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

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Puzzling Issues

Main Phase of Geomagnetic Storms

Response of Equatorial and Low latitudes

Survey of literature

- Structures of sudden enhancements/depressions in daytime low latitude TEC during main phase (MP) of geomagnetic storms have remained unpredictable

- In a particular season, in the presence of a background meridional wind, how does plasma redistribute in the EIA region?
- Is it symmetric in both the hemispheres?

- What is the definitive role of perturbation electric field during daytime?
- Response to suddenly Switching polarity of penetration electric field after a stable configuration?

Instantaneous: The electric field (IEF-Ey)of interplanetary origin can instantaneously penetrate from high latitudes to the dip equator known as prompt penetration electric field (PPEF).

Delayed: Effects of perturbation winds in terms of disturbance dynamo and composition changes reach after more than 8-10 hours to days. Also TADs/TIDs arrive with a definite delay.

Structure of low latitude TEC during Main Phase Remains extremely Puzzling

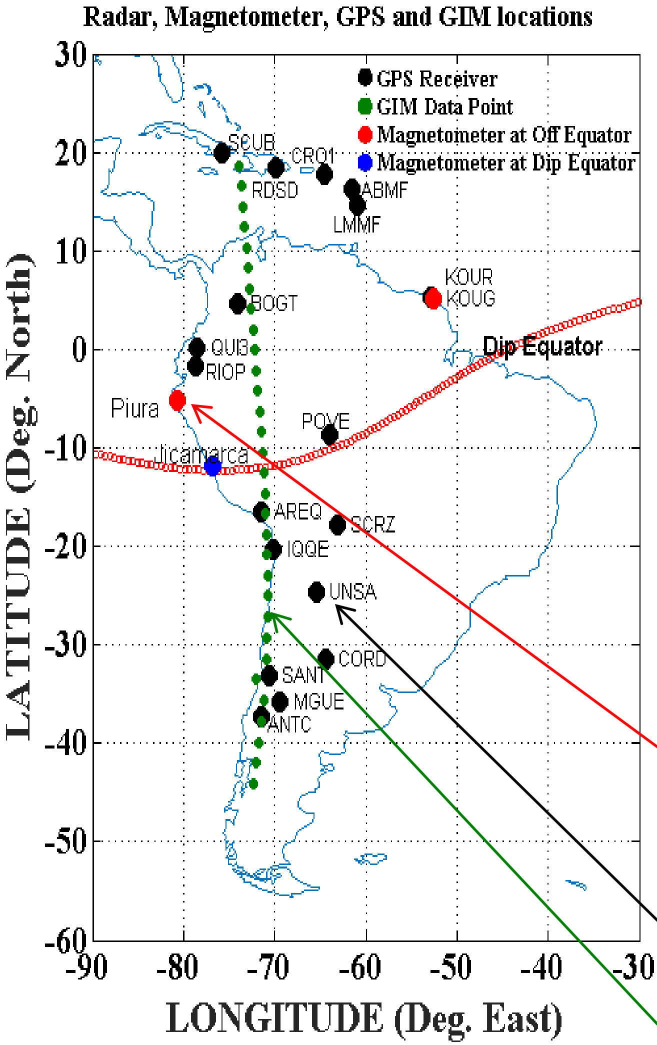
Aim of this study

Resolve the specific tasks of finding the **Daytime**

1. **Structure** of the equatorial and low latitude **TEC** under Impact of **dominant PPEF**
2. Resulting **hemispheric asymmetry** during the main phase

Data and Method

Simultaneous long term observations across the dip equator from the South American sector



From Years 2000 to 2018

1. ACE Observations : IMF Bz and IEF Ey
2. SYM-H and ASYM-H indices
3. Vertical ExB drift from Jicamarca ISR and JULIA - DAYTIME
4. ANN model to derive ExB drift using Delta-H.
5. Delta-H from magnetometers at Jicamarca and Piura/Kourou
6. Observation of GPS – TEC (15-20 sites)
7. Global Ionospheric Maps - VTEC

Artificial Neural Network model for daytime Vertical ExB Drift

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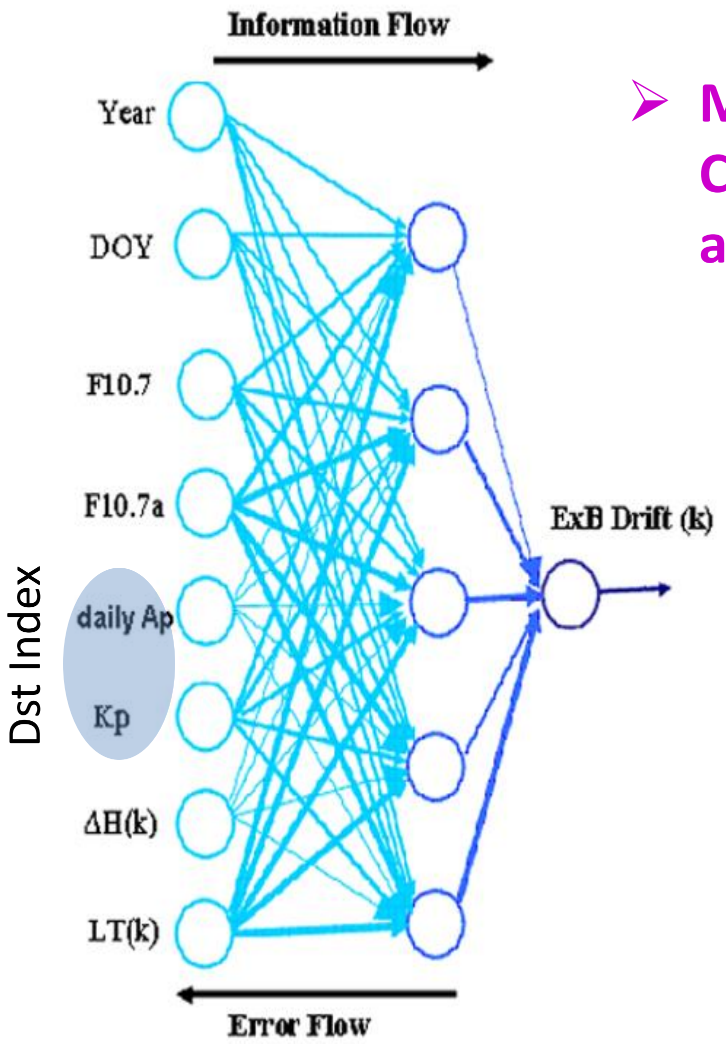
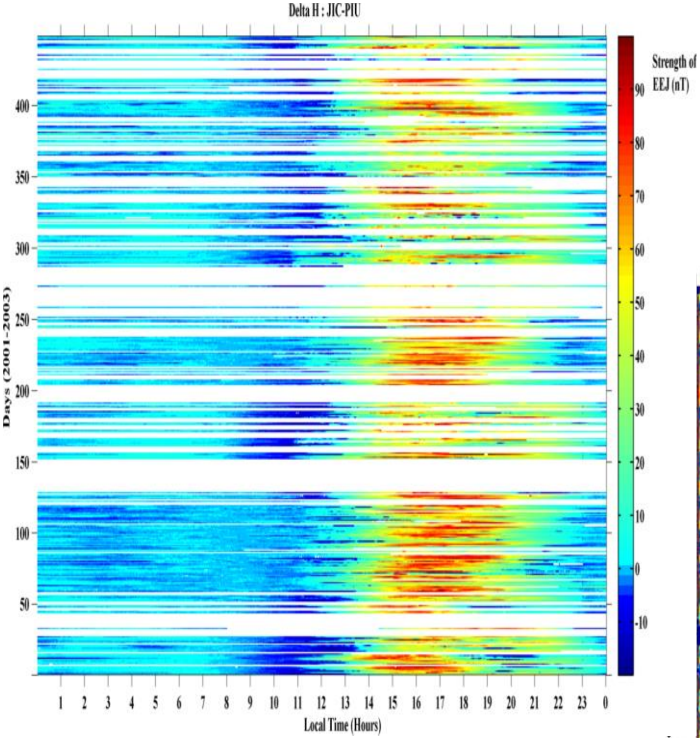


- **Multilayer Perceptron Feed Forward Fully Connected Neural Network with a sigmoid activation function.**
  - ✓ **1070 Days of ΔH (from LISN)**
  - ✓ **ΔH** between January 2001 to December 2003 from **Jicamarca** (11.92^{O}S, 76.87^{O}W) and **Piura** (5.18^{O}S, 80.64^{O}W).
  - ✓ **JULIA vertical ExB drift data of 405 day during 2001 and 2003 used for training**
  - ✓ **Validation using ISR Drift**

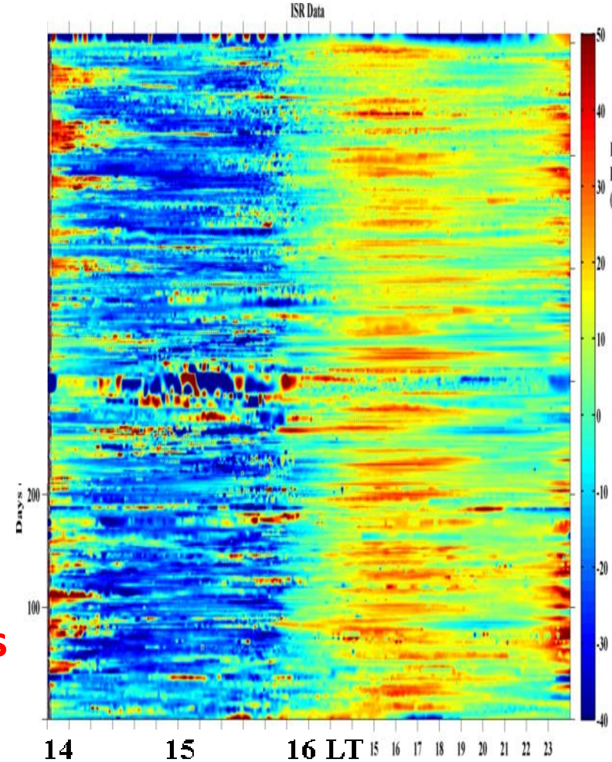
14101 training samples

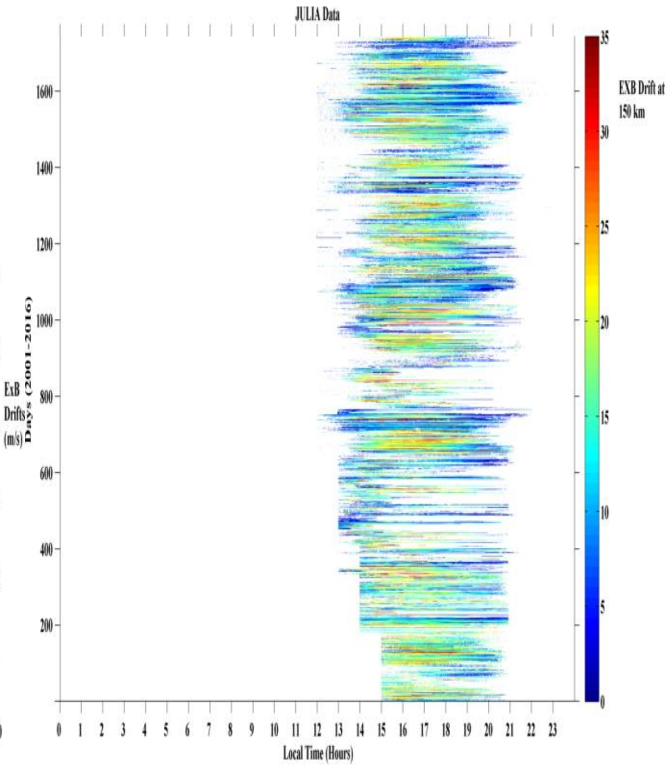
Training : 150-km JULIA Drifts **Validation : ISR Drift**



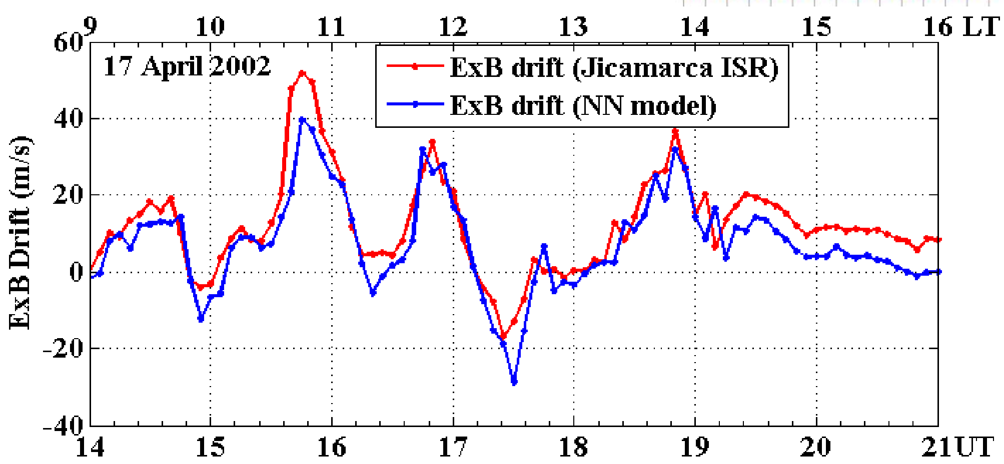
ΔH
- Leveled and quality checked
- Duration = JULIA observations

JICAMARCA ISR Observations of Vertical ExB drift





JULIA Observations of Vertical ExB drift



Validation of model ExB drift on a storm day of 17 April 2002

Min RMSE = 2.3 m/s of ExB drift

Finally an Exhaustive list of all storms is made

Criteria = min. Dst ≤ -100 nT between 2000 and 2018

Selection is narrowed down for

1. Daytime occurrence of sudden southward turning of IMF-Bz at the beginning of MP
2. Simultaneous availability of all data sets

All constraints allowed us to analyze TOTAL

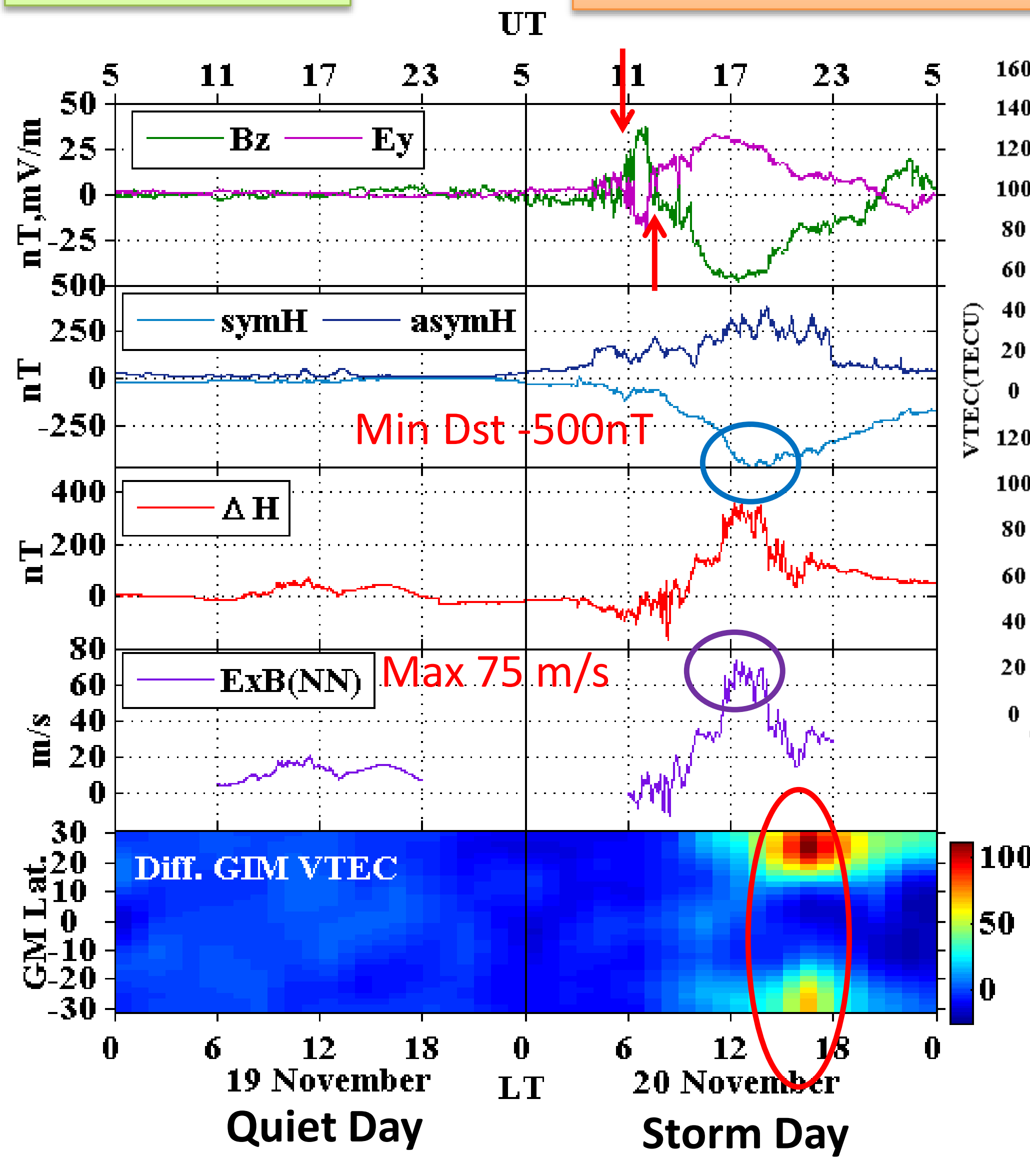
37 geomagnetic storms including

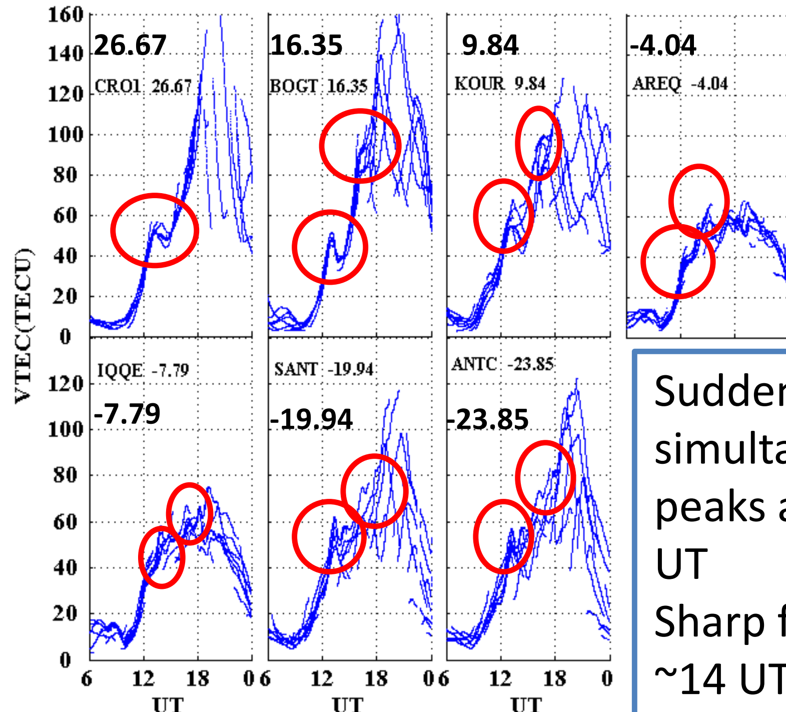
7 major storms (min Dst ≤ -200 nT) +

30 moderate storms (-100 nT ≥ min. Dst ≥ -200 nT)

Results

1. 20 November 2003



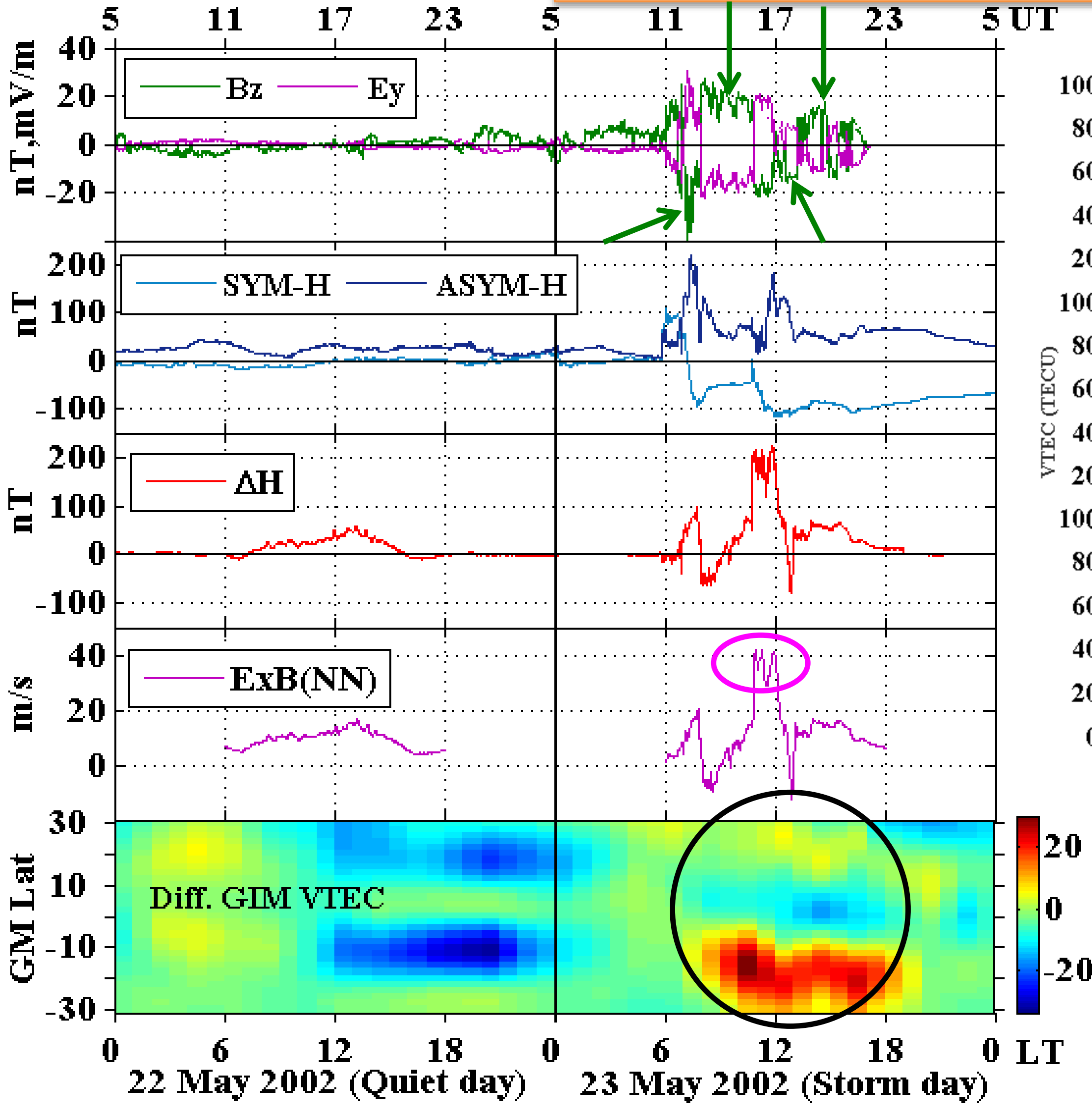


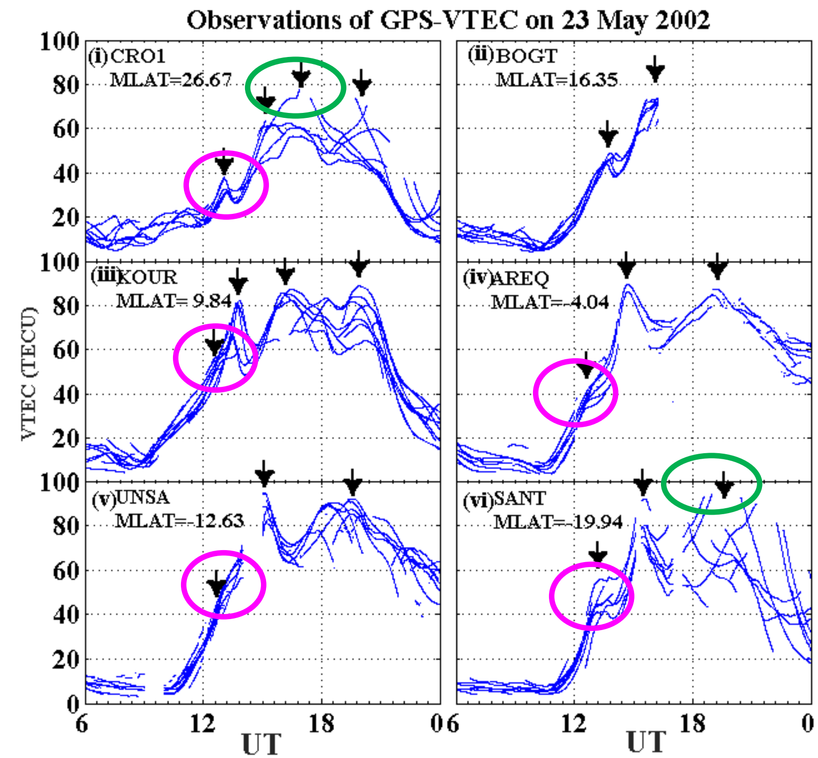
Sudden simultaneous peaks at ~12 UT
Sharp fall at ~14 UT
Peak at 17 UT

- ✓ IMF Bz sudden northward at 11 UT
- ✓ Southward at 12 UT
- ✓ Brief reversal at 14 UT
- ✓ Continues to remain southward
- ✓ Gradually turns northward

Asymmetry of ~40 TECU with northern hemisphere more perturbed than southern hemisphere

2. 23 May 2002





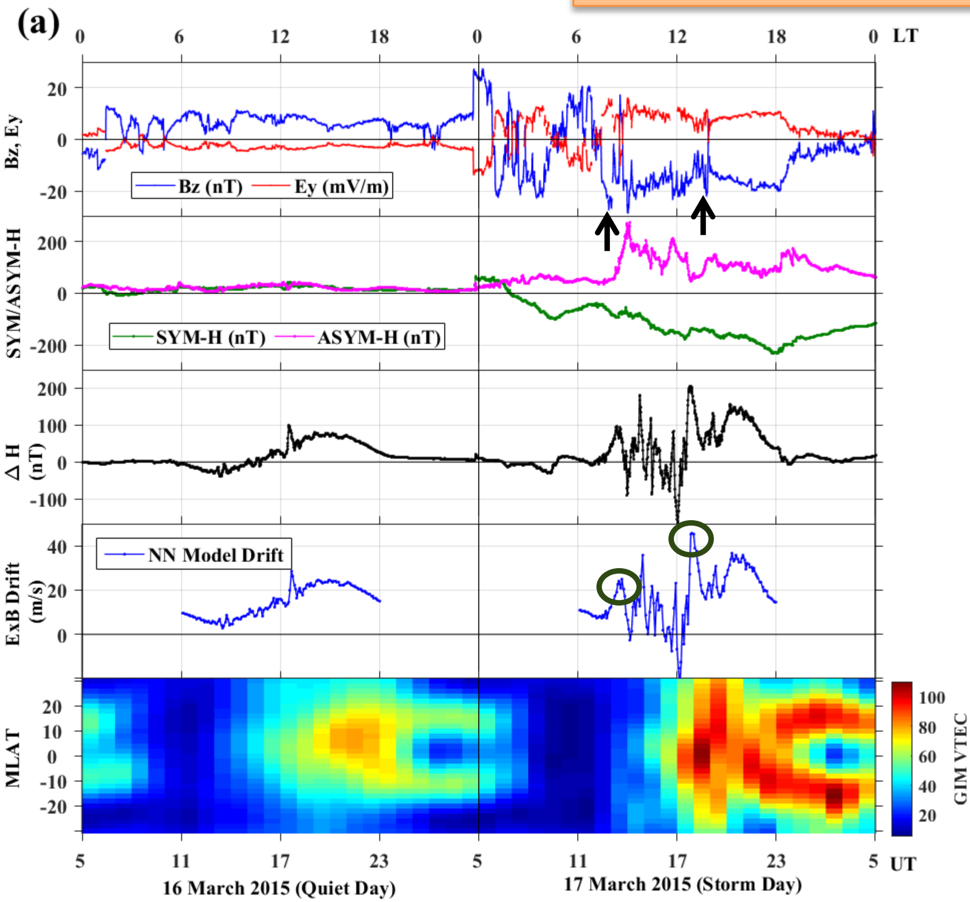
Episodic fluctuations between 12-13 UT, 15-16 UT, 17-18 UT and then between 19-20 UT

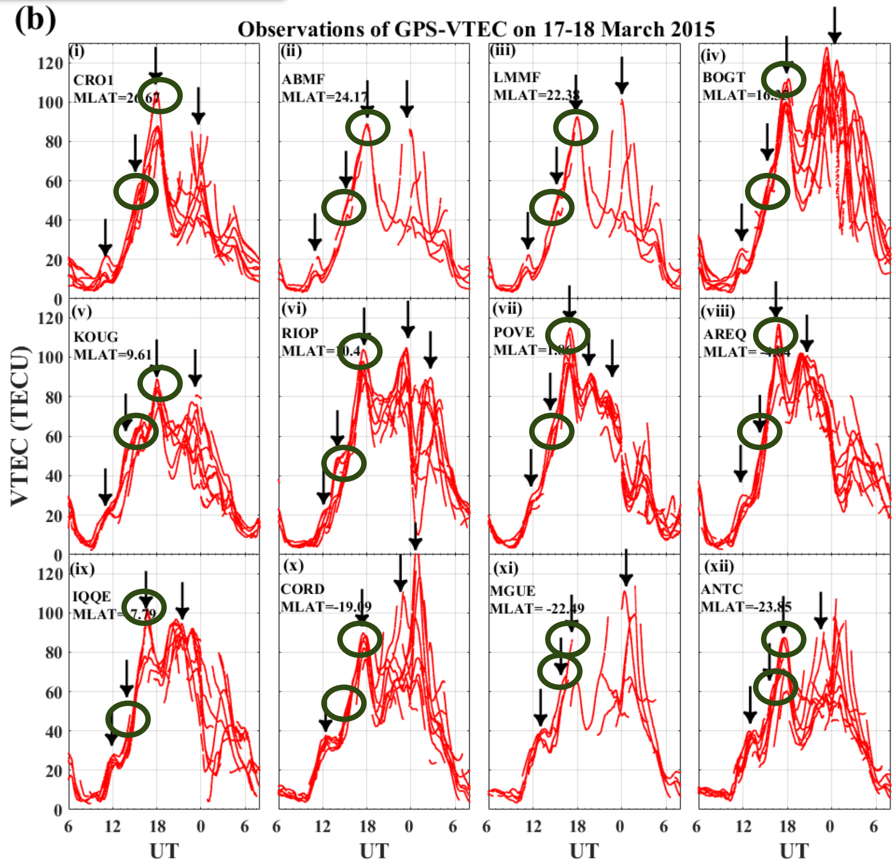
Simultaneous sharp peaks at 13 UT 15-16 UT and 19-20 UT.

Inter hemispheric asymmetry of ~20 TECU where southern hemisphere is more perturbed

Maximum VTEC at different times

3. 17 March 2015

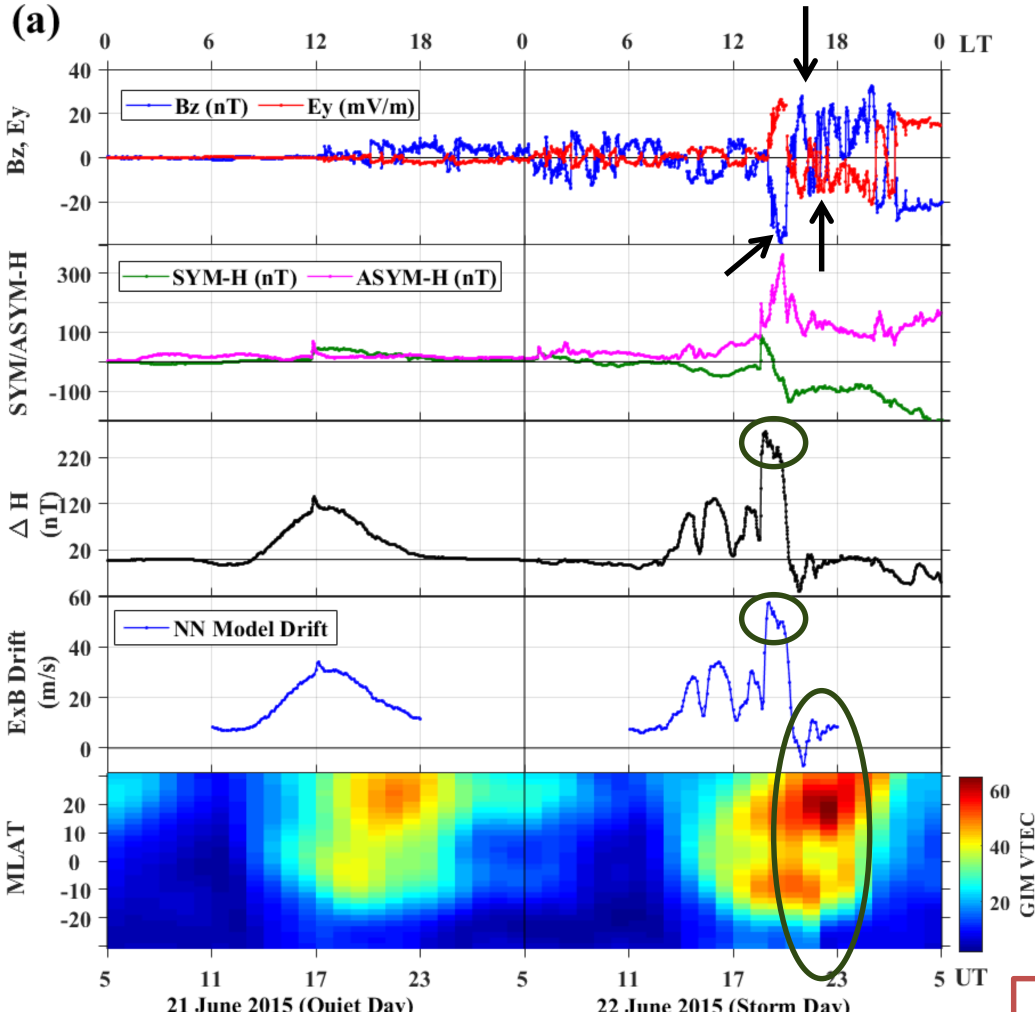


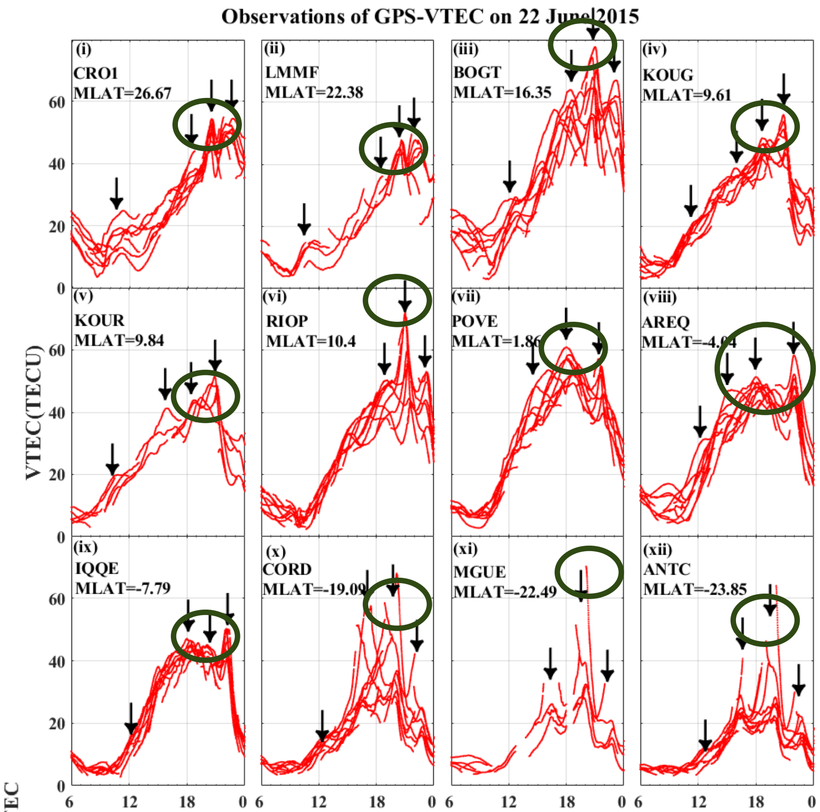


St. Patrick's Day storm of 17 March 2015

- IMF Bz short lived southward excursions at ~1130 UT and 1230 UT
- Continuously southward from 14 UT till 00 UT
- 3 peaks in observed VTEC at around 12, 14 and 17-18 UT simultaneous
- large unusual enhancements between 17-19 UT in the afternoon sector
- unusual presence of crests of EIA between local evening and midnight sector during 23-5 UT.
- hemispheric asymmetry of different scales at different times

4. 22 June 2015



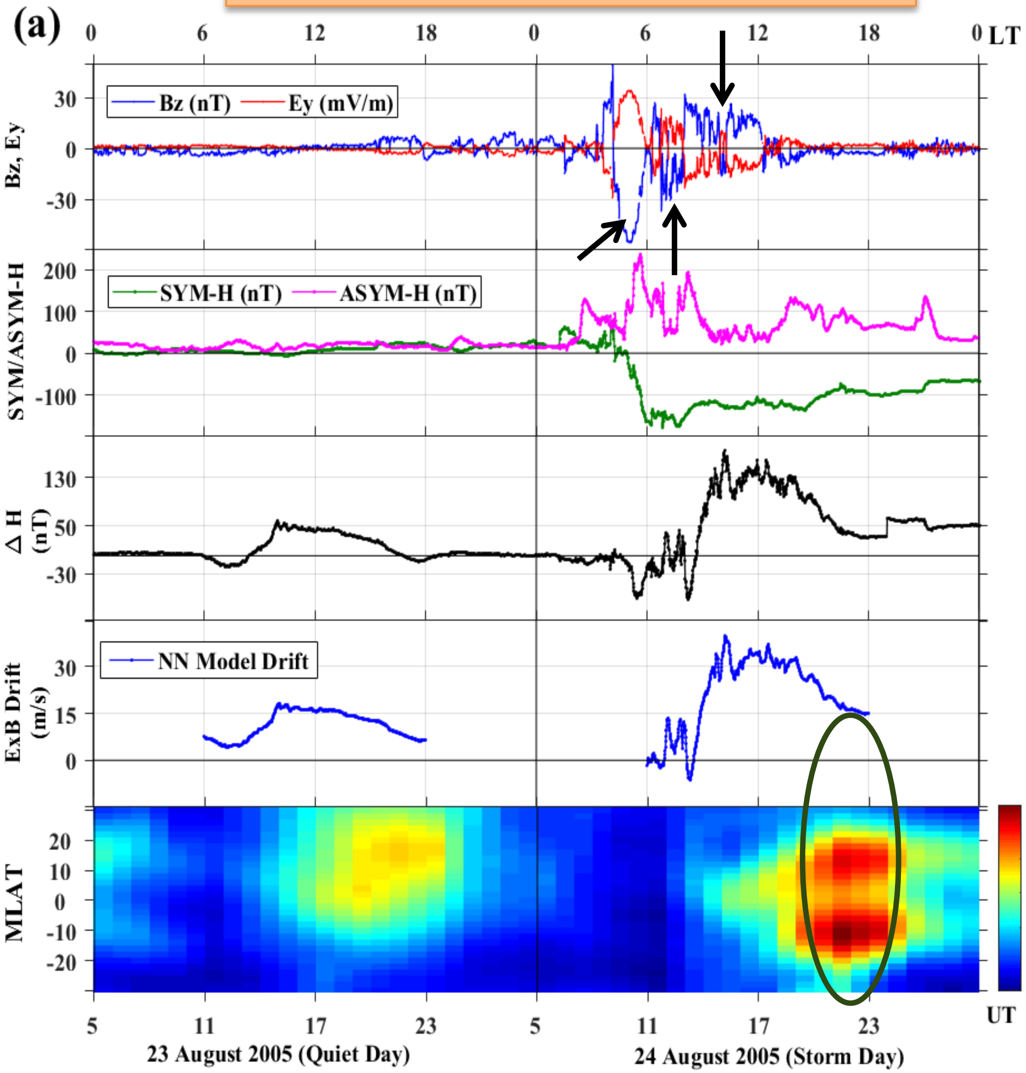


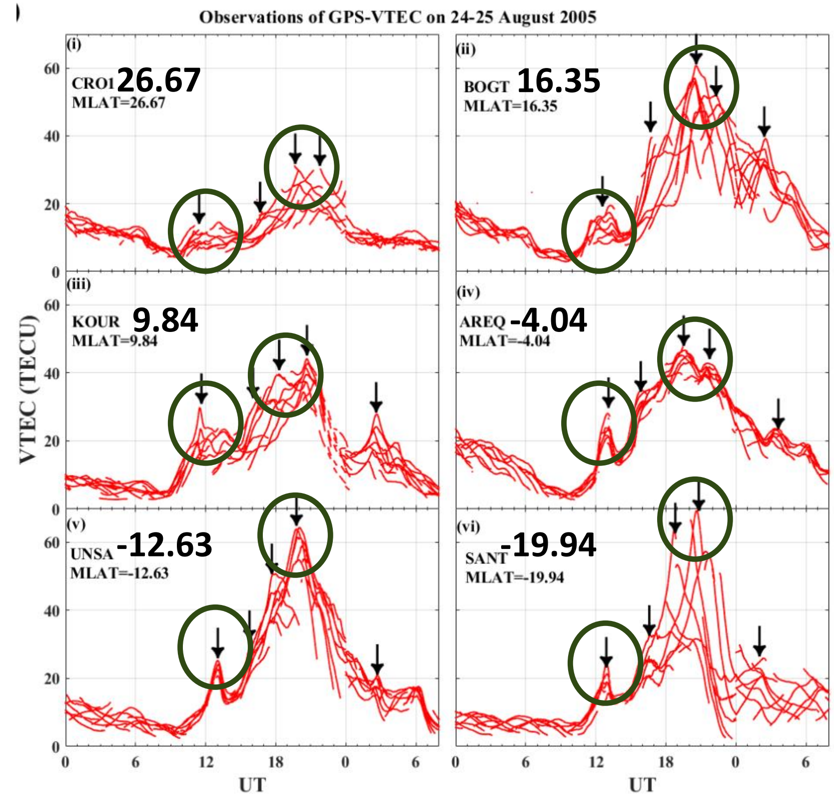
Dominant peaks in VTEC between 16-18 UT, 19-21 UT, 22-23 UT

Episodic fluctuations in IMF-Bz and IEF-Ey reflected in ΔH and vertical ExB drift with peaks at 14.5, 15.5, 18.5 and 19.5 UT and falls at 15, 17, 19 and 20.5 UT

- GIM-VTEC shows large enhancement on both sides of dip equator
- Peak VTEC over the crests of EIA of ~78 TECU and 68 TECU simultaneously occur at 21 UT

5. 24 August 2005



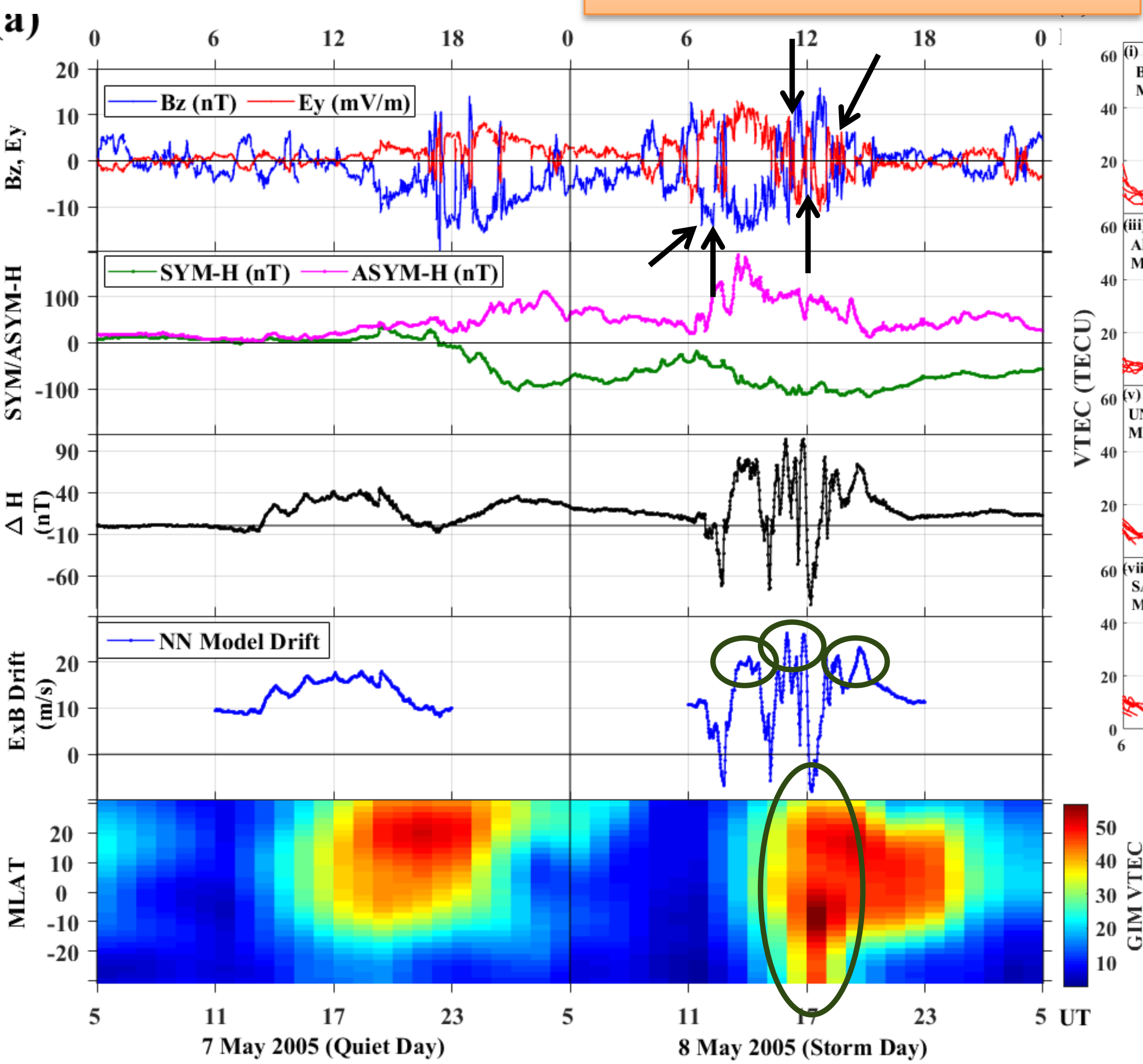


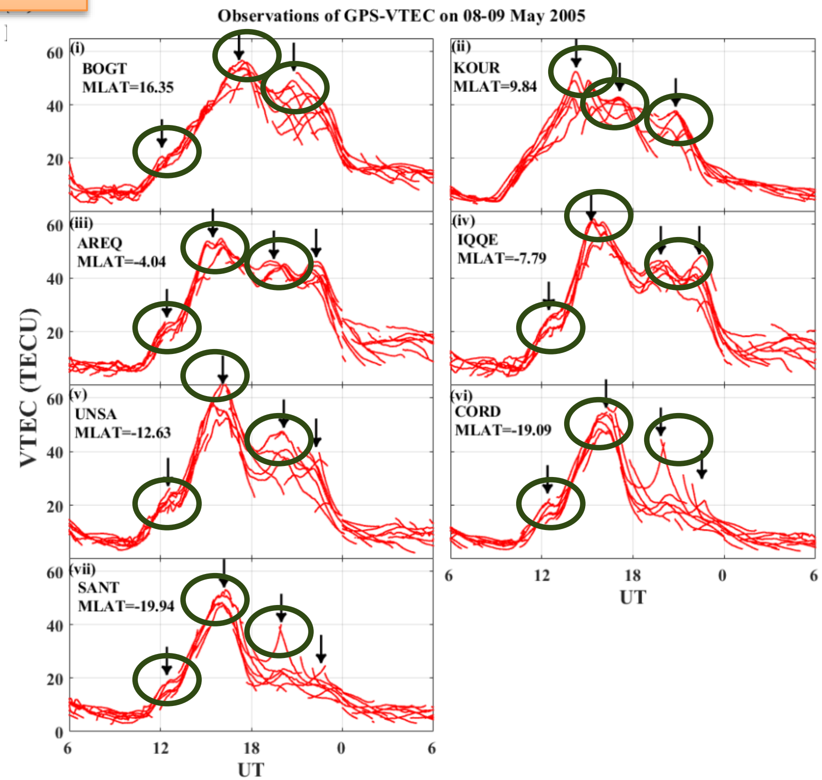
IMF-Bz southward between 9-11 UT
sharp northward after 11 UT
southward between 11.5 UT-13 UT
prolonged northward fluctuations till 17 UT

maximum VTEC up to 70 TECU in southern hemisphere and less than 60 TECU over northern hemisphere

sharp peaks simultaneously in VTEC between 11-13 UT, 16 -17 UT, 18-19 UT, 20-21 UT and 3 UT

6. 8 May 2005



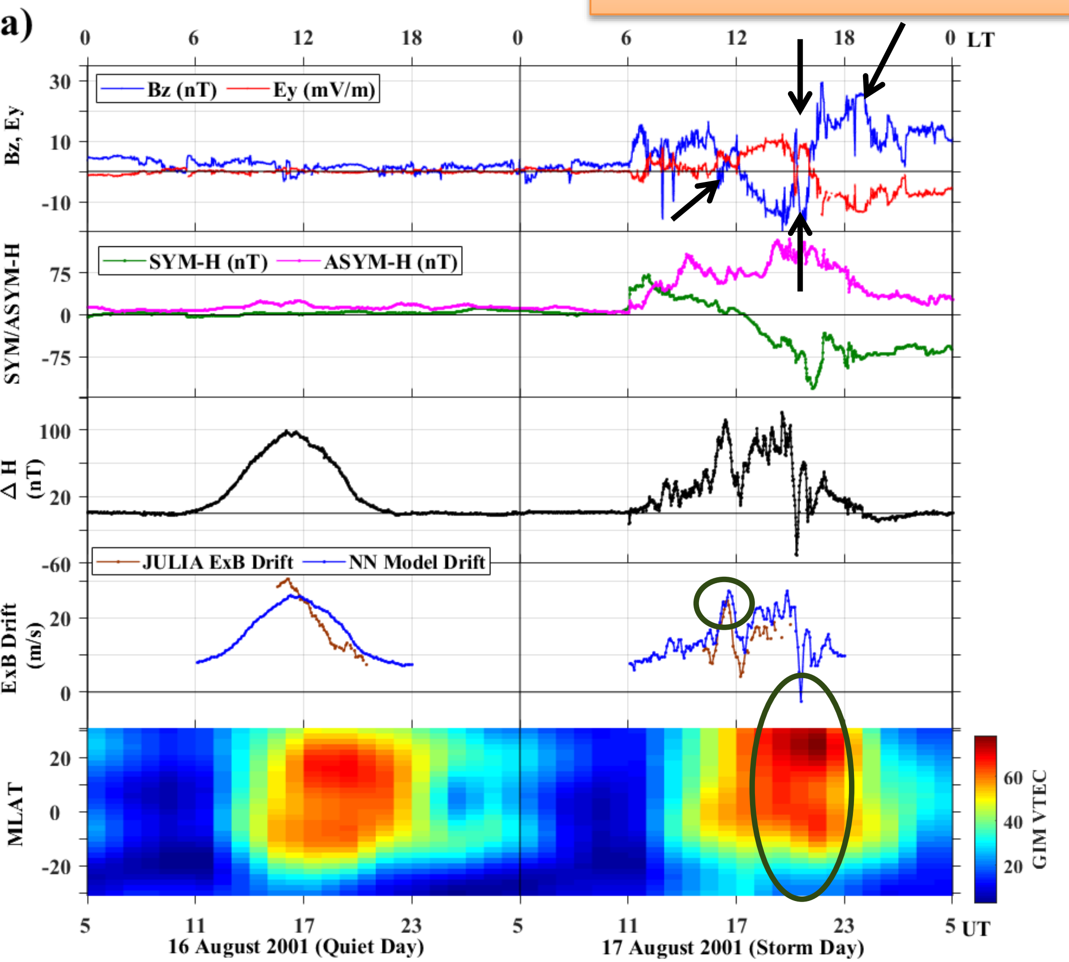


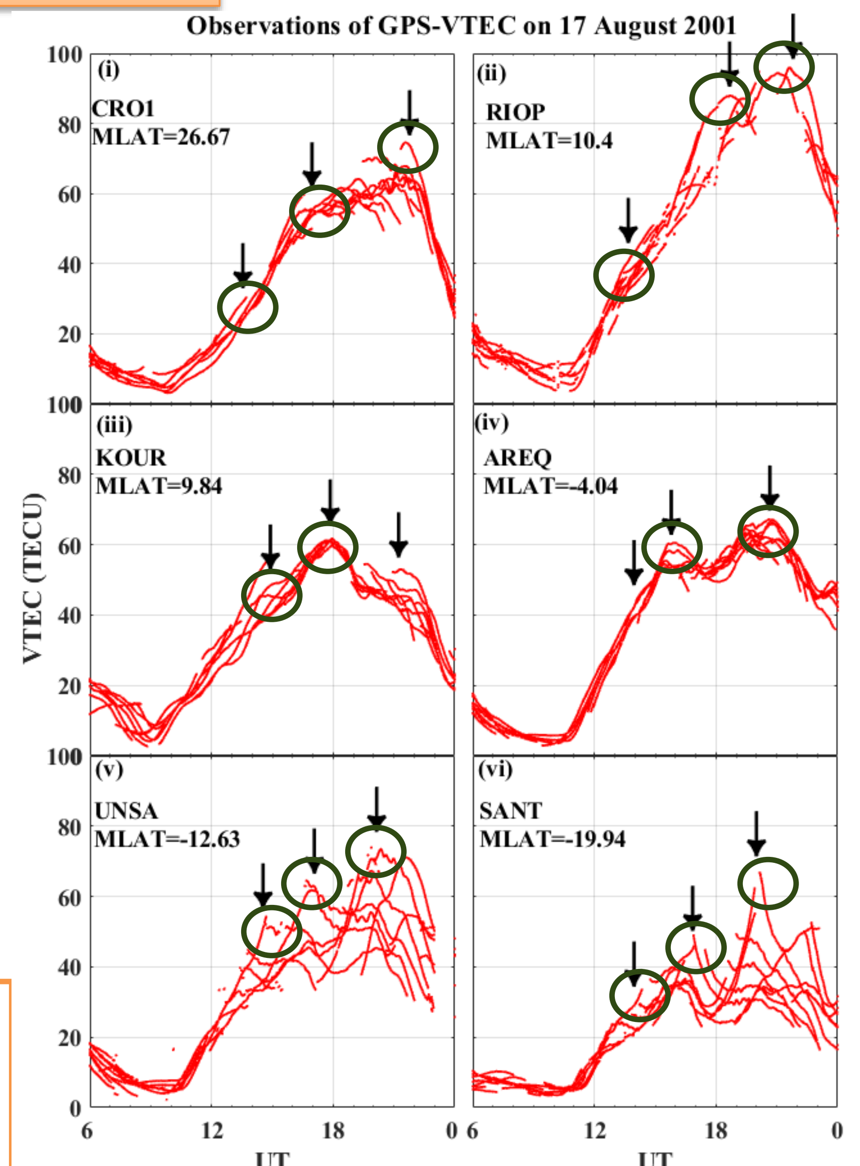
- Episodic variations in IMF Bz and IEF Ey at 12 UT, between 13-14 UT, 15-16 UT, 17 UT and 18-19 UT
- Corresponding peaks and fall in ExB drift

Hemispheric asymmetry is found to exist in terms of excess 10 TECU in southern hemispheric

Simultaneous peaks in VTEC between 12-13 UT, 16-17 UT , 19-20 UT and 22-23 UT

7. 17 August 2001





- IMF Bz shows fluctuations from 11 UT and turns southward at ~15 UT with further episodic reversal
- ExB drifts rise from ~9 m/s to ~28 m/s and then fall back to 5 m/s in a course of 2 hours
- Simultaneous peaks and depressions in VTEC

Asymmetry of ~15 TECU between 18-21 UT biased towards northern hemisphere

Conclusions: My bit of contribution to resolve the puzzle

- ✓ Sudden polarity reversals of PPEF from eastward to westward and vise-versa directly reflect as **sharp upward to downward** variation in the equatorial vertical ExB drift.

- ✓ This causes the formation of **sudden peaks and valleys in VTEC simultaneously** over a range of low latitudes.

- ✓ This study, for the first time, establishes the **dominant and independent control of PPEF** on day time low latitude VTEC during main phase.

- ✓ With switching polarity of PPEF, simultaneous rise and fall of TEC is observed in tandem with fluctuations in ExB drift, but with different intensities in either hemispheres.

- ✓ **Inter hemispheric asymmetry** is found to exist regardless of season.

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Interhemispheric Asymmetry in Response of Low-Latitude Ionosphere to Perturbation Electric Fields in the Main Phase of Geomagnetic Storms

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Key Points:
- Rigorous analysis of low-latitude ionospheric response to the main phase of 7 major and 30 moderate geomagnetic storms from solar cycles 23 and 24 is presented
- Coincident episodic occurrence of peaks and steep falls in VTEC are ascertained due to episodic eastward and westward penetration electric fields in daytime
- PPEF-associated departures in VTEC range between −30 and 100 TECU along with observed hemispheric asymmetry in EIA region of ~10 to 30 TECU

Supporting Information:
- Supporting Information S1

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Abstract Structures of sudden enhancements/depressions and associated interhemispheric asymmetry in low-latitude total electron content (TEC) during the main phase (MP) of geomagnetic storms have remained unpredictable majorly due to oscillating equatorial vertical E×B drifts and resultant redistribution of plasma in low latitudes in a given seasonal background. Robust analysis of 7 major and 30 moderate ionospheric storms during the years 2000–2018 is performed with comprehensive literature review encompassing various sources of asymmetry in magnetosphere-ionosphere coupling. Taking advantage of simultaneous long-term observations of E×B drift from Jicamarca, *H* component from magnetometers, and global ionospheric map vertical TEC (VTEC) and TEC observations across the dip equator from the South American sector, simultaneous formation of peaks and valleys in VTEC and associated asymmetry are studied. Additionally, a three-layer neural network-based E×B drift model is developed using delta-*H* observations that provide drift estimates in the absence of Jicamarca drifts. The

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Thank you for your kind attention