Evaluation of Interhemispheric Asymmetry using Total Electron Content at High Latitudes During Geomagnetic Storms

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ABSTRACT

Geomagnetic storms cause significant disturbances in the high-latitude ionosphere. Studying these impacts is challenging due to the complex magnetosphere-ionosphere coupling and physical mechanisms involved. Here, we utilized measurements from the Global Navigation Satellite System (GNSS) network to calculate the Total Electron Content (TEC) across GNSS receivers at magnetically **conjugate points in Antarctica, Canada, and the United States. We analyzed 25 geomagnetic storms during Solar Cycle 24 (SC24)**, examining the interhemispheric behavior and differences in TEC under varying seasonal and solar conditions, driven by distinct geomagnetic storm drivers. **Our results revealed differences in the interhemispheric velocity of TEC disturbances moving from the poles toward the equator.** While comparisons of disturbance velocities with various solar wind and magnetospheric parameters did not show clear relationships, a notable correlation emerges when the rate of decrease in the Dst index is larger than -60 nT/h during storms. **This correlation is more pronounced in the Northern Hemisphere than in the Southern Hemisphere.** Furthermore, we identified significant variations in the timing of the maximum vertical TEC (vTEC) occurrence relative to the onset of the storm's main phase. Finally, **we studied the relationship between the velocities and seasonal variations**, including the different storm drivers, and the results do suggest true hemispherical differences.

METHODOLOGY

- Eight closely magnetically conjugate points were selected using seventeen GNSS receivers located within the auroral regions, as shown in Fig. 1.
- TEC Extraction was done using the GNSS TEC Calibration Software ICTP (Ciraolo et al., 2007).
- vTEC was calculated over the receiver using a weighting function, as described in Çepni et al. 2013.
- To establish a baseline, three quiet days preceding each storm were selected, based on Dst indices greater than -20 nT and AL indices greater than -100 nT.

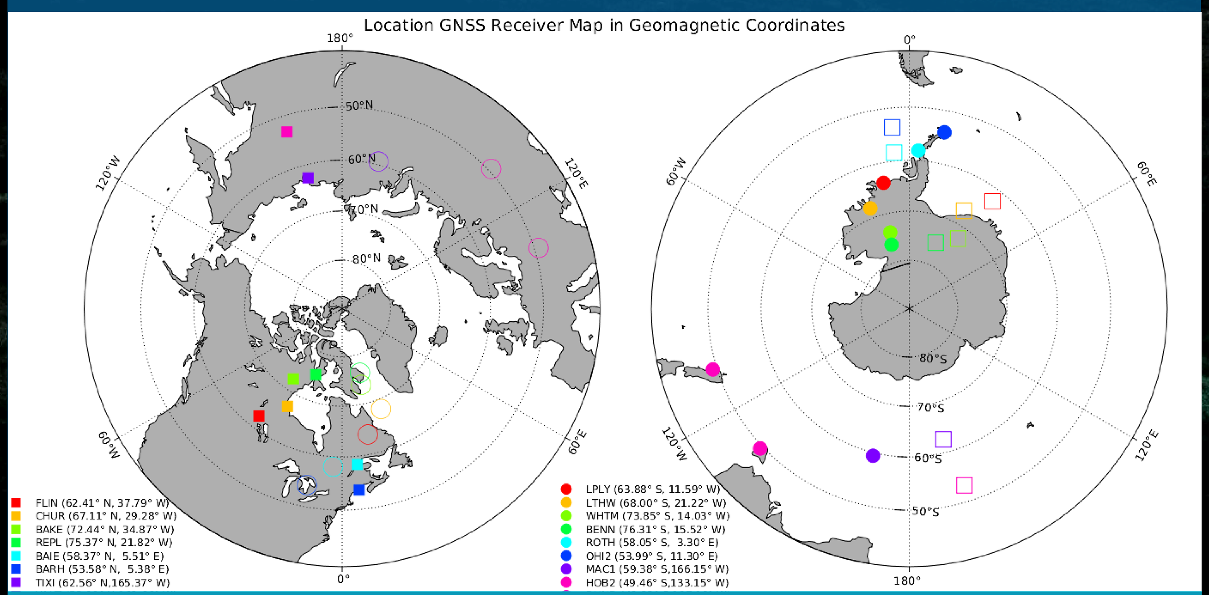

Fig. 1: Locations of the GNSS receivers. Solid circles represent the instruments in the Southern Hemisphere, while the unfilled squares indicate their conjugate locations in the Northern Hemisphere. The colors represent the conjugate pairs.

RESULTS

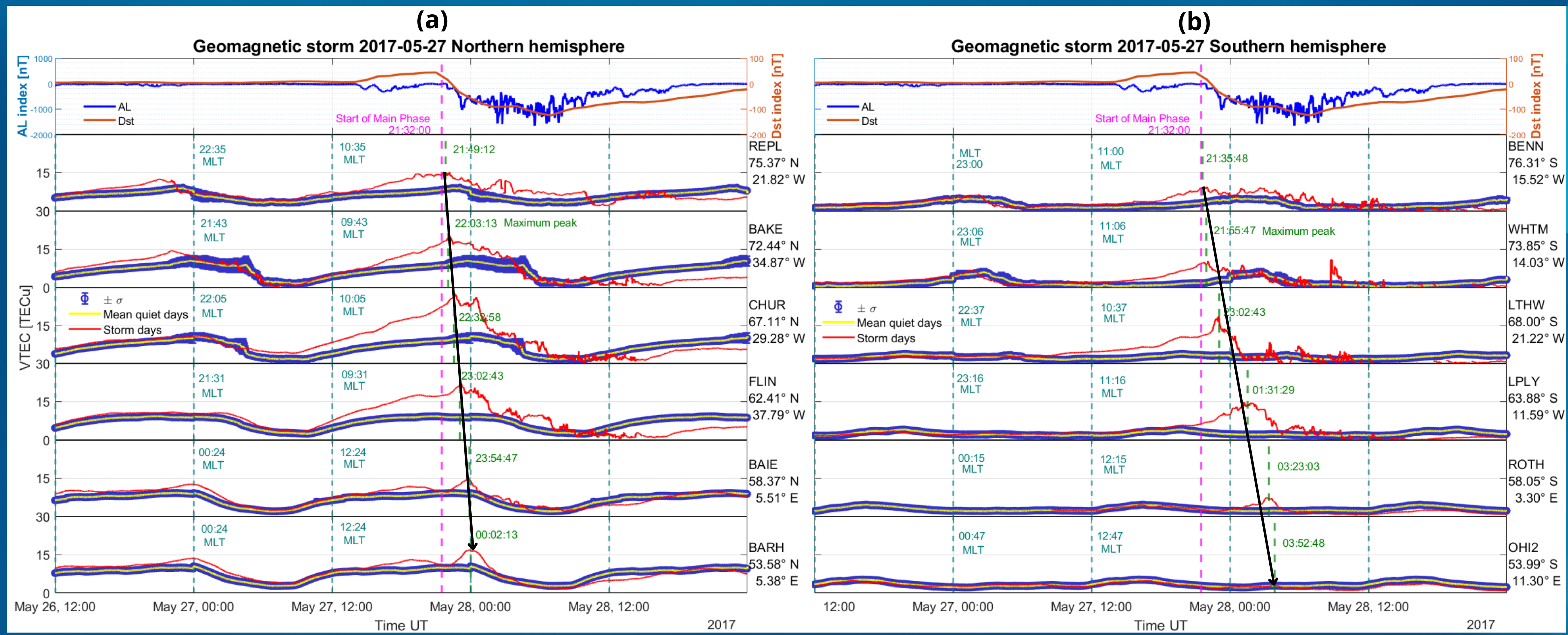

Fig. 2: Response of the Dst, AL, and vTEC indices to the geomagnetic storm of May 27, 2017. Panel (a) shows the latitudinal response in Canada and the USA (Northern Hemisphere), while panel (b) presents the conjugate points in Antarctica. The magenta dashed lines indicate the start of the main phase; the green dashed lines mark the time of the vTEC peak; and the cyan dashed lines represent the Magnetic Local Time (MLT) for each receiver.

- The stations are distributed from the pole toward the equator.
- The maximum vTEC values occurred after the start of the main phase of the storm.
- The black arrows indicate a trend toward the equator in both hemispheres.

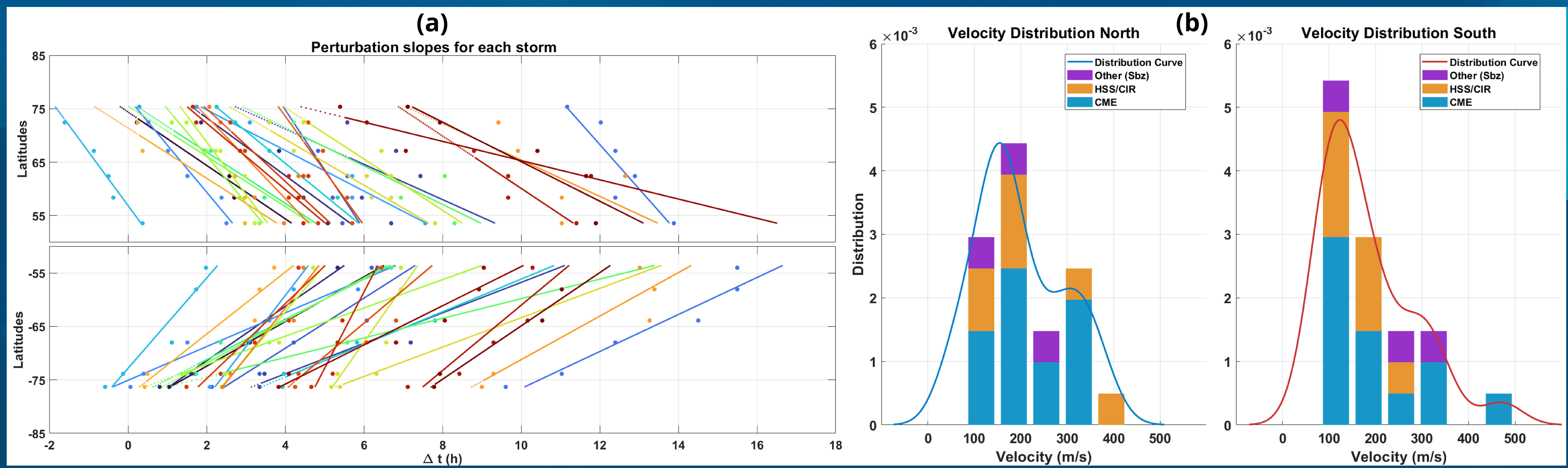

Fig. 3: Panel (a) shows the dots indicating the time difference between each vTEC peak and the start of the main phase of the storm. The slopes represent the observed trend for each hemisphere, and each color corresponds to a different storm. Panel (b) shows the distribution of velocities calculated from the slopes. The colors indicate the driver that triggered each storm.

- The velocity distribution suggests an asymmetry between the two hemispheres, with faster velocities occurring in the Northern Hemisphere.
- No clear preference in velocity is observed according to the storm drivers.

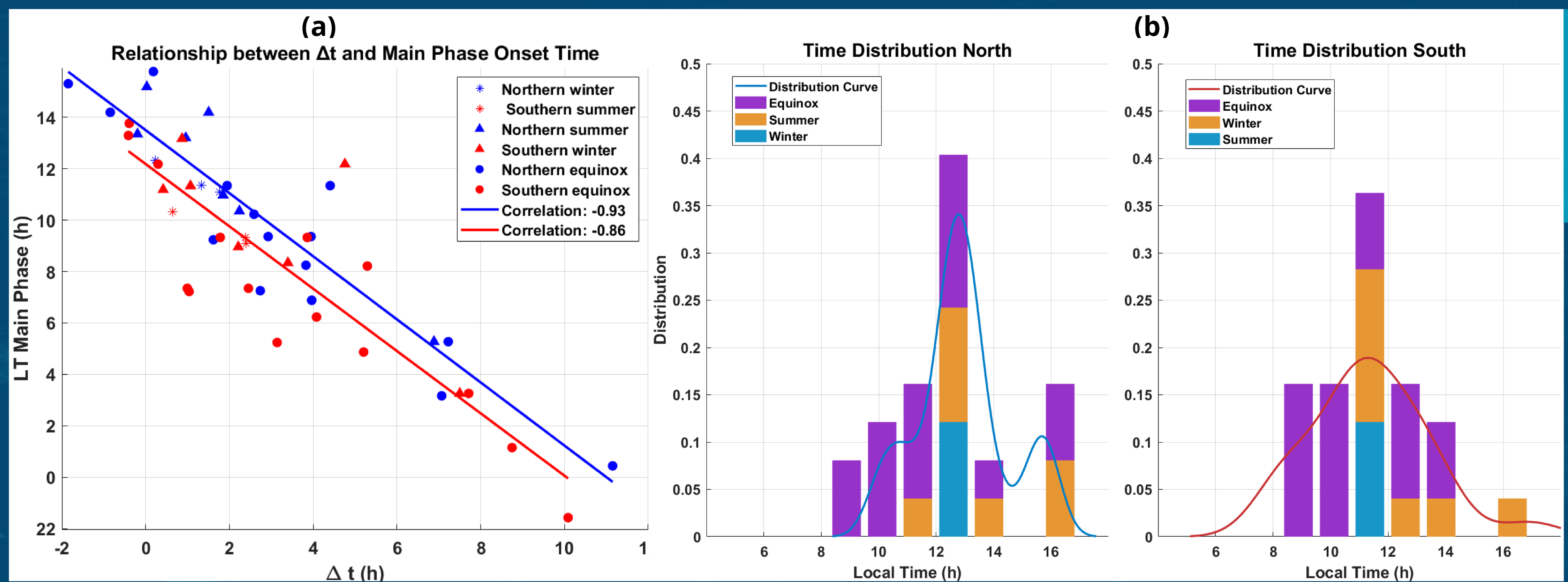

Fig. 4: Panel (a) shows the relationship between the time difference (between the peak at the most polar station and the start of the main phase) and the Local Time (LT) of the main phase onset. Blue dots represent the Northern Hemisphere and red dots represent the Southern Hemisphere. Panel (b) indicates the time range in which the peaks occurred in both hemispheres. The colors represent the corresponding seasons.

- The disturbance occurred mainly in the Northern Hemisphere between 11:00 and 14:00 local time.
- In the Southern Hemisphere, the disturbance was concentrated primarily between 08:00 and 13:00 LT.
- No clear seasonal preference was observed in the timing of the peak values.

CONCLUSIONS

- For the 25 analyzed storms, disturbances propagating from the pole toward the equator were detected in both hemispheres. The propagation velocities of these disturbances were determined and compared with several parameters, including solar wind velocity, Bz, and Dst, among others. In addition, the timing of the maximum vTEC value over the most polar receiver was calculated.
- Interhemispheric differences were observed in the velocity of the disturbances, with results indicating that disturbances in the Northern Hemisphere move faster than those in the Southern Hemisphere.
- The peak of the disturbances occurred around local midday in both hemispheres, starting earlier in the Southern Hemisphere.

FUTURE WORK

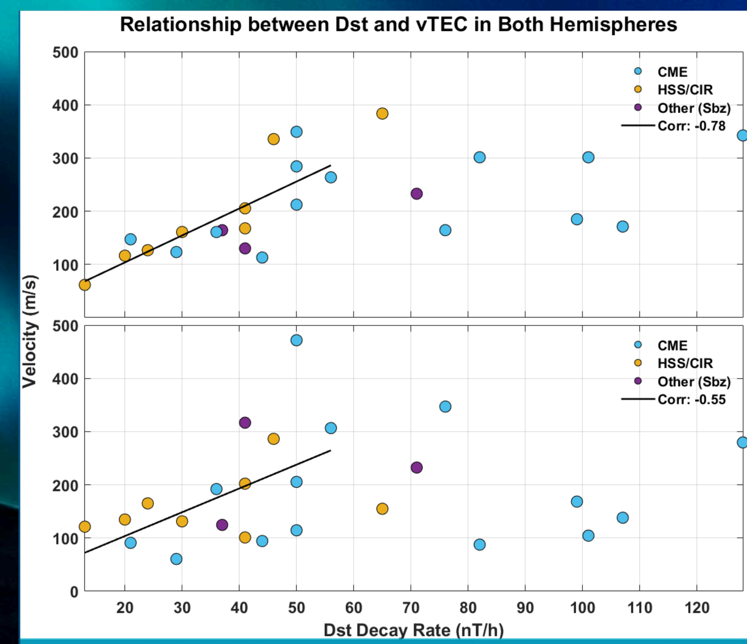

Figure 5: Dst index decay rate (nT/h) and the calculated velocities for each storm. Colors represent the storm drivers.

A possible relationship was identified between the propagation velocity of the disturbances and the rate of decrease of the Dst index during the first 3 hours after the onset of the Main Phase. However, the physical mechanism behind this relationship has not yet been determined.

ACKNOWLEDGEMENTS

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- Photo Credit: Stein Egil Liland

REFERENCES

- Ciraolo et al. (2007) - Calibration errors on experimental slant total electron content (TEC) determined with GPS.
- Çepni et al. (2013) - High-resolution station-based diurnal ionospheric total electron content (TEC) from dual-frequency GPS observations.

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