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Temporal and spatial evolutions of storm-time ionospheric disturbances in the low and midlatitudes as seen in the GNSS-TEC and SuperDARN radar observations

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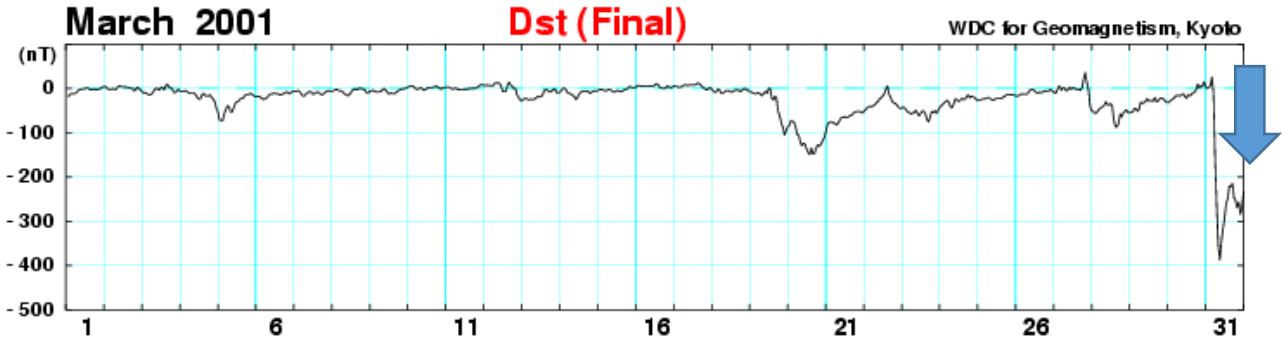
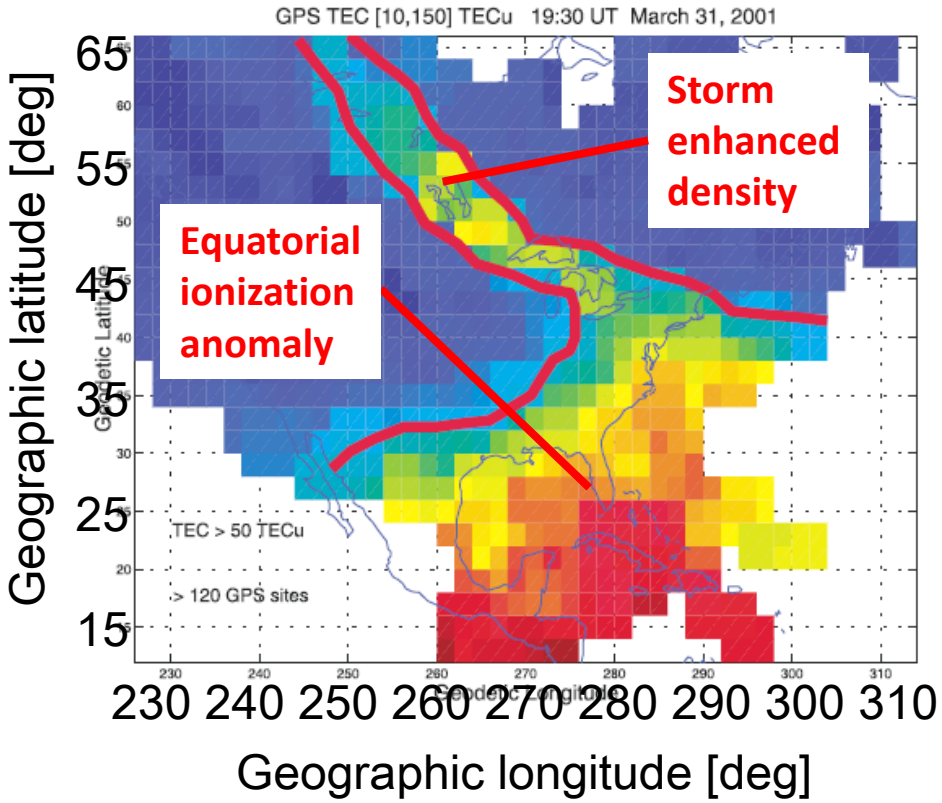
1. Introduction

1.1 Storm-time low- and middle-latitude ionospheric variation



http://wdc.kugi.kyoto-u.ac.jp/dst_final/200103/index-j.html

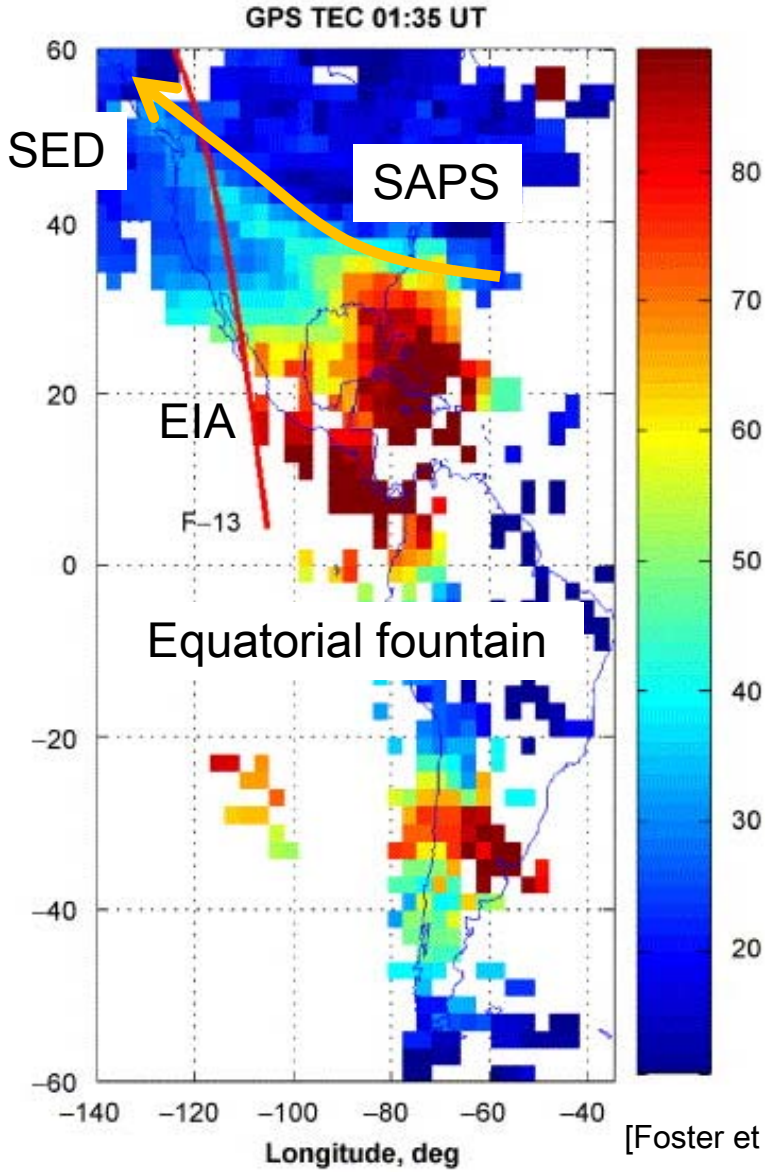


[Foster et al., 2002]

- **High plasma density with a narrow structure extending from the low to high latitudes**
- **Increasing height of the maximum electron density in the F-region**
- **Increasing electron density in the topside ionosphere**
- **Low electron temperature**

GPS-TEC map in the American sector

1.2 Generation mechanism of the SED plume



[Foster et al., 2007]

Equatorial fountain is intensified due to prompt penetration of polar electric field to the equator

[e.g., Huang et al., 2005]

Equatorial ionization anomaly (EIA) extends to higher latitude.

[e.g., Kelley et al., 2004; Tsurutani et al., 2004]

The higher portion of EIA is transported westward due to sub-auroral polarization stream (SAPS) during geomagnetic storms.

[e.g., Foster et al., 2007]

1. Introduction

1.3 Problems of previous works and purpose of this study

[Problems]

Different kinds of generation mechanism of SED have been proposed by previous studies, but it is unknown which mechanism mainly contributes to the formation of SED.

1. **Equatorward neutral wind [Anderson, 1976]**
2. **Expansion of the equatorial ionization anomaly (EIA) to the high-latitude regions [Kelley et al., 2004]**
3. **Westward transportation of ionospheric plasmas due to sub-auroral polarization stream (SAPS) [Foster et al., 2007]**
4. **Uplifting of ionospheric plasmas due to localized ExB drift [Zou et al., 2013; Liu et al., 2016]**

[Purpose of the present study]

We clarify the generation mechanism of SED in the subauroral and mid-latitude regions during a geomagnetic storm using global GNSS-TEC data and midlatitude SuperDARN radar data.

2. Observation data and analysis method

2.1 Observation dataset

○Solar wind and interplanetary magnetic field (IMF)

・・・ OMNI data (from CDAWeb, NASA)

○Geomagnetic indices (from WDC , Kyoto)

Kp index・・・Identification of geomagnetically quiet days

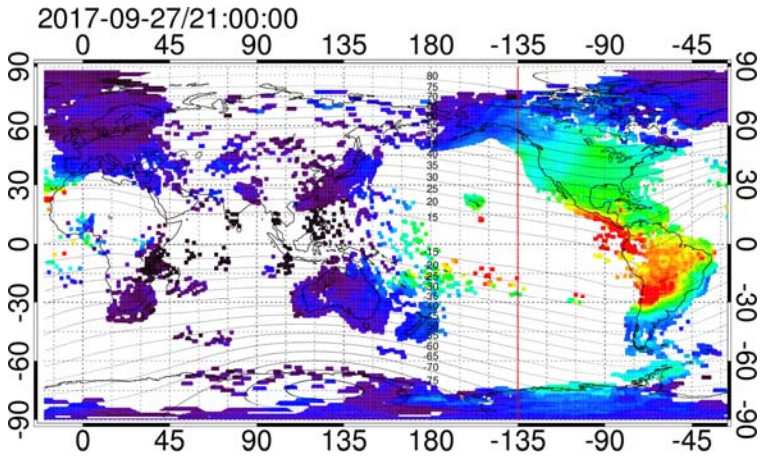
SYM-H index・・・ Identification of geomagnetic storms

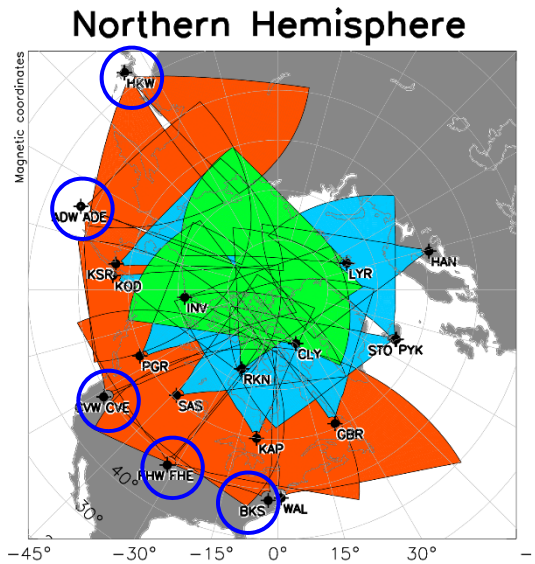
○Global GNSS-TEC (from DRWING/PWING, NICT/ISEE) (more than 8600 GNSS stations)

・・・ Time and spatial resolutions: 5 min and 0.5x0.5 degrees

○SuperDARN radar (from ISEE, Nagoya university)

・・・ADE, ADW, BKS, CVE, CVW, FHE, FHW, HKW, and HOK (9 midlatitude radars)





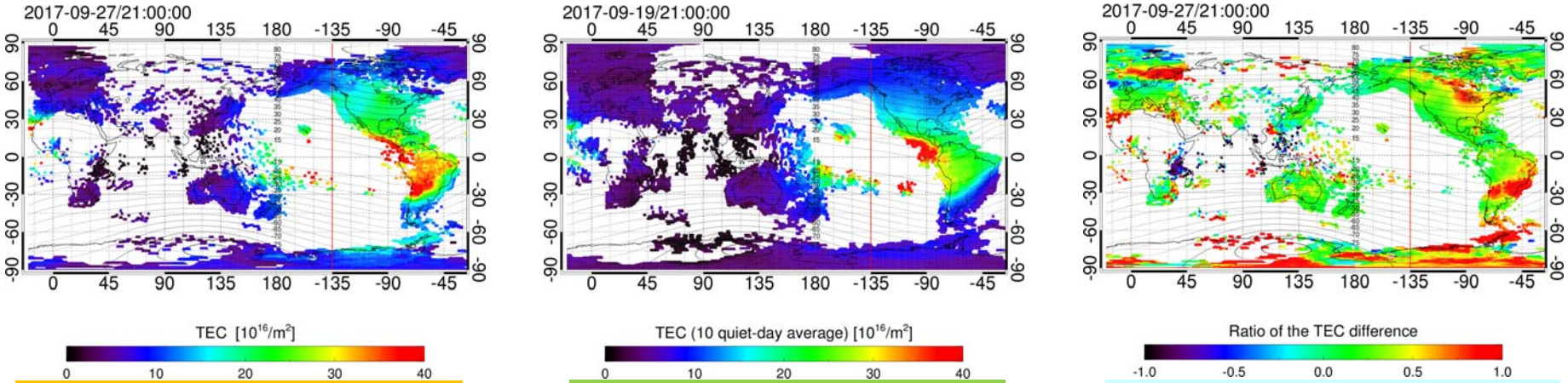
2. Observation data and analysis method

2.2 Analysis method

○We first calculate a difference value of TEC from an average TEC of 10 geomagnetically quiet days in each month, and normalized it by the average quiet-day TEC.

rTEC = (TEC_st – TEC_sq)/|TEC_sq|

(ex. 2017/09/27 21:00) **(ex. 10 quiet days in Sep.)**

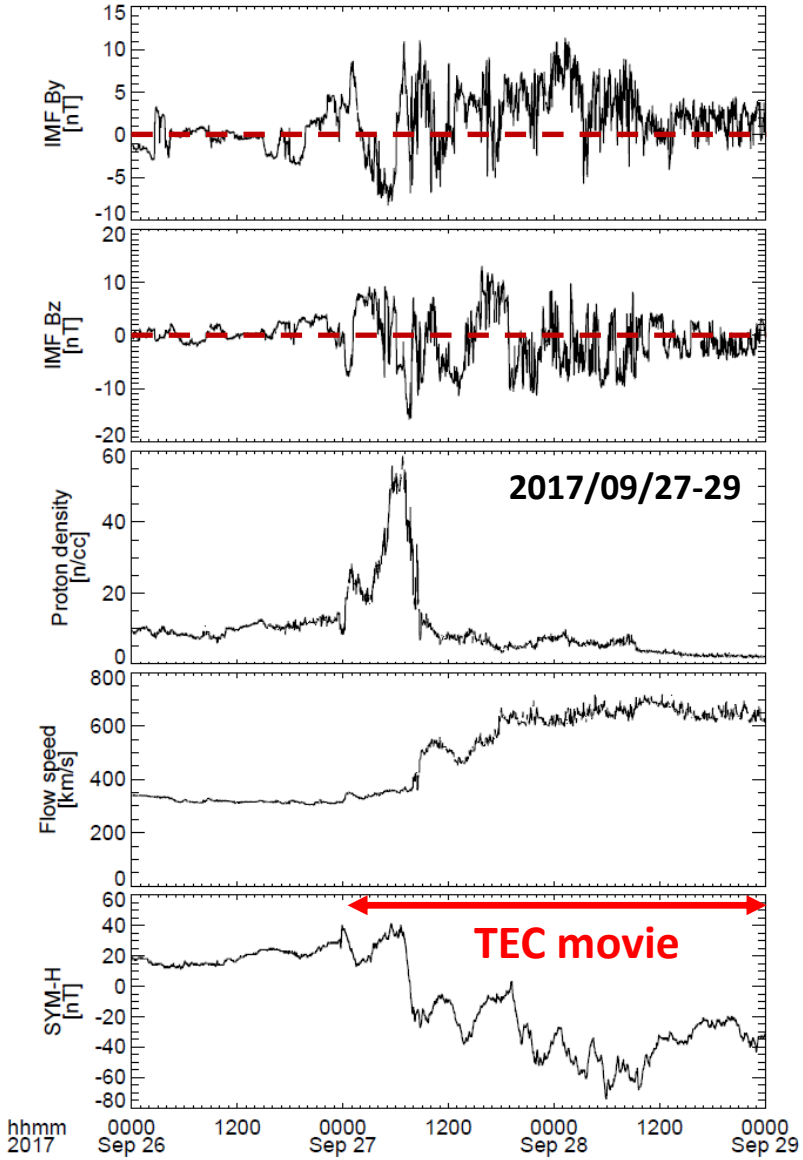


Global TEC data during a geomagnetic storm — **Averaged TEC data of 10 quiet days** = **Global rTEC data during a geomagnetic storm**

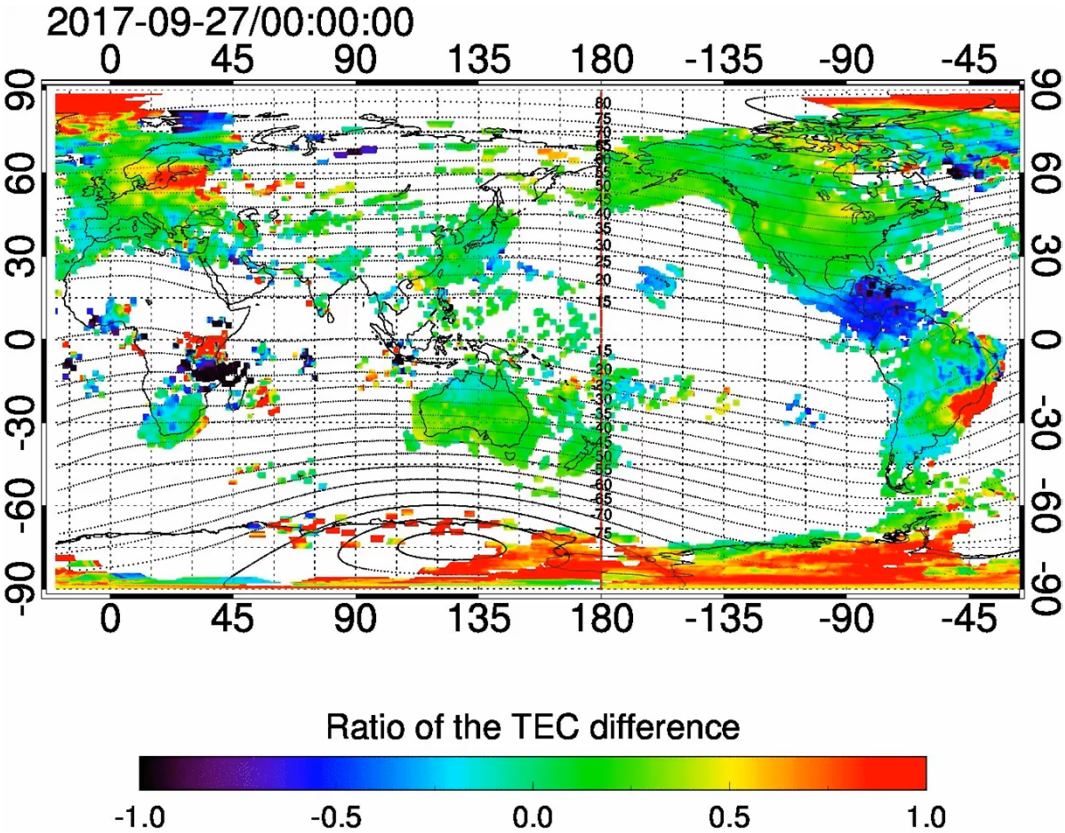
○We create two-dimensional rTEC maps in both geographical and geomagnetic coordinates.

3. Analysis results

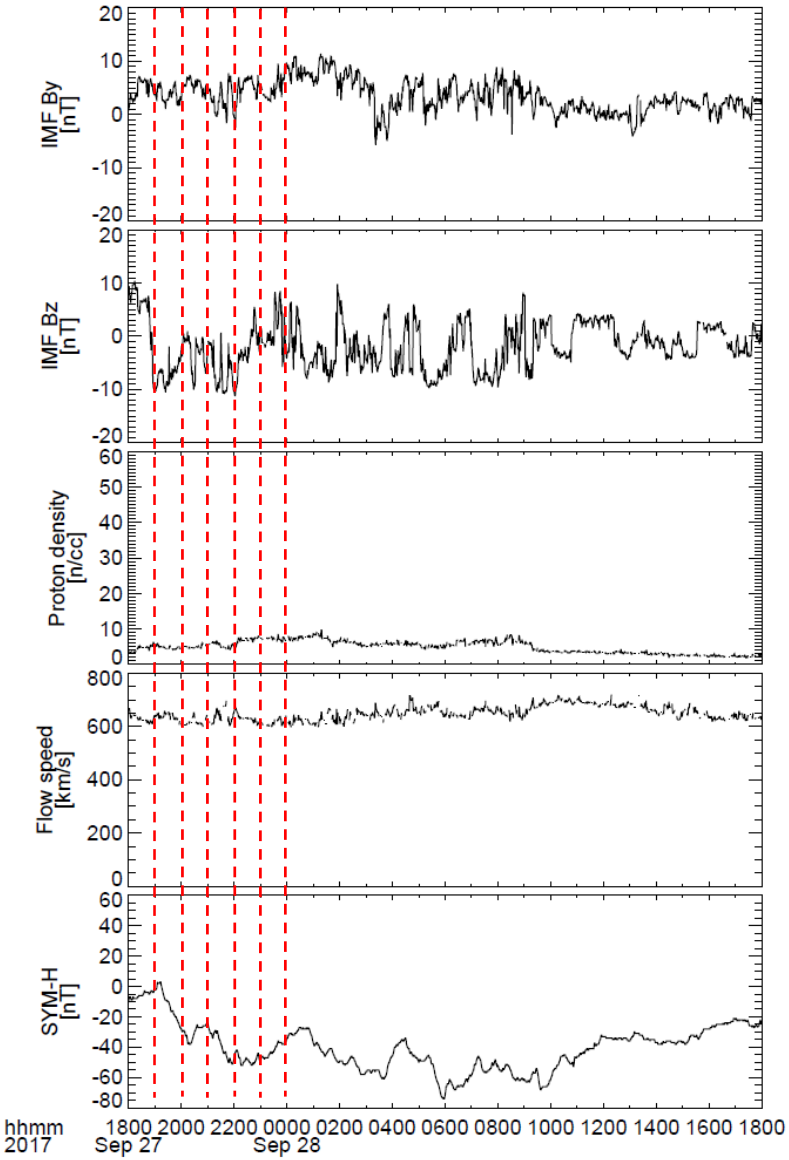
3.1 Global TEC variation during a storm event on 27-28 Sep. 2017

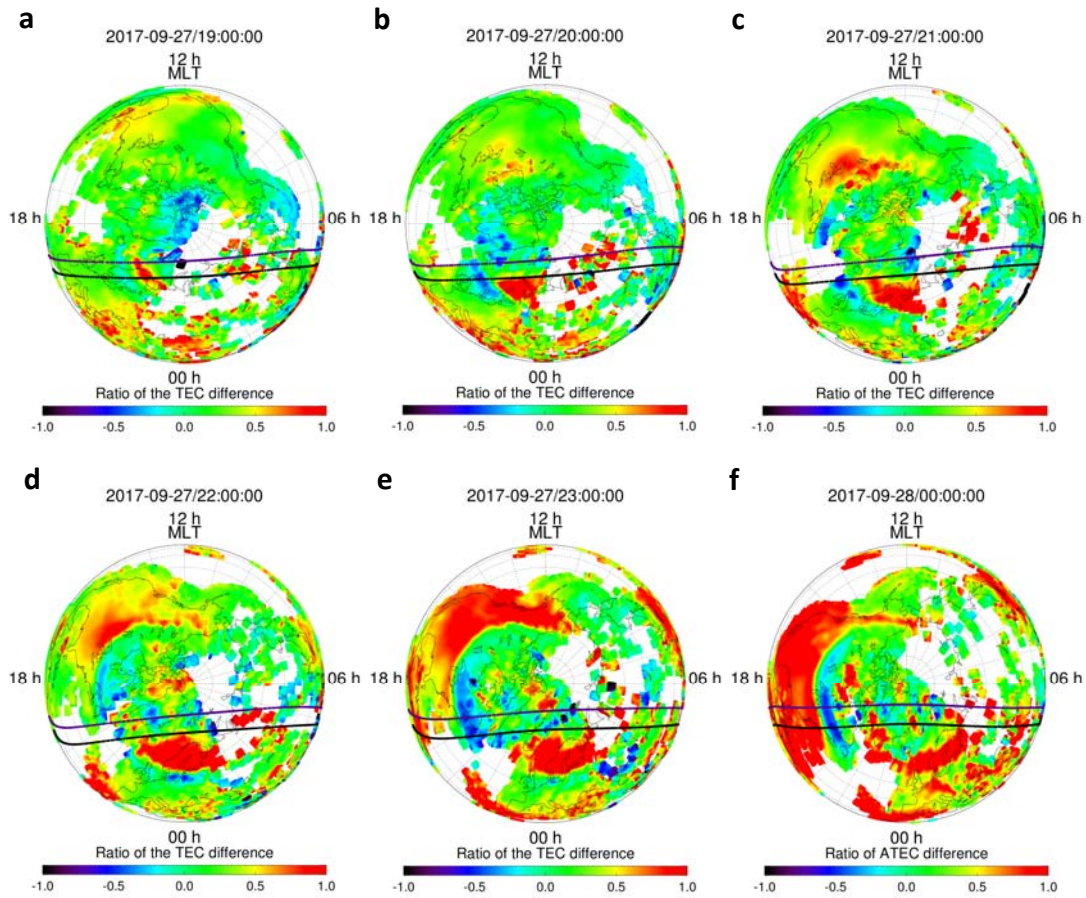


An enhanced TEC region appears in the midlatitudes in North America.



3.2 Polar map of rTEC in geomagnetic coordinates

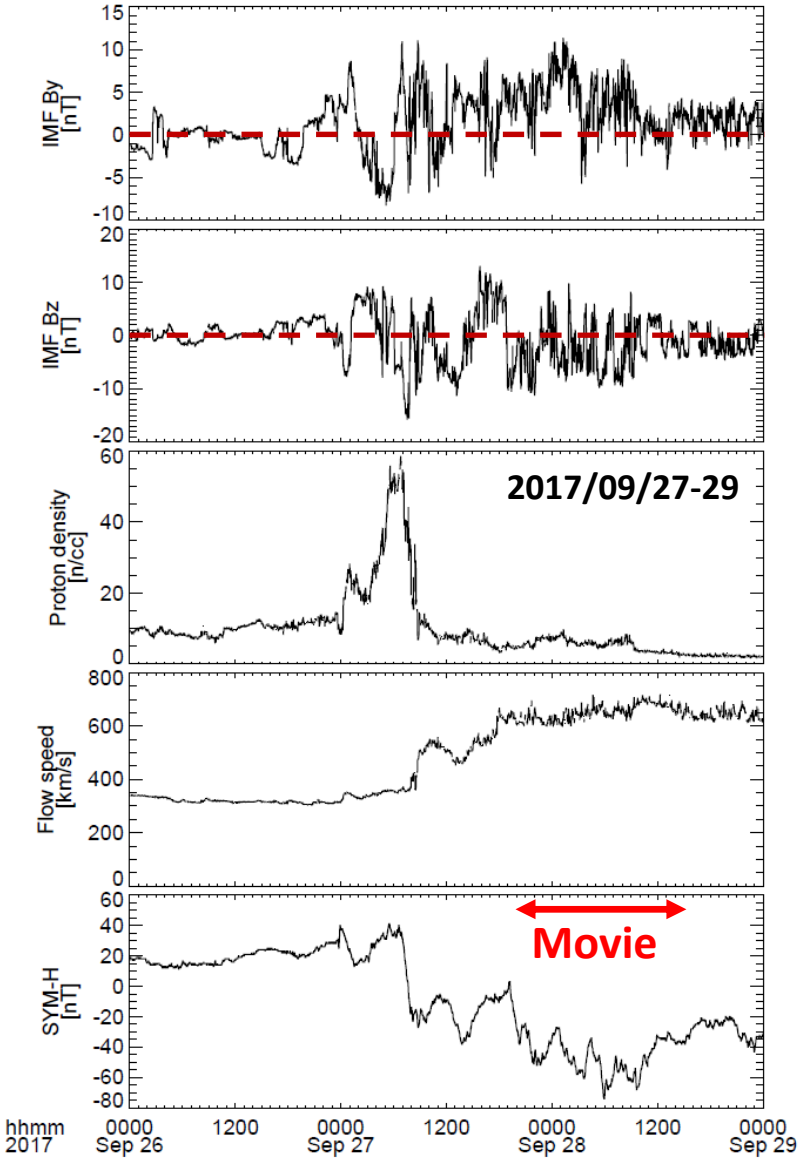


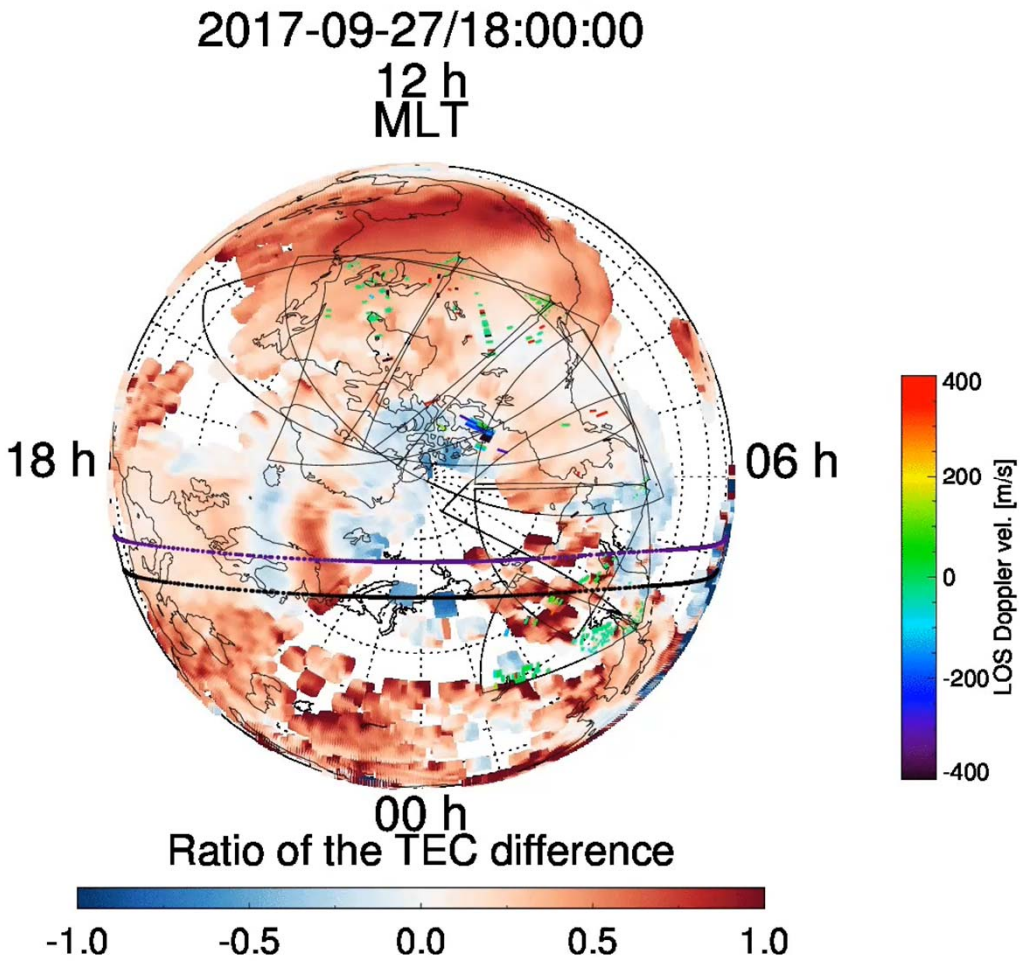


The TEC enhancement starts near the afternoon (13-15 h MLT) within 1 hour after the onset of the storm main phase and expands to the low latitudes.

3. Analysis results

3.3 Comparison between rTEC and SuperDARN radar data

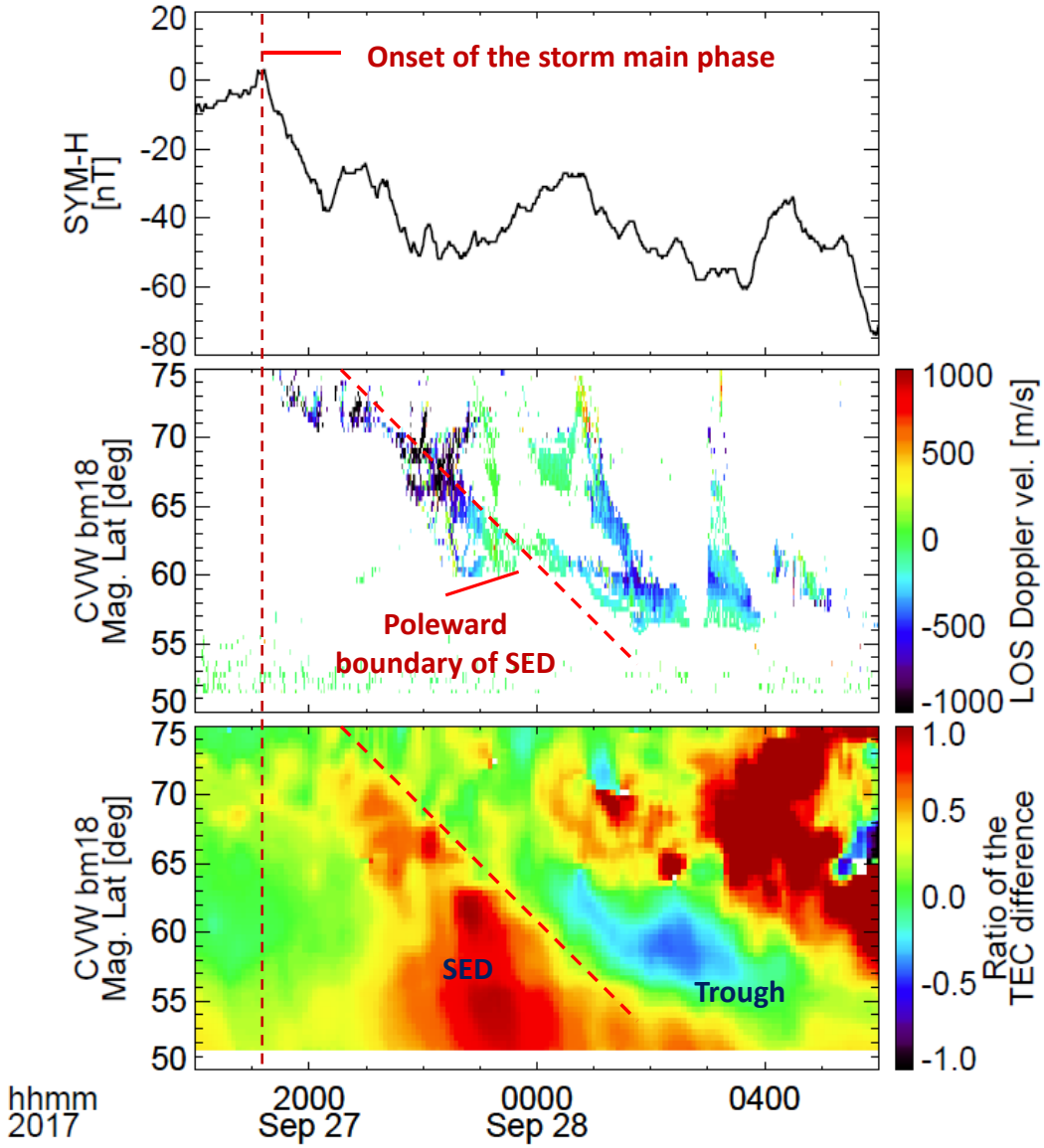


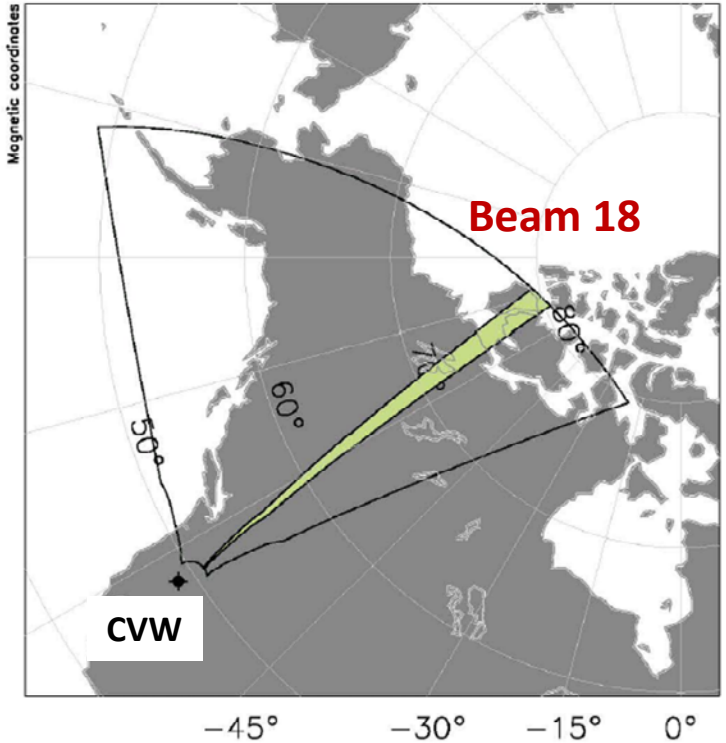


The westward flow appears inside the midlatitude trough and around the SED.

3. Analysis results

3.4 Comparison between the M-T plots of rTEC and Doppler velocity





http://vt.superdarn.org/tiki-index.php?page=DaViT+RTP

The poleward flow with a velocity of ~1000 m/s is observed inside the SED plume or midlatitude trough.

4. Discussion

4.1 Characteristics of storm-time TEC variation

- **During the storm main phase, the TEC enhancement related to the SED plume first appears in the subauroral or midlatitude regions, and moves equatorward with a longitudinal extent.**

  -->This feature cannot be explained by the generation mechanism of SED proposed by Kelly et al. [2004] and Tsurutani et al. [2004].

- **Several hours after an appearance of the midlatitude enhanced TEC region, another TEC enhancement occurs in the low-latitude region associated with a super fountain effects due to prompt penetration electric field to the equator.**

- **Finally, the midlatitude enhanced TEC region meets the equatorial ionization anomaly in the low latitude.**

- **The large plasma flow with a velocity of ~1000 m/s is collocated inside the SED plume or midlatitude trough.**

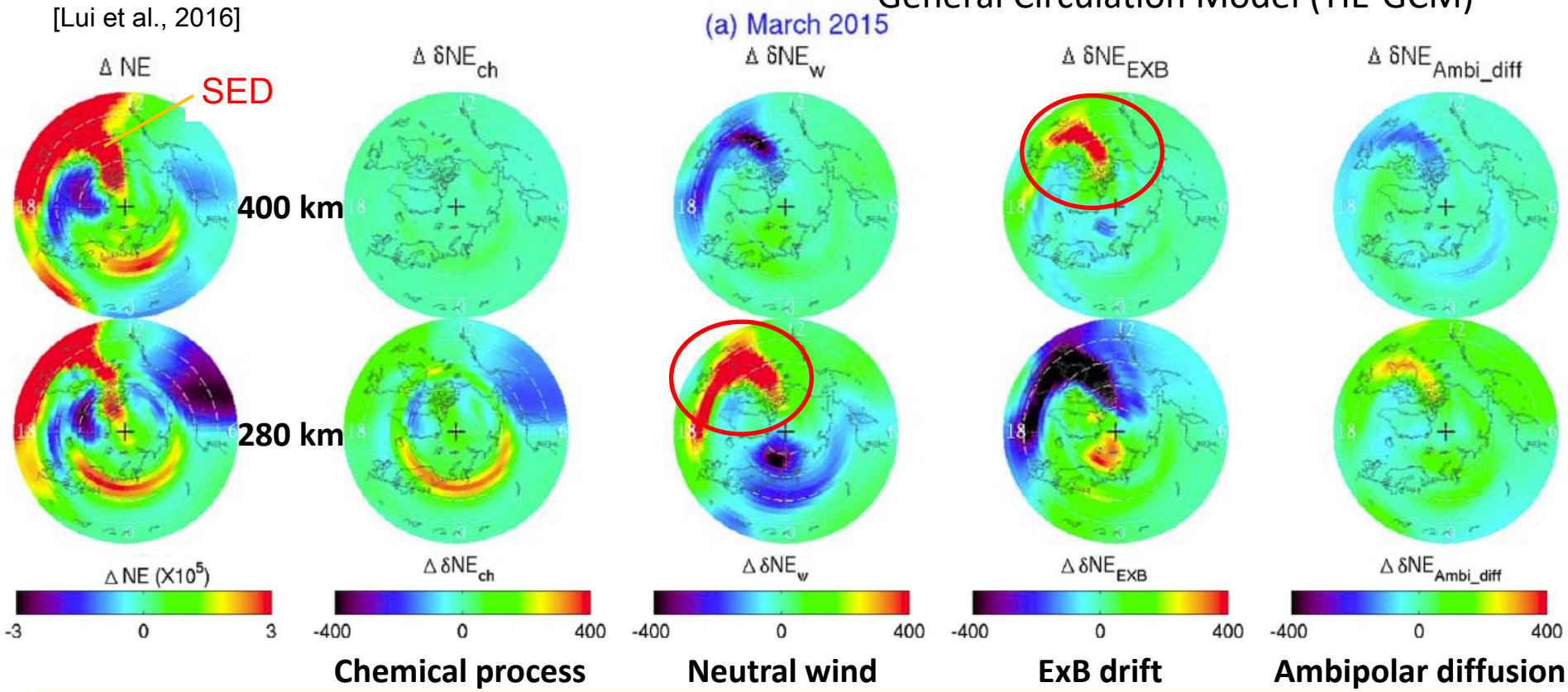
  -->This result suggests that the strong convection electric field plays an important role in generation of the SED plume.

4. Discussion

4.2 Relative importance of horizontal and vertical transports to the formation of SED

Thermosphere Ionosphere Electrodynamic General Circulation Model (TIE-GCM)

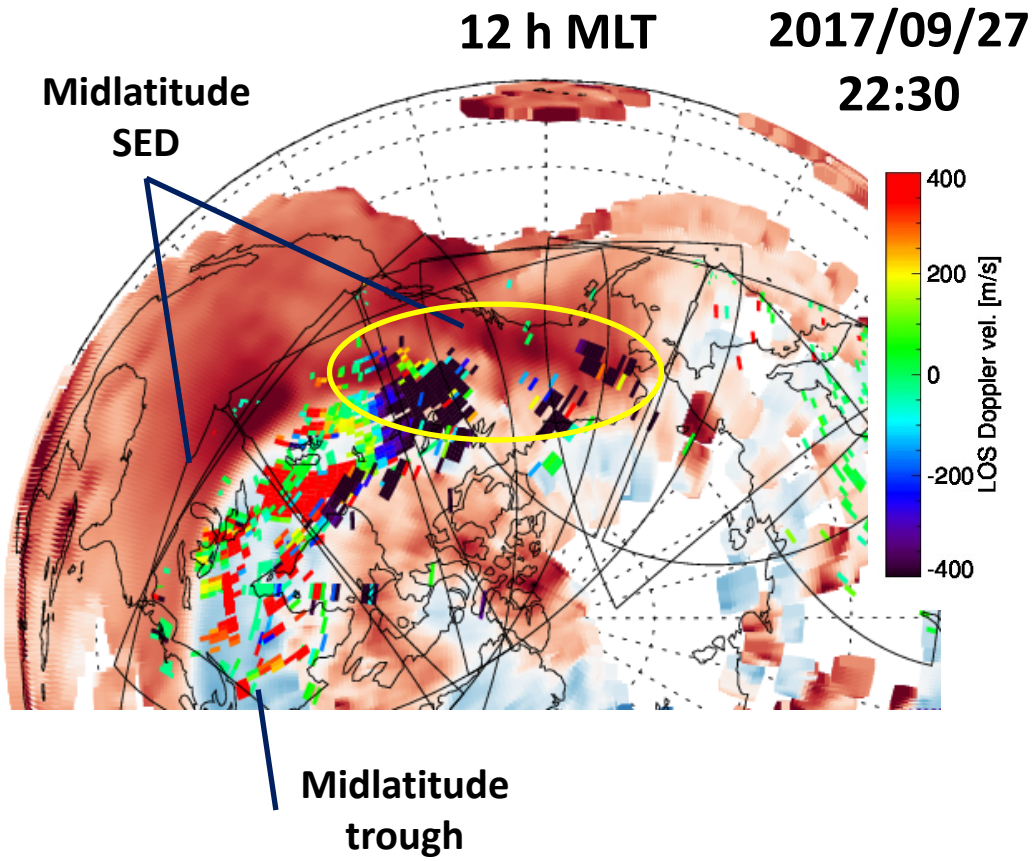
[Lui et al., 2016]

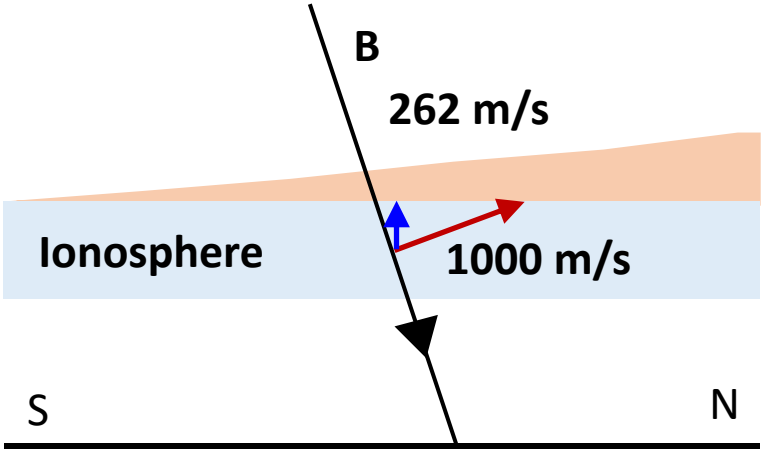


In the topside ionosphere, upward E x B ion drifts are most important in SED.
In the bottomside F region ionosphere, neutral winds play a major role in generating SEDs.

4. Discussion

4.3 Estimation of vertical ExB drift from the observation data





IGRF at 300 km (55° N, 121° W)
Inclination:74.8°
Declination: 16.3°
Total F: 49056.4 nT

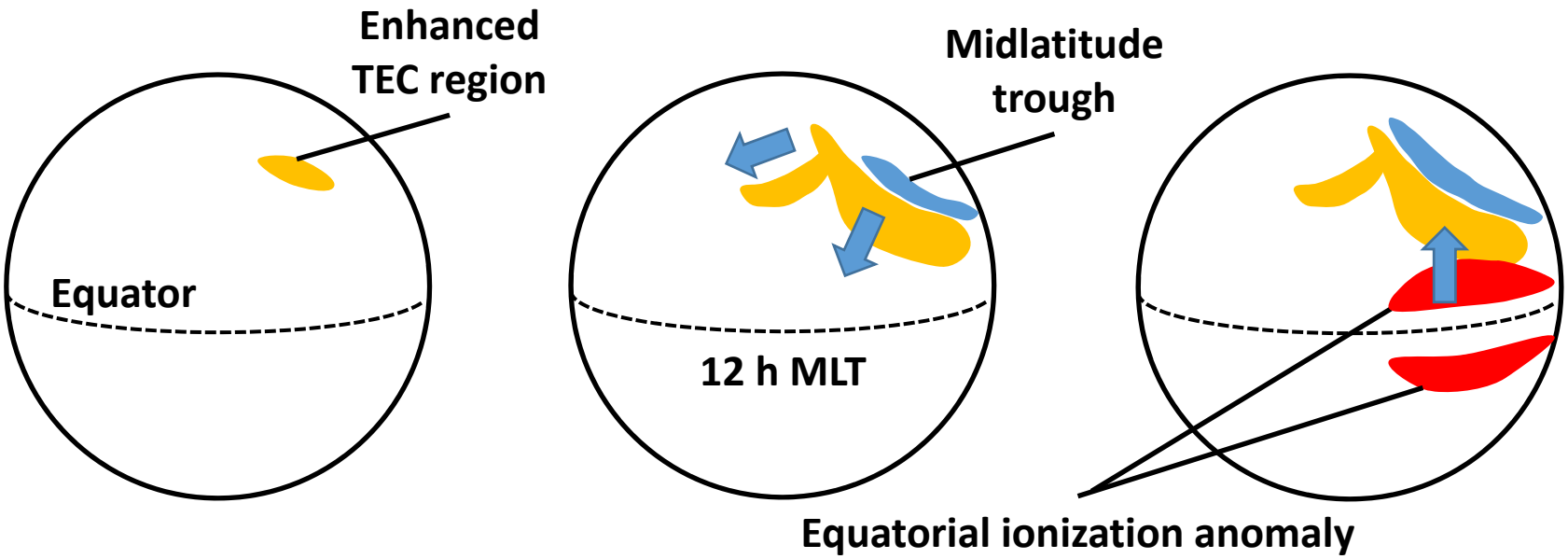
Upward velocity component of the electric field drift is estimated as

Vz = 1000*cos74.8° = 262 m/s

Ionospheric plasmas experience an upward movement of 300 km for 20 minutes as they are transported by SAPS with an increase of geomagnetic latitude.

4. Discussion

4.4 Proposed scenario to produce the midlatitude enhanced TEC



Appearance of enhanced TEC region in the high latitudes in the noon or afternoon sector after the onset of the storm main phase.

Expansion of enhanced TEC region to lower latitudes and wider longitudes and appearance of the midlatitude trough above the enhanced TEC region.

Enhancement of equatorial ionization anomaly in the evening sector and expansion to higher latitudes.

5. Conclusions

○To clarify the generation mechanism of the SED plume in the subauroral and midlatitude ionosphere during a geomagnetic storm, we analyze the global GNSS-TEC data together with solar wind, IMF, geomagnetic indices (SYM-H and Kp), and midlatitude SuperDARN radars.

The main results are shown below.

1. During the main phase of a geomagnetic storm, the TEC enhancement is first observed in the subauroral or midlatitude regions, and moves equatorward with a longitudinal expansion.
2. The midlatitude enhanced TEC region corresponding to the SED plume meets the EIA extended to the low- and midlatitude region.
3. A strong ionospheric plasma flow with a speed of more than 1000 m/s is observed inside the SED plume.
4. The storm-time plasma flow uplift the ionospheric plasma due to the effect of declination or inclination of the ambient magnetic field.

→It is suggested that storm-time ionospheric convection electric fields play an important role in the formation of the SED plume.