On the Simultaneous Effect of Prompt Penetration Electric Field and Associated Hemispheric Asymmetry in Low Latitude Ionosphere

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ABSTRACT

For the first time, a robust study is performed to characterise sudden enhancements/depressions and associated inter-hemispheric asymmetry in low latitude total electron content (TEC) during main phase (MP) of geomagnetic storms. 7 major and 30 moderate storms over 2000-2018 are examined in detail using multiple long term datasets of ExB drift observations from ISR, Jicamarca, H-component from magnetometers, GIM-VTEC and GPS-TEC observations across the dip equator from the South American sector. Simultaneous high magnitude short lived (1-2 hours) enhancements and depressions in VTEC are found in both hemispheres with differences ranging between -30 to 100 TECU compared to quiet time mean. A notable hemispheric asymmetry is also found irrespective of the season. Sudden rise followed by steep fall in VTEC over both hemispheres concurrent with fluctuations in episodic eastward and westward penetration electric field point out the dominant control of PPEF (Prompt Penetration Electric Field) on low latitudes daytime ionosphere during main phase competing with effect of TADs.

Key words: Equatorial and Low Latitude Ionosphere, Ionospheric Storm, Prompt Penetration Electric Field, Hemispheric Asymmetry, Equatorial Electrodynamics, GPS TEC, GIM VTEC

1. Rigorous study using Multiple Long Term Data

We have considered the simultaneous availability of several data sets including Jicamarca Radar, Magnetometers, and GPS TEC observations along with ACE satellite data and GIM data to analyse all the geomagnetic storms that occurred during 2000-2018 with minimum Dst≤-100 nT, to discern the effect of PPEF on equatorial and low latitude ionosphere over the South American Sector. Thus, a total of 88 storms are considered with 67 storms during 2000-2006 and 21 storms during 2011-2018. Further, only those storms are considered where sudden southward turning of IMF-Bz at beginning of the MP occurs during daytime.

In order to substantiate the role of PPEF in simultaneous occurrence of peaks in both hemispheres and the hemispheric asymmetry in magnitude of VTEC in low latitude ionosphere, 2 example cases, one from winter solstice and another from September equinox are shown below. Starting from interplanetary parameters of IMF-Bz and IEF-Ey, the plots below show the variations transcending to the low latitude ionosphere in terms of sym–H and asym-H index, the equatorial electrojet, vertical ExB drift and the TEC. Artificial neural network based ExB drift are generated and used in place of JULIA or Jicamarca ISR in their absence. Though the GIM VTEC is useful in analysing the latitudinal and hemispheric asymmetry, the GPS VTEC measurements enable demarcation of the exact epoch at which TEC rises and falls. These peaks are well identified in tune with effect of PPEF as can be seen below.

2. Artificial Neural Network based ExB Drift

The role of fluctuating ExB drifts during the main phase is known to be a crucial in determining the restricting of equatorial and low latitude ionosphere. However, direct measurements of this drift are not available from Jicamarca continuously. So, a neural network based ExB drift model is specifically developed using ΔH measurements. In this indigenously developed 3 layer model with 1 hidden layer, 8 inputs are fed which includes F10.7cm Solar flux and its 81-day running average, Kp and Ap indices, local time, year, day of year and ΔH. The network is trained with JULIA data using 14101 training samples from 01 August 2001 to 30 September 2003. The network undergoes supervised learning until a minimum RMS error of ~2.5 m/s is achieved. This network is employed to generate ExB drifts whenever radar drifts are not available for a given storm.

3. Results

Case 1: 20 November 2003

The Halloween storm of 20 November 2003 is shown in figure 1a. 19 November was a quiet day and on 20 November, IMF Bz started fluctuating with a sudden northward shift at 11 UT. At 12 UT, a sudden southward excursion is seen with a brief reversal at 14 UT. IMF Bz continues to remain southward till 19 UT, after which it turns north\ward. Sym H index is observed to have reached the minimum value of ~-500 nT at ~18 UT, after which the storm recovers. ΔH also exhibits multiple fluctuations on the storm day. ANN based vertical ExB drift is found to peak at ~14 and 18 Ut with a maximum value of ~75 m/s. The storm effect on GIM VTEC is deciphered by subtracting the quiet time monthly mean from the storm day values, thus removing any seasonal trend. A clear asymmetry of ~40 TECU is found with the northern hemisphere being more affected by the storm than the southern hemisphere. The effect of sudden reversals of IMF Bz on low latitude ionosphere is highlighted by blue circles in Figure 1b. Sudden simultaneous peaks at all stations are found at ~12 UT, coinciding with the sudden southward turning of IMF Bz. A fall in VTEC at ~14 UT is evident corresponding to the northward turning as indicated by the blue arrow in Figure 1a. This shows the instantaneous effect of penetration electric field on low latitude TEC. Also, as seen in the GIM data, stations in the southern hemisphere recorded lesser perturbation amplitude compared to stations in northern hemisphere.

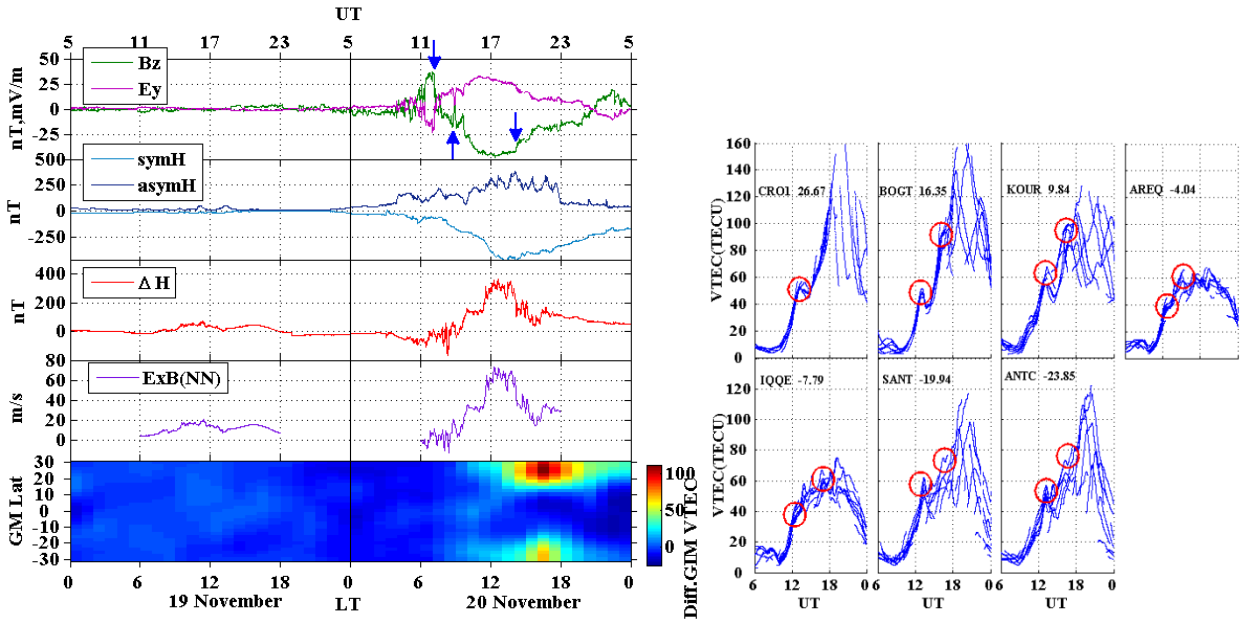

Figure 1a. IMF-Bz and IEF-Ey, SYM-H and ASYM-H indices, ΔH measurements, ANN derived vertical ExB drift over Jicamarca and latitudinal variation of difference GIM VTEC on a quiet day on 19 November 2003 and storm

day of 20 November 2003 are shown from top to bottom panels Blue arrows indicate sudden turning of IMF Bz. 1b. GPS-VTEC observations on 20 November 2003 from 06-24 UT with stations arranged in panels from north to south geomagnetic latitude from left to right. IGS name of station and its geomagnetic latitude is given in each panel. Red circles correspond to simultaneous peaks in VTEC corresponding to blue arrows in 1a.

Case 2: 26 August 2018

A recent geomagnetic storm that occurred on 26 August 2018 is shown in figure 2. As can be seen in Figure 2a., IMF-Bz turned southward on 25 August and continued to remain so for more than 15 hours until it made a sudden northward jerk at ~10 UT on 26 August. Interesting developments follow with 3 consecutive southward excursions of IMF Bz at 12 UT, 16 UT and 20 UT lasting about 2 hours each. Sym-H index shows a minimum most value of ~200 nT on 26 August and ΔH shows multiple fluctuations with a peak of ~50 nT at ~20 UT. In tune with the perturbation electric field, ANN derived vertical ExB drift rises and falls and reaches a maximum of ~25 m/s at 20 UT. In the difference GIM TEC map, the northern hemisphere shows a negative storm effect as opposed to the southern hemisphere with a positive storm effect. The maximum amplitude of asymmetry is ~12 TECU as can be seen at ~18 and 23 UT. GPS TEC from 12 available stations is shown in Figure 2b. Exactly when the IEF Ey turns eastward a simultaneous peak in TEC is observed as shown by the blue circles. Sharp peaks at ~12 UT, 16 UT and 20 UT are clearly observed over all stations along with valleys corresponding to the effect of polarity reversal of the penetration electric field.

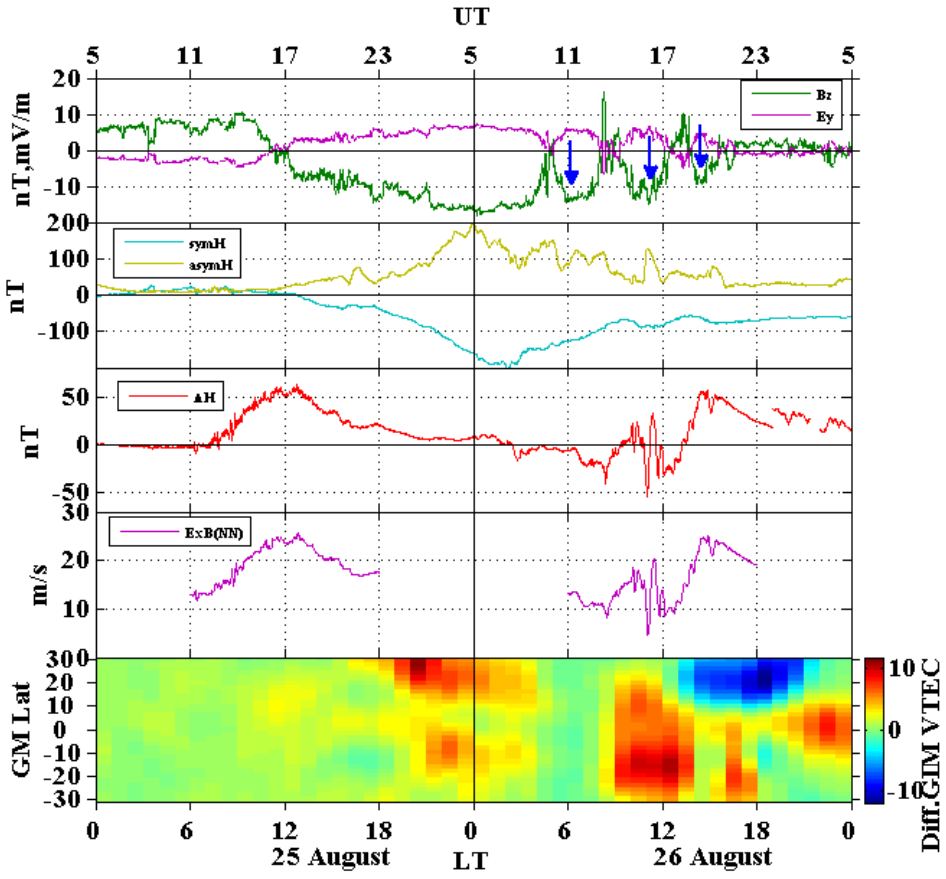

Figure 2a. Same as Figure 1a, but for 26 August 2018.

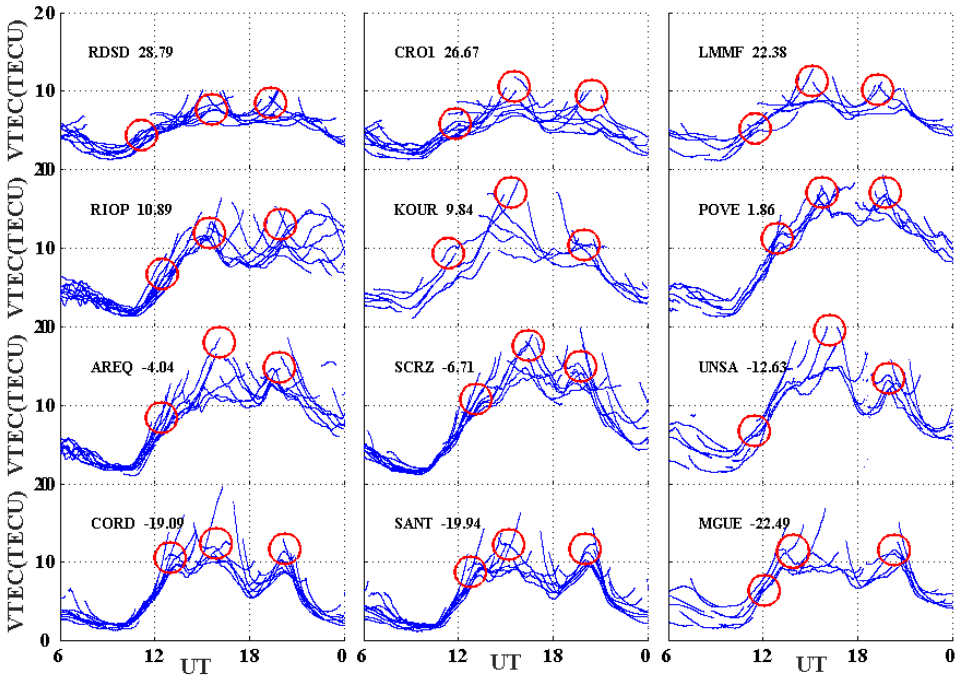

Figure 2b. Same as Figure 1b, but for 26 August 2018

4. Summary

Two cases are picked to represent a rigorous analysis of 37 events spanning 18 years of multiple data to demonstrate the instant effect of penetration electric field and the hemispheric asymmetry associated with it regardless of the season of storm occurrence. Results from major and moderate storm would be presented to showcase the common features of VTEC variation during main phase of most of the storms. This study highlights the role of PPEF that mostly is undermined in presence of large scale TIDs reported in literature recently.

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