Recurrent geomagnetic storms and equinoctial ionospheric F-region in the low magnetic latitude: a case study

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Abstract. This paper analyses a case study of 27-day recurrent geomagnetic storms (RGSs) and the ionospheric F-region over Peruvian, Ascension Island, and Port Stanley during vernal equinox in 2006. The RGSs are categorized into High-Intensity Long-Duration Continuous AE Activity (HILDCAA) and non-HILDCAA cases. The solar wind plasma, Ionosonde, and magnetometer data are used. The results reveal that in both cases prompt penetration electric field and disturbance dynamo electric field (DDEF) control the ionospheric plasma and affect night time spread F (SF) that disturbs the HF-radio communications in equatorial and southern crest of equatorial ionization anomaly (EIA). The SF at magnetic equator is delayed, more predominant, and last longer than at the southern EIA. DDEFs and thermospheric winds persist in the recovery phase of storm with stronger ones can inhibit the SF.

1. Introduction

Recurrent geomagnetic storms (RGSs) are the most prominent storms during the declining and rising phases of the solar sunspot cycle. RGSs emerge from interaction of the magnetosphere with a complex stream structure that corotates with the Sun of a period ~27 days. The corotating structures comprise of high speed solar wind streams (HSSs) and corotating interaction regions (CIRs). When the expanding HSSs from coronal holes interact with slow-speed up streams, CIRs are formed near the ecliptic plane with intense magnetic field and plasma. CIRs and HSSs are responsible for weak-to-moderate geomagnetic activity/disturbance at Earth. Negative interplanetary magnetic field Bz components (IMF Bz) of large-amplitude Alfven waves within some HSSs lead to "High-Intensity Long-Duration Continuous AE Activity" or HILDCAA that can last for a few to many days [1].

During daytime of quiet magnetic periods, there are intense eastward ionospheric electric fields flow along the magnetic equator called equatorial electrojet (EEJ) created by the ionospheric dynamo process. The eastward electric field and the north–south geomagnetic field produce the uplift of plasma in E region to F region by vertical **E**×**B** drift. Then the plasma diffuses downward along the geomagnetic field lines into both hemispheres, producing the equatorial ionization anomaly (EIA). EIA is characterized by a broad trough in the F-region electron density at the magnetic equator and two crests of enhanced electron density at about ±15° magnetic latitudes. Low magnetic latitudes, between $\pm 20^{o}$ magnetic latitudes, are well-defined regions where a night time spread F (SF) signature on ionograms is indicated, known as equatorial SF (ESF). These irregularities induce rapid changes in both the amplitude and phase of radio signals such as high frequency radio wave (2.31–25.82 MHz) passion through them, generating scintillations that seriously degrade trans-ionospheric radio communications. The generalized Rayleigh-Taylor (GRT) instability is a basic mechanism in forming ESF [2]. Even though the postsunset rise of the equatorial F layer is well reproduced climatologically with the ESF [3], the day-to-day variability of ESF remains a long-standing problem.

Effects of RGSs during solar minimum on spatial and temporal variations of the critical values of F-layer have not been intensively investigated. Sobral *et al*. [4] found significant coupling processes between the auroral zone and the equatorial ionosphere and pointed that the effects on ESF development processes are not clear and systematic during the HILDCAA events. Therefore, it is imperative to investigate variations of the F-layer during RGSs from a number of locations and tools in more case studies. This study covers equinoctial months in 2006, solar minimum conditions.

2. Data Presentation

RGSs were characterized using 1-minute-averaged solar wind plasma parameters shifted to the Earth's bow shock nose already and geomagnetic indices, symH (Dst) and auroral electrojet (AE) as obtained from OMNI database. The 15-min ionograms and digisonde in 2006 were obtained from digital ionogram database (DIDBase) [5] but removed some erratic points of large deviation value comparing to its nearby, which is not affect the overall results. We also employed dH data from the difference of horizontal (*H*) geomagnetic fields measured at pairs of stations in Peru, Jicamarca and Piura as listed in table 1. The subtraction can eliminate both the global Sq current system and the Dst ring current component in *H*, that is only related to the EEJ.

Table 1. Geographic and geomagnetic coordinates of the magnetometers and ionosondes.

Station	Geographic (degree)		Dip angle	Local time
	Latitude	Longitude	(degree)	(hr)
Jicamarca	11.9°S	76.8°W	0.8°N	LT=UT-5.12
Piura	5.20°S	80.0°W	6.8°N	LT=UT-5.12
Ascension Island	7.95°S	13.4°W	16°S	LT=UT-0.90
Port Stanley	51.6°S	56.9°W	40.6°S	LT=UT-3.80

3. Observational Results and Discussion

Figure 1 shows moderate geomagnetic storms that recurred as RGSs: Event 1 (9-24 March, 2006 (DOY 68-83)) and Event 2 (6-17April 2006 (DOY 96-107)) during vernal equinox. Note each storm was classified into two cases: non-HILDCAA (no.1) and HILDCAA (no.2) as shown in figure 1. HILDCAA is defined as AE index not below 200 nT, peak over 1,000 nT, and outside the main phase.

3.1. Geomagnetic Activity

From figure 1, characteristics of the RGSs are abrupt increase in the solar wind dynamic pressure (P), increase in the solar wind speed (V) in the following days, and rapid north-south fluctuations in Bz in association with the HILDCAA events. In the main phase, the symH index was lower in Event 1, indicating weaker storms. The AE values of non-HILDCAA and HILDCAA types were larger for Event 2, suggesting a higher energy input into high latitude regions.

3.2. Ionospheric Responses

As shown in figure 1, the ionospheric responses to both cases indicated that virtual height of F-layer base (h’F) and height of the F-layer peak (hmF2) were lifted during the main phase when the eastward prompt penetration electric field (PPEF) was presented (enhanced EEJ). At equatorial station Jicamarca, F-region critical frequency (foF2) tended to increase during the storm times that suppressed EIA, whereas at the crest of EIA station Ascension Island showed the opposite sense for both cases. This indicates to westward disturbance dynamo electric field (DDEF) from Joule heating. The SF occurrences (green boxes in panel (a) and (b) in figure 1) at Jicamarca on the quiet days lasted from pre-to-post midnight about 8-10 hrs, starting from 2300 UT (1800 LT), while on storm days they lasted only about 1-4.5 hrs. SF delayed ~3 hrs in DOY 104 assumedly caused by strong DDEFs with

AE > 1,400 nT. The SF occurrences at Ascension Island on the quiet days lasted from pre-to-post midnight ~4 hrs, while on storm days they lasted in longer times about 6 hrs, but sometimes SF disappeared in Event 2. Note that SF at magnetic equator was more predominant than at the southern EIA, consistent with a previous study [5] since the irregularities are confined below F-region peak. Signatures of DDEFs persisted until the end of storm in both cases. Notice that DDEF was also present in DOY 69-71, 96 and 99 in non-HILDCAA case when AE ≥ 800 nT and EEJ was reduced.

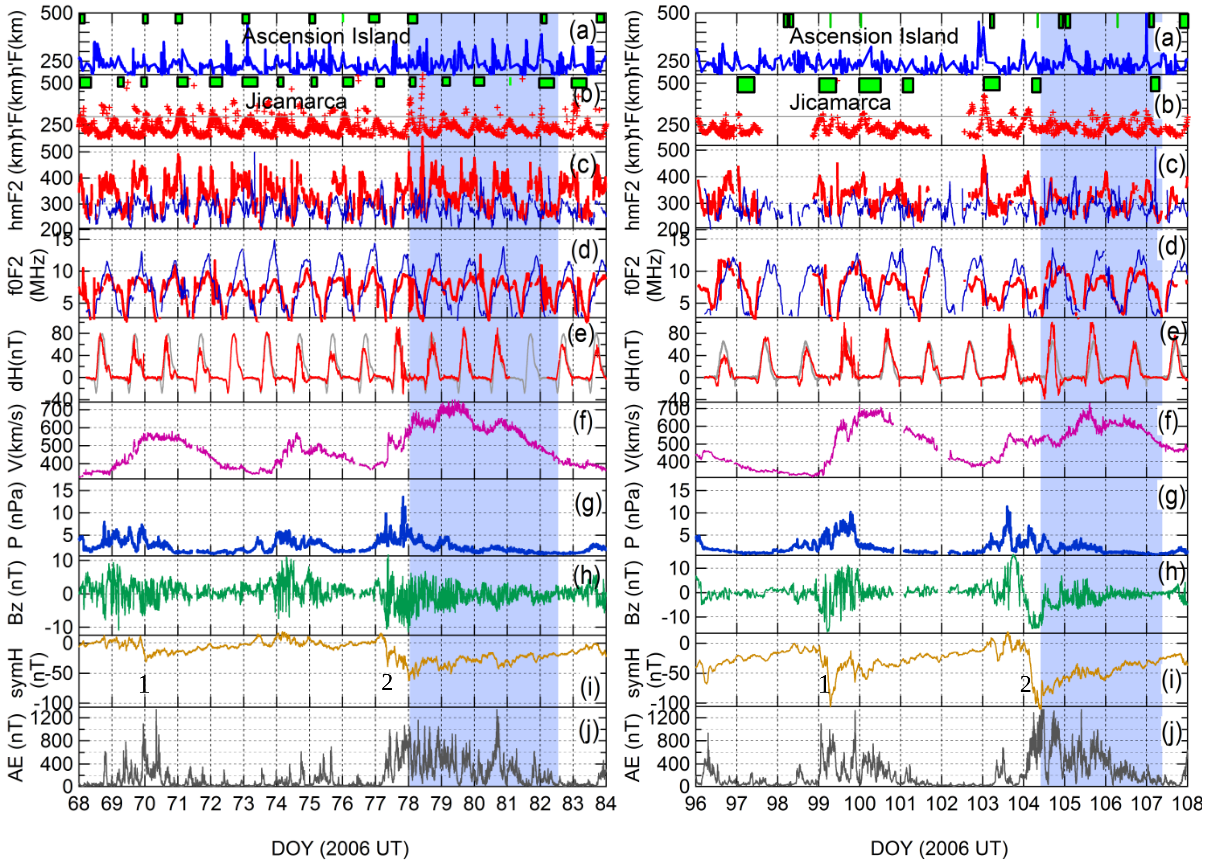

Figure 1. Left: Event 1 and right: Event 2. From top: (a-d) the ionospheric parameters where blue and red lines represent Ascension Island and Jicamarca data, (c) and (d) Ascension Island data are backward shifted to the time of Jicarmarca, (e) dH, (f-h) The solar wind parameters, and (i-j) the geomagnetic indices. Green boxes indicate SF occurrence times and blue shades are HILDCAA.

Magnetospheric PPEFs were evidently present in the main and recovery phases of RGSs as marked by the fluctuations of dH during storm times. We propose that non-HILDCAA and HILDCAA cases are basically affected by DDEFs and also the PPEFs with undershielding and overshielding conditions during CIR-induced geomagnetic storms [6]. When Bz tended southward that corresponds to the undershielding, dH (EEJ) was enhanced as seen in DOY 77, 104, and 105, while the behavior is opposite for the northward Bz. This daytime PPEF superposes on the disturbance winds associated with DDEF over the equatorial latitude during the HILDCAA events. This should cause reduced ionospheric effects in HILDCAA [7]. However, DDEFs inhibited ESF as clearly seen in DOY 104-105. Stronger DDEF in Event 2 was also indicated by the negative dH as a counter EEJ on the days that is consistent with the greater AE index. This study reconfirmed that variations in the height of the F layer and peak electron density changes are variable in responses to geomagnetic storms at the low-latitude ionosphere [8]. The ionospheric plasma in the storm-time equatorial and EIA regions exhibit complex spatial and temporal variations due to combined effects of disturbance electric fields, disturbed wind fields, and neutral composition changes [9].

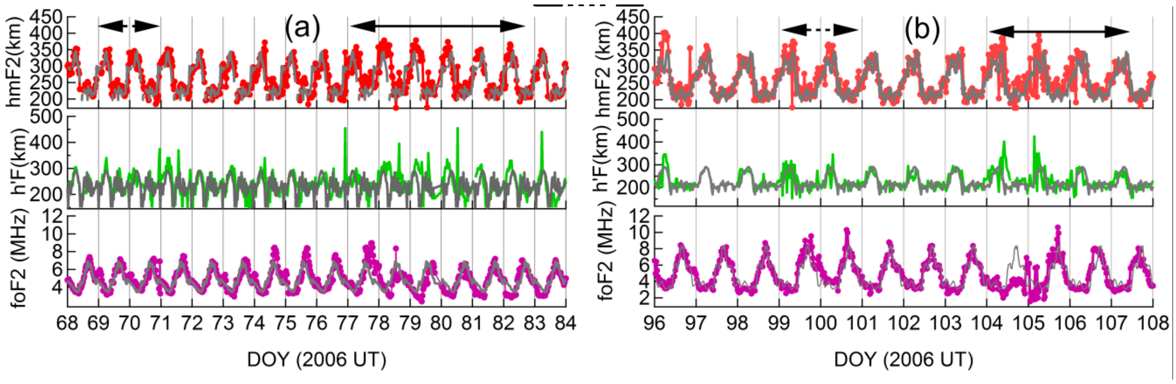

Figure 2. The ionospheric parameters for Port Stanley stations. Grey lines represent the quiet time values. Broken and solid arrows indicate non-HILDCAA and HILDCAA events, respectively.

During high AE activity in HILDCAA events the h'F increase centered around midnight (LT=UT-3.8) over Port Stanley in DOY 78-80, 82, and 105 as seen in figure 2. This suggests that equatorward propagating winds were present in those nights that the F-layers were lifted. During the following postmidnight hours hmF2 and h'F are simultaneously increased till morning time which correspond to the typical pattern of DDEFs [10]. Note that foF2 significantly increased in DOY 77 and 99-100, while decreased in DOY 104 when h'F was very high at ~0520 LT and increased in the following day. Sobral *et al*. [4] found the disturbance winds of aurora origin were present after the prereversal enhancement; hmF2 and h'F were higher during the HILDCAA than on quiet days, where the difference being larger at stations farther away from the equator as also found in this study.

4. Concluding Remarks

Results from a case study of RGSs during vernal equinox in 2006 indicate that variations in h'F, hmF2, and foF2 over three equatorial-low-latitude stations are consistent with variations of EEJ. Non-HILDCAA and HILDCAA are basically affected by DDEFs and also the PPEFs. It is found that strong DDEFs and thermospheric winds can suppress and delay the ESF during RGSs. SF at magnetic equator was more predominant than at the southern EIA. More case studies are required for further understanding in this topic.

Acknowledgements

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