Development or Inhibition of post-sunset ESF during geomagnetic storm – a multi-instrumental and multi-station study on its local time dependant response

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Abstract

Development or inhibition of ESF during magnetically active periods has been an important space weather topic of interest during the recent past in view of its importance in the satellite based navigational systems. The post-sunset equatorial ionosphere exhibits significant variability during storm times in the context of development/inhibition of ESF. A multi-instrumental (ground based and space borne) and multi-station study on the development/inhibition of post-sunset ESF during four geomagnetic storms in 2004 – 2005 has revealed that the prompt penetration phase may last for many hours (6-7 hrs) as the geomagnetic activity continues to intensify under the southward orientation of IMF Bz.. In this paper, we show the development of plasma bubble irregularities over a wide longitudinal extent of 92 degrees (one fourth of the equatorial ionosphere) due to the dusk time penetration of electric fields into low latitudes. In some cases where the AE-index does not represent any sudden increase, the dSymH/dt seems to be the better index to determine the time of penetration.

1. Introduction

The effect of geomagnetic storms on the equatorial and low latitude ionosphere in the context of development/inhibition of ESF is an important space weather concern and has drawn great attention during the recent past in view of its applications in the satellite based communication and navigational systems. Recently, Basu Su et al [2001] and Basu S et al [2001, 2005, 2007] have reported that there is an abrupt onset of VHF and L-band scintillations due to the prompt penetration of high latitude electric fields (eastward) into low latitudes, in the longitude sector for which the early evening period corresponds to the time of rapid decrease (50 nT/hr or larger) in the Sym-H/Dst index. An empirical model developed by Fejer and Scherliess [1997] also shows disturbance upward vertical drifts during the post-sunset hours due to prompt penetration effects, the pattern which is also confirmed recently by case studies [Maritinis et al. 2005 and references therein]. Huang et al [2005, 2006] have shown the penetration of electric field into the low latitude ionosphere without shielding continued for many hours as long as the magnetic activity continues to intensify and the IMF Bz remains southward. Therefore, it is plausible to expect, if the main phase of the storm lasts for many hours, then the local dusk period that coincides with the prompt penetration phase occurs over a wide longitudinal extent. Hence, the equatorial ionosphere over a wide longitudinal sector is susceptible for the development of ESF irregularities. In this paper, we show the presence of plasma bubble irregularities over a longitudinal width of 92 degrees (one fourth of the Earth's equatorial ionosphere) due to the penetration of eastward electric fields into equatorial latitudes during the entire main phase of the geomagnetic storm.

2. Data

The details of data used in this study are summarized in the following Table

Station	Geographic Co-ordinates Latitude	Longitude	Dip Latitude	Parameter(s)
Ionospheric sounders				
Trivandrum	8.5°N	76.5°E	0.7°N	h'F, Spread-F
SHAR	13.7°N	80.2°E	6.9°N	h'F, Spread-F
Hainan Is	19.4°N	109°E	13.4°N	h'F, Spread-F
Kwajalein Is	9.4°N	167°E	4.2°N	h'F, Spread-F
VHF and L-band scintillations				
Waltair	17.7°N	83.3°E	11.6°N	S4 – Index
Magnetometers				
Tirunelveli	8.7°N	77.7°N	0.9°N	EEJ Strength (ΔH_{T-A})
Alibagh	18.5°N	72.9°E	12.9°N	
GPS Receivers				
Trivandrum	8.5°N	76.5°E	0.7°N	TEC
Bhopal	23.17°N	77.27°E	18.5°N	TEC
Planar Longmuir Probe				
on board of CHAMP satellite				Electron density

3. Occurrence of ESF during geomagnetic storms

3.1 Storm of Feb 11-12, 2004

On 11th February 2004, the interplanetary magnetic field, IMF Bz turned southward around 0600 hrs UT and showed a strong negative component of -12 nT at 1040 hrs UT as may be seen from Fig. 2(a). During the same time, the AE-Index exhibits a sudden increase reaching a value of 900 nT [Fig. 2(b)]. A moderate geomagnetic storm has occurred, as the Sym-H Index [Fig. 2(c)] started decreasing from 1050 hrs UT gradually reaching a minimum value of -107 nT around 1740 hrs UT. The dSymH/dt exhibits a negative excursion of -7 nT/10 min at 1240 hrs UT and the IMF Bz is also southward during the same period.

The virtual height (*h'F*) over a low latitude station Hainan Is (19.4°N, 109°E, dip 13.4°N) *h'F* exhibits a pronounced increase around 1245 hrs UT, which corresponds to local post sunset hours (2001 hrs LT) over that station. This is precisely the time when that dSymH/dt exhibited a sharp decrease [Fig.2(d)]. The near simultaneity of sharp decrease in Sym-H Index and increase in *h'F* suggests that there is a prompt penetration of eastward electric fields into low latitudes around local dusk hours that augmented the normal F-region dynamo induced pre-reversal enhancement (*PRE*), thereby lifting the F-layer to higher altitudes and creating conditions favorable for the development of ESF. As such, an intense spread-F has been observed from the next ionogram, i.e., from 1300 hrs UT, which has continued to occur till 0230 hrs UT of the next morning. It may also be seen from Fig.2(f), during that evening the *h'F* over Trivandrum has also increased significantly from its quiet day value and reached to a maximum value of 400 km at 1450 hrs UT (≈ 2000 hrs LT). Subsequently, intense spread-F was observed, which also continued to occur till the pre-dawn hours of the next day.

3.2 Storm of Mar 9-12th 2004

A recurring moderate geomagnetic storm has occurred during 9-12th March 2004 which has similar manifestations over Indian equatorial ionosphere, and is presented in Fig. 2. Following the southward turning of IMF Bz [Fig. 6(a)], the AE-Index [Fig. 6(b)] started increasing from 1500 hrs LT reaching a value of 1200 nT around 2200 hrs LT. A moderate geomagnetic storm has occurred as the Sym-H index started decreasing from 1648 LT of 9th March 2004 reaching a minimum value of –75 nT at 2335 LT as seen from Fig. 6(c). The dSymH/dt [Fig. 6(d)] exhibits a negative excursion of -7 nT/10 min around 1930 hrs LT. The *h'F* at the equatorial station, Trivandrum [Fig. 6(f)] shows a marked increase from its quiet day value during the same period and intense Spread-F echoes were observed from 1945 LT, which continued up to 0530 LT of the next morning. Also, a nearly simultaneous onset of VHF and L-band [Fig. 6(g)] scintillations were observed from 1958 LT over Waltair. The VHF scintillations continued to occur up to 0300 LT of the next morning and the L-band scintillations also continued to occur for longer duration extending to the post-midnight hours which slowly decayed by about 0130 LT. Further, due to prolonged geomagnetic activity of this storm, i.e., up to the noon hours of the next day (10th March 2004), a strong reversal in the ElectroJet current is observed at the equator as may be seen from Fig. 6(e). During this evening (10th March 2004), the post sunset enhancement in the *h'F* at the equator is suppressed [Fig. 6(f)] and the occurrence of Spread-F and scintillations is inhibited [Fig. 6(g)].

3.3 Storm of May 15-16th 2005

An intense geomagnetic storm has occurred during 15-16th May 2005, the SC phase of which has occurred at 0230 hrs UT of 15th May. The main phase started around 0620 hrs UT and the Sym-H reached to a minimum value of -315 nT around 0825 hrs UT.

3.3.1 Response over Indian sector

Over Indian longitudinal sector, the main phase (rapid decrease in SymH) of the storm has occurred around local noon hours. Unfortunately, the *h'F* data of the equatorial station Trivandrum is not available on that day. Hence, the *h'F* data of a nearby low latitude station on the northern side of the equator, SHAR (13.7°N, 80.2°E, dip 6.9°N) is considered and plotted as a function of local time along with Sym-H index and presented in Fig.3. The thin line with scatter bars indicates the monthly mean quiet day variation of the h'F over SHAR for the month of May 2005. It can be seen from this figure that the h'F did not show any significant enhancement during the post sunset hours and no spread-F was observed during that evening. The VHF and L-band scintillation observations over Waltair also did not show any post-sunset scintillations during the same evening. However, during the post midnight hours, the h'F shows quite significant increase between 0200 to 0400 hrs LT, possibly due to the delayed disturbance dynamo electric fields, as the polarity of these electric fields are normally eastward during the post-midnight to early dawn hours [Blanc and Richmond. 1980; Scherliess and Fejer. 1977]. Subsequently, range type spread-F echoes were observed at SHAR between 0230 hrs to 0515 hrs LT as indicated in the figure.

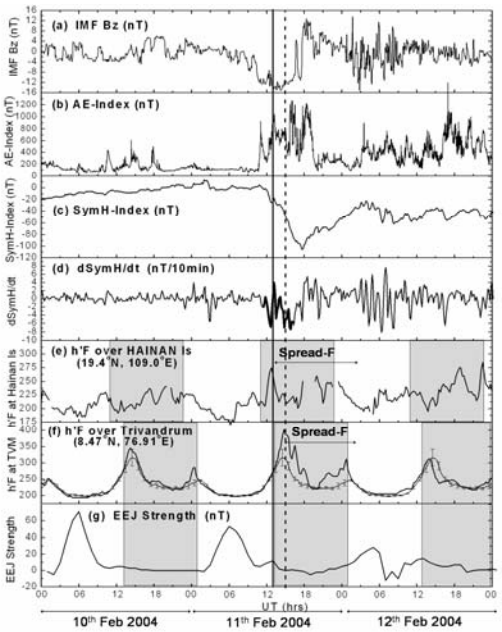

Fig.1: The response of equatorial and low latitude ionosphere to the geomagnetic storm of 10-12th Feb 2004.

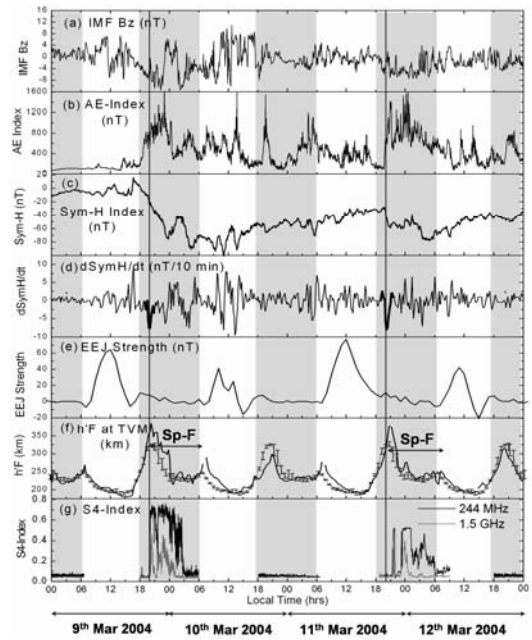

Fig. 2: The response of Indian equatorial and low latitude ionosphere to the geomagnetic storm of 09-12th Mar 2004.

3.3.2 Response over Pacific sector (Kwajalein Is)

The main phase of this storm has coincided with the local dusk hours over a pacific equatorial station Kwajalein Is (9.4°N, 167°E, dip 4.2°N), the local time of which is 11hrs 9min ahead of UT. The dSymH/dt exhibits a sharp negative excursion of -94 nT/10min at 1739 hrs LT. The h'F over this station [Fig.4(e)] has increased almost instantaneously and reached to a maximum value of 495 km at 1909 hrs LT with a maximum rate of increase of about 100 m/s [Fig. 4(f)] at 1809 hrs LT. Subsequently, intense spread-F echoes were observed from next ionogram, i.e., from 1819 hrs LT, which continued to occur beyond the local post-midnight hours (0309 hrs LT).

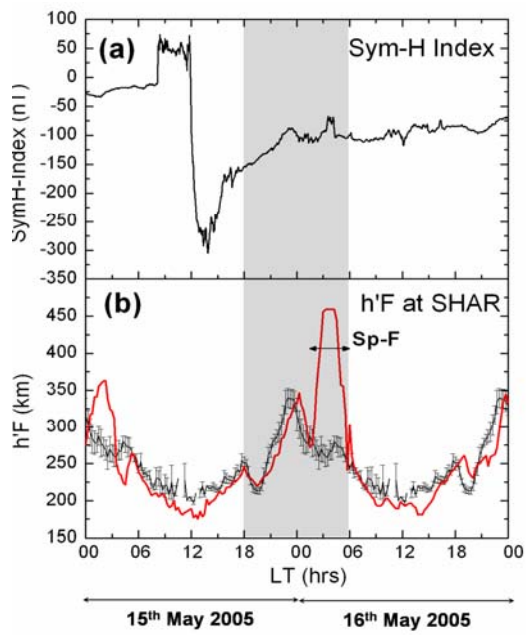

Fig. 3: The response of Indian equatorial and low latitude ionosphere to the geomagnetic storm of 15-16th May 2005.

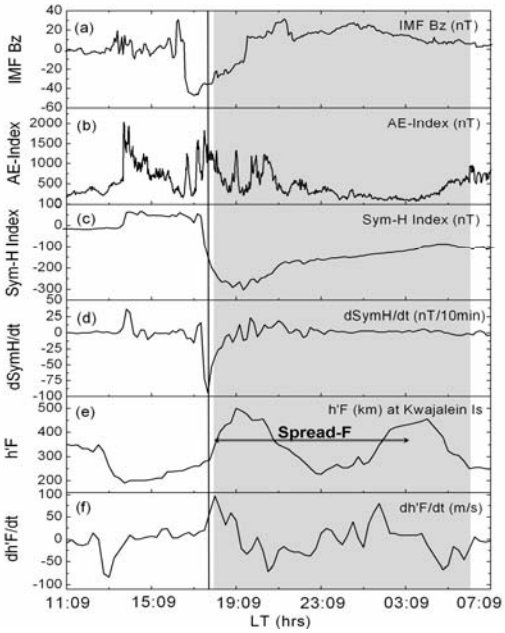

Fig. 4: The response of equatorial and low latitude ionosphere over Kwajalein Is to the geomagnetic storm of 15-16th May 2005.

The top panel in Fig. 5 shows the variation of SymH index as a function of UT, where the arrows A to F indicate the equator crossing times of six successive CHAMP orbits. The latitudinal profile of electron density over 277.48°E longitude [panel A] shows a well developed (asymmetric) Equatorial Ionization Anomaly (EIA). One and half

hours later, the electron density profile over 254.5°E longitude [panel B] shows a clear signature of electron density depletion (the electron density going down to zero level) superimposed on enhanced EIA. The enhancement in EIA and the presence of depletions suggest that the penetration of eastward electric fields into low latitudes has occurred over this longitudinal sector. Panels. C to F in Fig.5, also show the presence of electron density depletions (plasma bubbles) superimposed on EIA at different longitudes. Thus, the total longitudinal width, where the plasma bubbles were observed extends over a longitudinal width of about 92 degrees i.e., from 254.5°E to 162.3°E. In the application point of view, the presence of depletions/bubbles over such a wide longitudinal area could definitely lead to the degradation in the accuracy of position fixing by GPS based navigational systems

3.5 Storm of July 9 – 11th 2005

In Fig. 6 is shown the response of Indian equatorial and low latitude ionosphere to another moderate geomagnetic storm that occurred during 9-11th July 2005. Following the southward turning of IMF Bz, the AE-index started increasing [Fig. 6(b)] gradually from 1200 hrs LT of 9th July and the Sym-H index started decreasing [Fig. 6(c)] almost simultaneously. On the next day, i.e., on 10th July 2005, a strong reversal in ElectroJet current was observed [Fig. 6(e)] during the afternoon hours. This can be inferred as due to the presence of strong westward electric fields of disturbance dynamo origin because of continued geomagnetic activity during morning to noon hours. The TEC measured by GPS receivers located at Indian equatorial station Trivandrum also shows much higher values (about 10-12 TEC units) than the TEC at the anomaly crest station, Bhopal during the most of the daytime hours of 10th July 2005. Strong reversal in Equatorial ElectroJet current [Fig. 6(e)] and the total suppression of EIAduring the afternoon hours indicates the presence strong westward electric fields of ionospheric disturbance dynamo (IDD) origin due to continued geomagnetic activity for more than 24 hours from the past. However, during this evening the rate of change of Sym-H index suddenly decreased to a value of -30 nT/10 min at 1910 hrs LT as may be seen from Figs. 6(c) and 6(d). At the same time, the virtual height of the F-layer (*h'F*) over Trivandrum showed a rapid increase [Fig. 6(f)] indicating the prompt penetration of eastward electric fields into equatorial latitudes. Subsequently, intense spread-F over Trivandrum and scintillations at VHF (244 MHz) and L-band (1.5 GHz) frequencies over Waltair were observed as can be seen from Figs.6(f) and 6(g). It should be emphasized here, that the prompt penetration of strong eastward electric fields corresponding to rapid decrease in Sym-H index prevailed over the strong ambient westward electric fields of disturbance dynamo origin, and augmented the normal PRE thereby creating favorable conditions for the development of ESF irregularities.

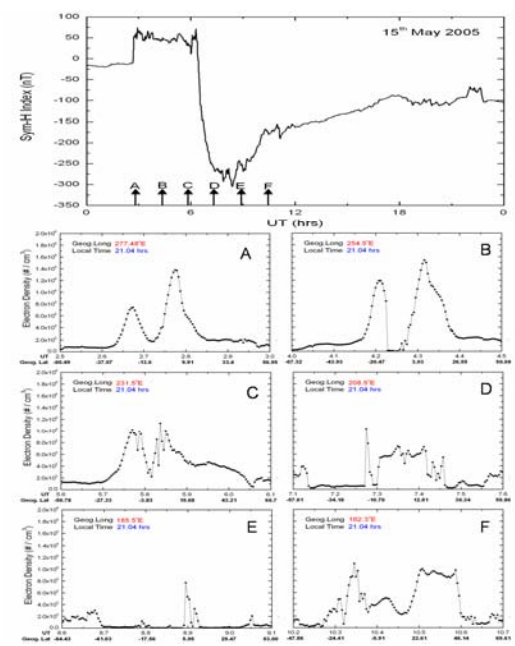

Fig.5: A series of latitudinal profiles of electron density measured by Planar Longmuir Probe (PLP) onboard CHAMP satellite during its successive orbits on 15th May 2005.

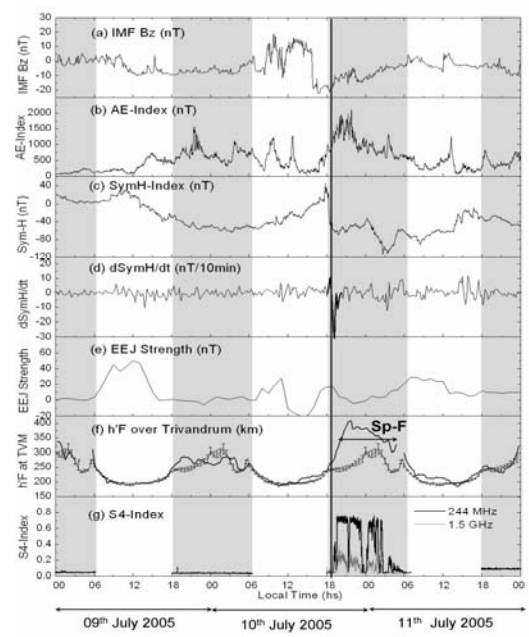

Fig. 6:The response of Indian equatorial and low latitude ionosphere to the geomagnetic storm of 09-11th July 2005.