (146/108 TECU) was around Geographic 23.0 N/5.0 S (Geomagnetic. 14.0 N/14.0 S). Similarly in the north-American sector, Lin et al. (2005a) also found the largest TEC value (more than 170 TECU) at Geographic 14.0 N (Geomagnetic 25.0 N) on the storm day, while the corresponding TEC on the prestorm day was around 90 TECU at Geographic 2.5 N (Geomagnetic 13.5 N). Also simulation results of Lin et al. (2005b) show that the maximum TEC on prestorm day (28 Oct) was 78 TECU (at Geographic 27.0 N; Geomagnetic 13.7 N), while the storm day TEC was 158 TECU at 19.0 N Geographic latitude (Geomagnetic 30.0 N). Tsurutani et al. (2005) reported an increase of 12 TECU (13 %) at Libreville (Geographic 0.35 N, 9.67 E) in African region on the storm day (29 Oct 2003) from their chosen control day (27 Oct 2003) value (90 TECU), their results differ from our studies due to their way of selection of control day and longitudinal constraints. Similar studies have been done by Mannucci et al. (2005) confirming 50–250 % increase in TEC (30 min averaged) across the ±30° Magnetic latitude.

The morning two-phase enhancements of TEC with a small notch in between them, on the 30 and 31 Oct 2003 are noticed more prominently towards the equatorial station and diminished away from the equator, with clear absentia at the mid-latitude (POL2) station. The distinguishable notch amid consecutive enhancements is due to suppressed eastward electric field during the recovery phase. However, the daytime TEC fluctuated by straddling across mean CQ-Days level up to the latitudes of Mumbai, beyond which and until Delhi, the diurnal level remained pretty below the mean CQ-Days level, though the difference at the mid-latitude (POL2) station is unremarkable, attributing it to be a low latitude phenomena.

4 Conclusions

In this work, we have presented the ionospheric F layer density (ionosonde) and TEC (GPS) from several locations along the Indian longitude sector corresponding to the Halloween Storm event (29–31 Oct 2003) showing changes in ionospheric conditions considerably. The results obtained in this study are summarized below.

(i) This paper has used multi-technique measurements, namely Magnetometer, Ionosonde and GPS-TEC observations, to understand changes in the ionosphere in the low latitude Indian region during the extreme geomagnetic storm of 29–31 Oct 2003. Since it is the EEJ strength manifesting the net zonal electric field that eventually controls the plasma dynamics in the low latitude EIA region, and can be apparently estimated from the horizontal H variation of magnetometers as a proxy index. Hence the magnetometer data is absolutely necessary for investigating any low latitude ionospheric phenomena.

(ii) It is well known that the equatorial electrodynamics is reflected in the net transportation and subsequent diffusion of F-layer plasma, and major portion of the ionospheric TEC corresponds to the F-region; hence the ionosonde/GPS observations are essential in this aspect.

(iii) During the episode of the extreme geomagnetic disturbances, the regular EEJ index ($\Delta H_{\mathrm{TIR}} - \Delta H_{\mathrm{ABG}}$) is not valid, as many other current systems are in progress, substantially disrupting the magnetometer H variations beneath the ionospheric dynamo region. However, the Control/Q-Days considered invariably in most of the studies, for accessing the storm effects, might also be influenced by the unusual EEJ currents, especially the occurrences of CEJ on the Control/Q-Days would lead to erroneous interpretation of the effects. We do understand that it is very hard to define the typical day over the equatorial region as the parameters appears to vary from day to day. Therefore in the present study, we have carefully chosen the typical quiet days (CQ-Days) based on EEJ strength and its normalcy in the diurnal pattern, which is not followed in any of the previous studies relating this event.

(iv) Ionospheric abnormalities during storms or any other solar-terrestrial events are understood by comparing changes during the events with the Control/Q-Days, which are in general believed to be normal days. Our study shows that it is not sufficient to merely choose the Control/Q-Days particularly in this EIA region since the zonal electric field corresponding to EEJ plays a large role in horizontal transformation and gradients in the low latitude ionosphere. Very few studies check the nature of EEJ conditions on the chosen Control/Quiet days, and in this study care has been taken to select the best Quiet days (CQ-Days) on the basis of typical magnitude and normalcy in pattern of the EEJ.

(v) The dramatic enhancement of h'F during the progressing phase of the consecutive storm days from the mean chosen CQ-Days are markedly noticed at the equatorial Trivandrum (↑75 km and 100 km) and beyond EIA crest location Delhi (↑300 km and 250 km). Nevertheless, the effect was relatively more pronounced at the latter station. Furthermore, the corresponding foF2 appeared to be drastically decreased by 2–3 MHz at Trivandrum, but we did not notice such effect at Delhi. We found the overall daytime foF2 level more than 3 MHz higher than the mean CQ-Days at Trivandrum but declined at Delhi on 30 and 31 Oct 2003, except few hours of unusual enhancement in the morning corresponding to the suppressed eastward electric field.

(vi) The widespread availability of GAGAN and IGS network of GPS stations across the Indian longitudes prompted us to carry out spatial variations of TEC across the longitudinal region. In this study we have processed data from 8 GPS stations at different latitudes, the highest enhancement in TEC was seen on 29 Oct 2003 at all stations. Conversely, the subsequent days witnessed lowered TEC due to suppressed eastward electric field in the morning throughout the episode of the recovery period. We found no substantial change in TEC during 30–31 Oct 2003 at the mid-latitude POL2 station, suggesting the above effect attributed to the low latitude phenomena. All the stations from equator to anomaly crest witnessed night-time depressions below mean CQ-Days level. Observations indicate the maximum positive deviation of TEC at the mid-latitude station POL2 (140 %), followed by Jodhpur (108 %), deviations at other stations were within the range of 60–90 %. All these results are in good agreement with earlier reports of this event in the Indian as well as other latitude/longitude sectors.

(vii) Ionospheric electron density/TEC are very much important parameters for studying its characteristics and effects on precise positioning, navigational applications, and electromagnetic signal transmissions. Geomagnetic storms reconnected ionospheric disturbances provide unique opportunities to investigate different current systems and phenomena and their solar/terrestrial drivers during different activity conditions at diverse longitude/latitude extents. The study has been undertaken anticipating the understanding would certainly help the readers/researchers for improving the existing regional models over equatorial low latitudes.

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