Impact of Solar Wind High Speed Streams on Ionospheric Current Systems

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Introduction

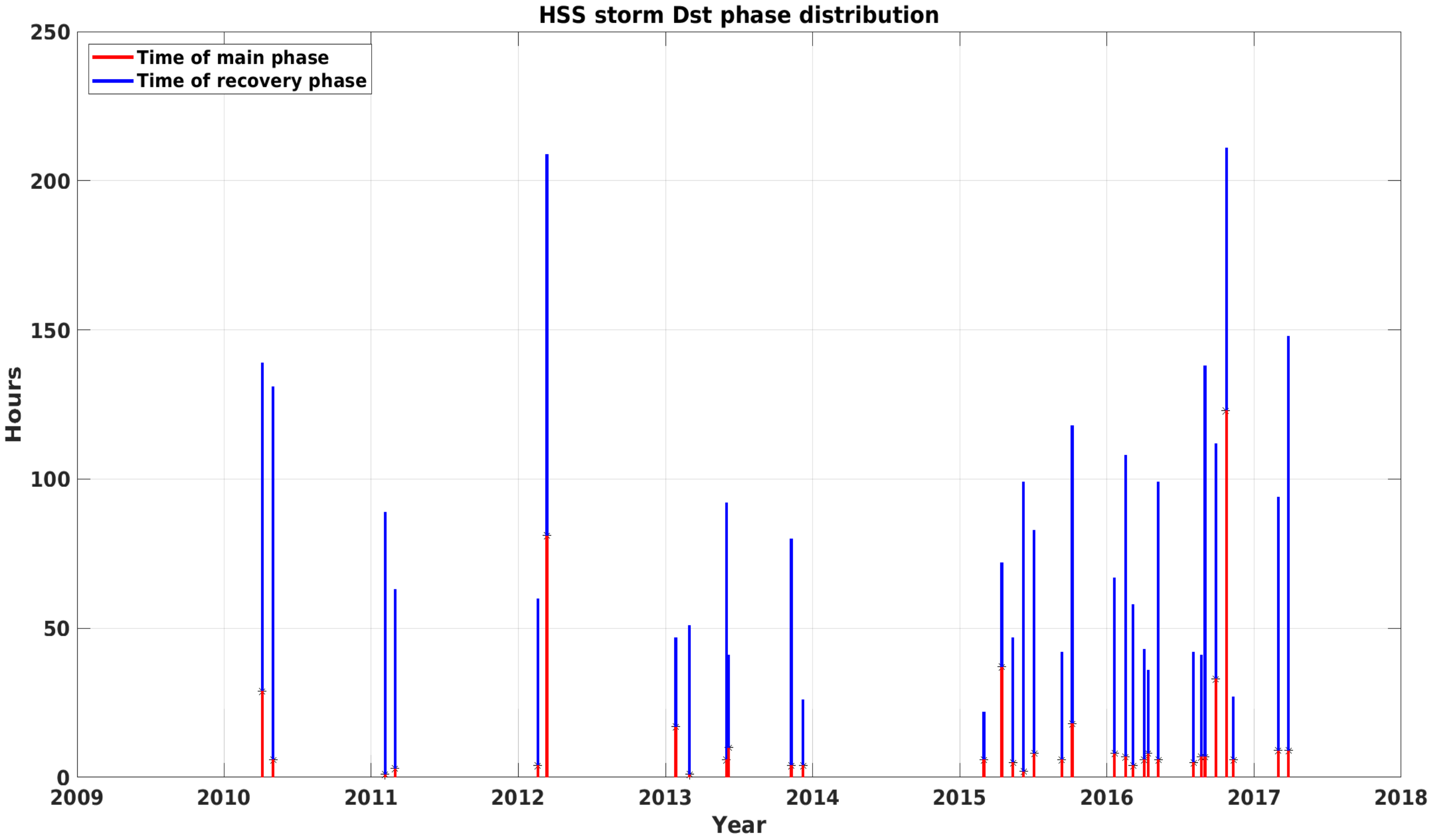
- High speed solar wind streams (HSS) are streams emanating from coronal holes with significantly higher solar wind (SW) velocity than the quiet time SW. Such streams overtake the upstream slower solar wind, creating a region of enhanced proton density and interplanetary magnetic field (IMF) strength that can give rise to severe and long lasting geomagnetic storms. Sometime these streams are recurring as the coronal hole rotates with the Sun, and create co-rotating interaction regions (CIR) against the slower solar wind stream.

- In our study we will be looking at the ionospheric currents response to HSS/CIR related geomagnetic storms – both the temporal and spatial evolution of the current system – and how different properties of the HSS/CIR can impact the current system.

Method to detect HSS geomagnetic storms

- The geomagnetic storms were detected by applying an algorithm to the Dst index (Partamies et al. 2013):
  - Storm start when the Dst first crosses to < -15 nT
  - Abrupt decrease of Dst, dDst/dt < -2 nT/hr
  - Minimum Dst ≤ -50 nT
  - End of recovery phase when Dst crosses to > -15 nT after reaching Dst minimum
- We then cross-referenced all the detected storms with Grandin et al. (2019) list of HSS events to find all the HSS related geomagnetic storms.

- From 2009-2018 we detected 51 HSS related geomagnetic storms
  - We have full data coverage for 33/51 storms, and will be using these 33 storms for the remaining of the study



Distribution of the HSS related geomagnetic storms with data coverage. Red line shows the main phase of the storm and blue line the recovery phase. Event #6 and #29 are compound events – reaching a local Dst minimum < -50 nT before almost recovering back to >-15 nT, then reaching a second more critical Dst minimum afterwards – hence the artificially long main phase duration. These events still fit nicely into our study as the first Dst minimum is < -50 nT and the second minimum is in both cases more than 60 hours after the first.

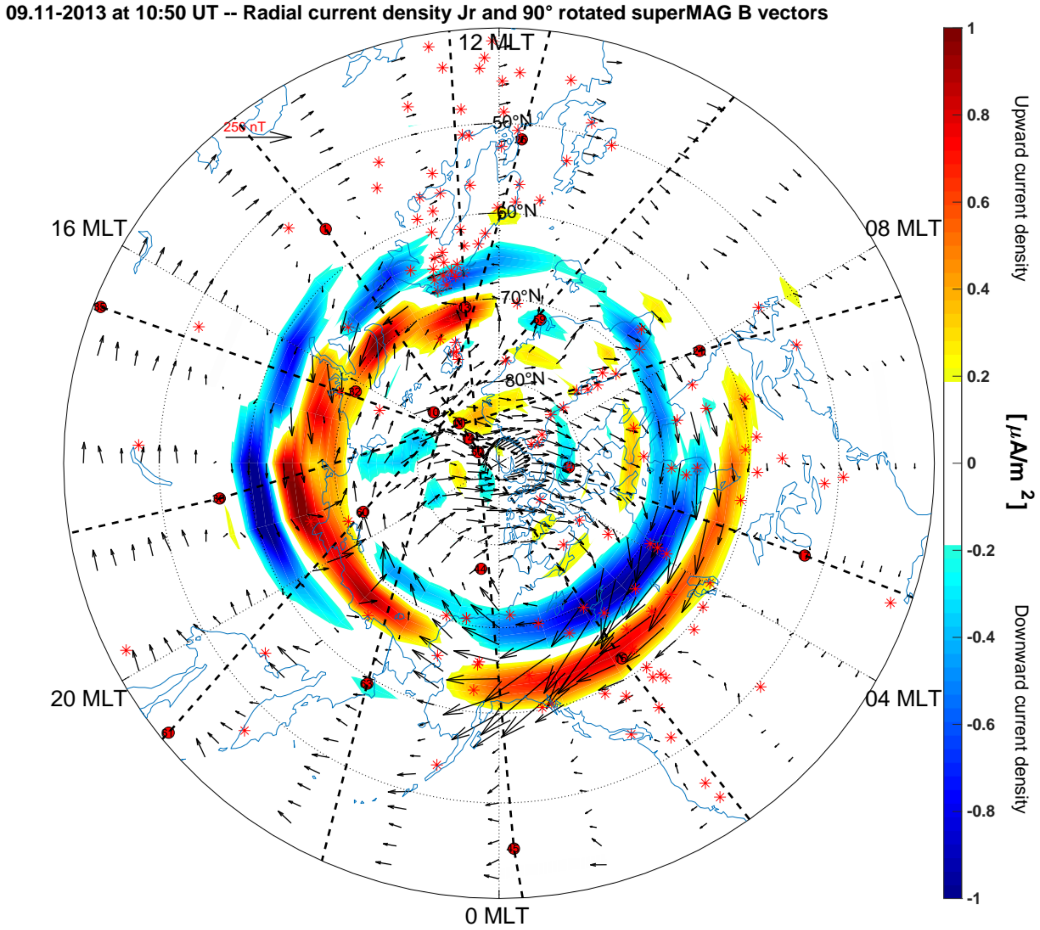
Data – AMPERE and SuperMAG

- We will be using data from the Active Magnetosphere and Planetary Electrodynamic Response Experiment (AMPERE) and the SuperMAG collaboration to get a view of both the field aligned and horizontal currents in the northern hemisphere
- AMPERE
  - > 66 satellites in 6 orbit planes at 780 km altitude
  - From the AMPERE we will get the radial current density from northern hemisphere at 10 minutes resolution
- SuperMAG – Collaboration of magnetometer stations
  - > 140 stations above 40° MLAT
  - From the SuperMAG we will find equivalent horizontal currents
- OMNIWeb
  - We will be using solar wind data from OMNIWeb mapped to the bow shock to relate the interplanetary conditions to the observed current systems

- Figure to the right shows AMPERE and SuperMAG data ten hours into one of the geomagnetic storms in our study. Color plot shows the upward and downward field aligned current (FAC) density and the vectors show fitted ground magnetic field perturbation from SuperMAG rotated by 90° to indicate behavior of the horizontal currents.

- Red circles are Iridium satellites used to derive the AMPERE radial current density – here shown for the position at exactly 10:50 UT. Dashed lines show the six trajectory planes of the satellites. Within ten minutes each satellite travels the separation distance between itself and the next satellite ahead, therefore measurements for each 10-minute data product is collected along the entire trajectory line.

- Red stars are the location of magnetometer stations used in the SuperMAG collaboration above 40 MLat.



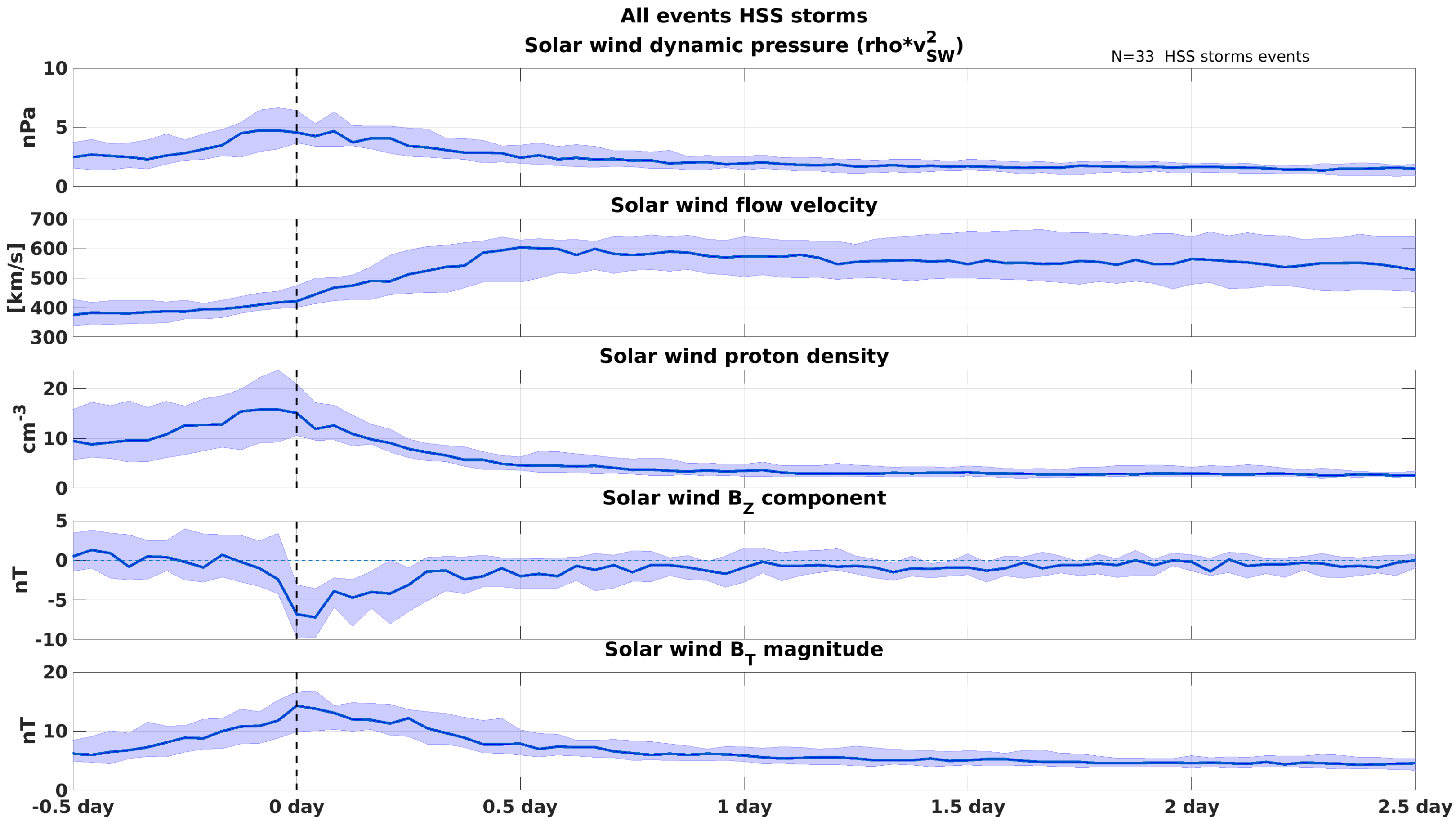
Storm start: T+ 00d10h00m

Storm start defined as the time Dst starts monotonically decreasing from -15nT

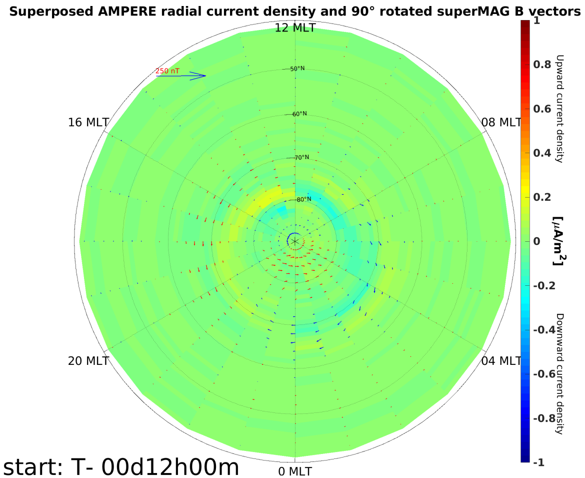
Superposed epoch analysis

- The analysis in this study is done using superposed epoch analysis of the 33 events with full data coverage
- Zero epoch = the time Dst crosses -15 nT (storm start)

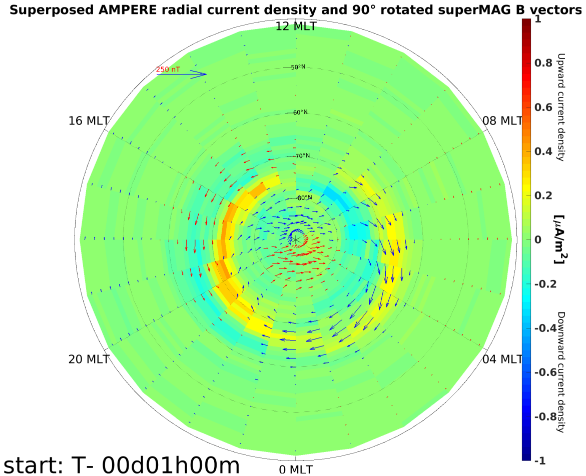
From the superposed epoch analysis we will be outlining the median value as well as the upper and lower quartiles. We chose the median/upper-lower quartiles over the mean/standard-deviation to make our data less affected by storms that's highly deviating from the average and to show a more realistic picture of the common behavior of the storms.



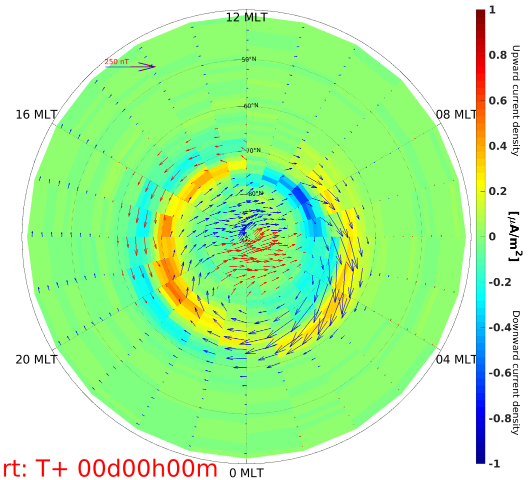
Superposed solar wind parameters from OMNIWeb.
Maximum B_T and negative B_Z are observed around storm start. Most storms begin in the early phase of the HSS, before the solar wind reaches 500 km/s and during the time the solar wind plasma is significantly compressed, around the peak of the solar wind dynamic pressure.



Storm start: T- 00d12h00m



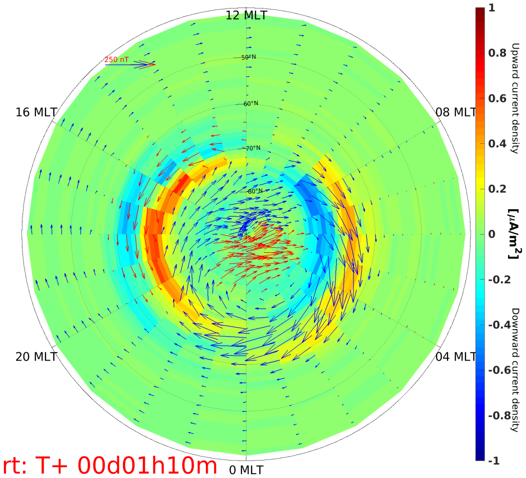
Storm start: T- 00d01h00m



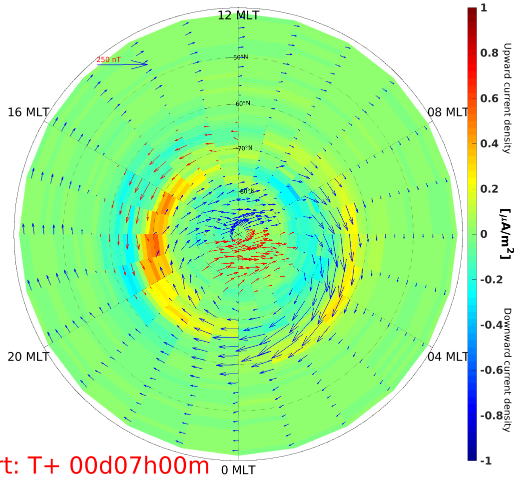
Storm start: T+ 00d00h00m
Storm start

Superposed AMPERE FAC density and SuperMAG rotated magnetic field perturbation from all 33 storms at different times with respect to the zero epoch

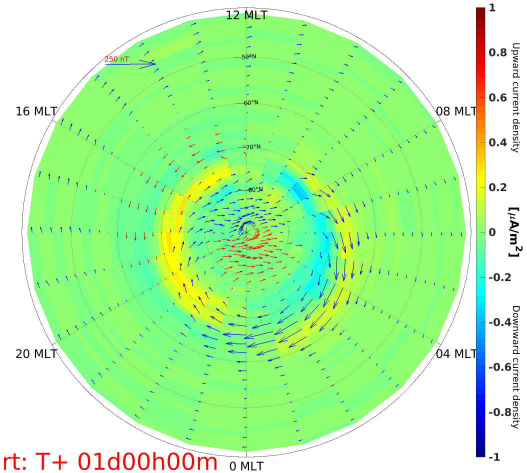
- 1st figure is 12 hours before zero epoch, during quiet time condition. Faint Region 1 and 2 currents visible
- 2nd figure show slight increase in both the upward and downward FAC and minor enhancements in both the westward electrojet (WEJ) and eastward electrojet (EEJ)
- 3rd figure is at the zero epoch corresponding to the time Dst crosses to < -15 nT



Storm start: T+ 00d01h10m
FAC maximum

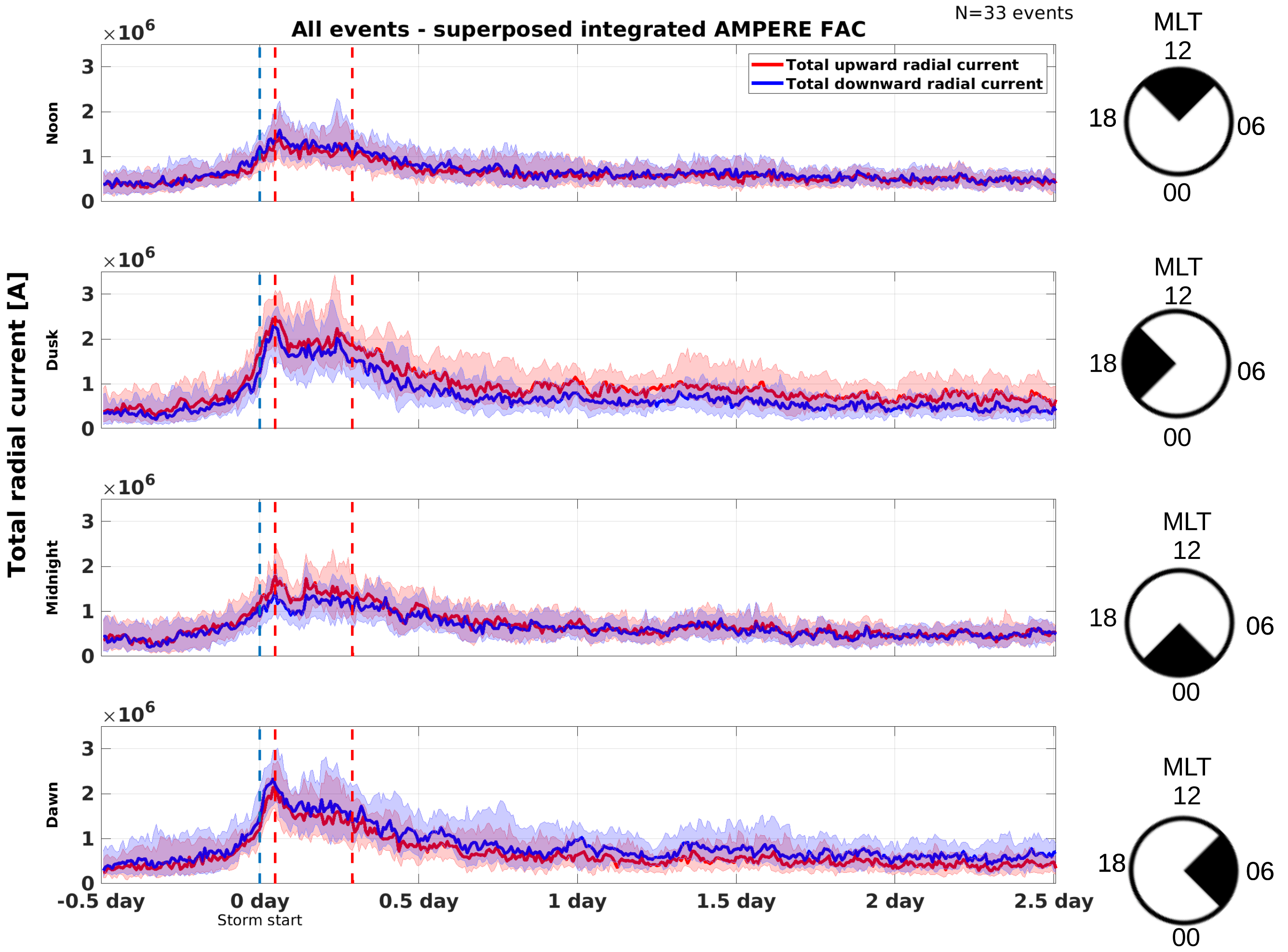


Storm start: T+ 00d07h00m
Dst minimum

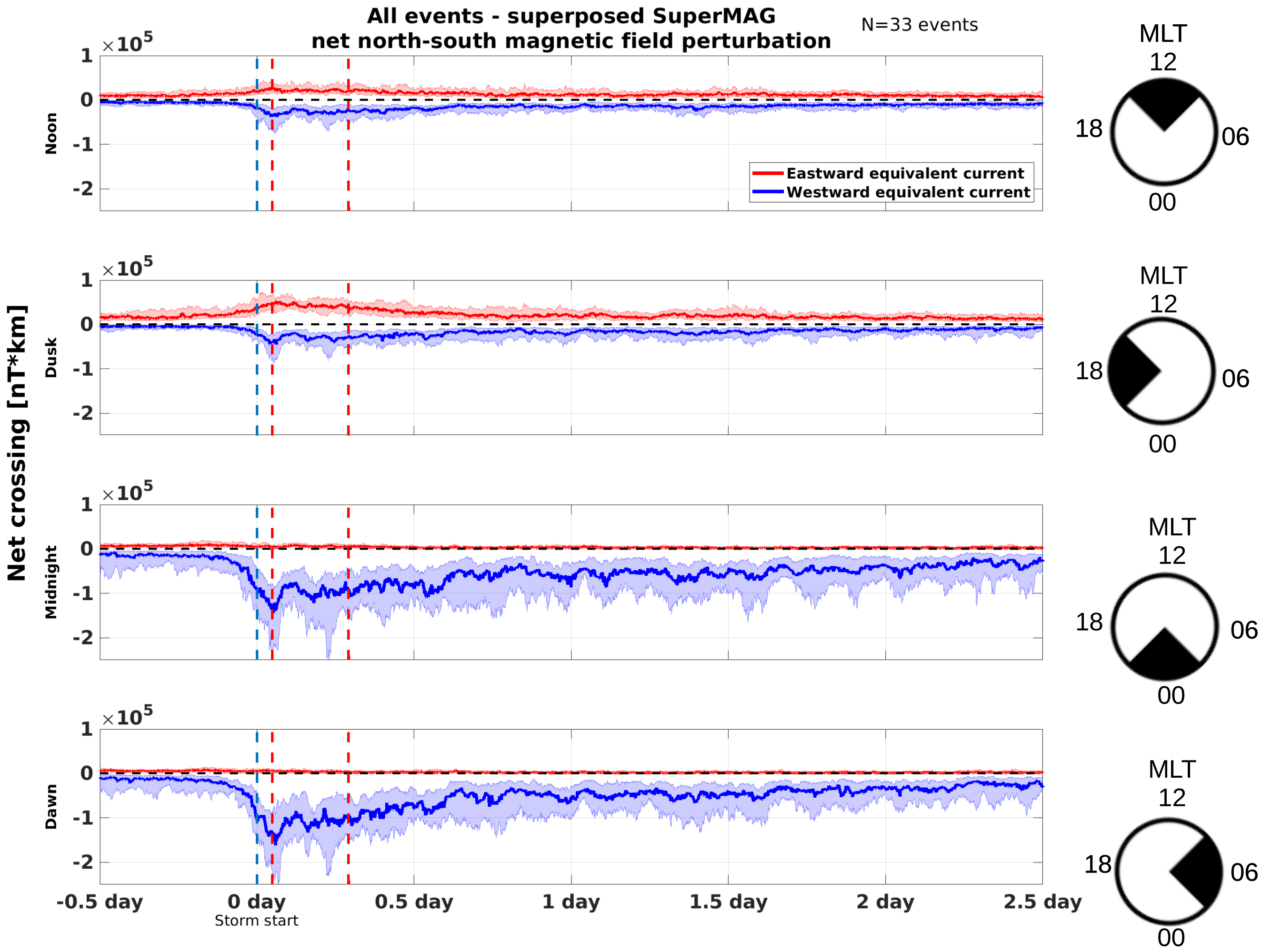


Storm start: T+ 01d00h00m
Recovery phase

- 4th figure is 1 hour and 10 minutes after zero epoch; time of maximum integrated FAC. Large enhancements in both Region 1 and 2 currents accompanied by large WEJ and EEJ
- 5th figure is at the Dst minimum
- 6th figure is one day after zero epoch, in the storm recovery phase. Ionospheric activity level still enhanced compared to the quiet time conditions



- Integrated AMPERE FAC – red line is the upward and blue is the downward FAC – shown here in four different MLT sectors
- Blue dashed line is the zero epoch. Red dashed lines show the time of maximum integrated FAC and Dst minimum (1 hour 10 mins and 7 hours after zero epoch, respectively)
- Current start responding to the storm before zero epoch and reaches a maximum integrated value 1 hour and 10 mins after zero epoch
- Maximum integrated FAC (|upward| + |downward|) = 16.2 MA
- At Dst minimum the peak activity level has passed
- Total integrated FAC at Dst minimum = 12.3 MA
- Largest currents and variability is observed in the dusk and dawn sector



- Integrated WEJ < 0, integrated EEJ > 0 (integrated from 54 to 76 MLat)
- Maximum horizontal current activity occurs at the same time as maximum integrated FAC from AMPERE
- Enhancement in horizontal currents closely resembles enhancement observed in the FAC
- Maximum integrated WEJ in dawn sector is ~ 3 times larger than maximum integrated EEJ in dusk sector
- WEJ extends far into the midnight sector and is of similar magnitude in both the dawn and midnight sector

Summary

- Work still in progress
- Majority of the geomagnetic storms starts in the early phase of the HSS/CIR events and the time of zero epoch coincides with the maximum IMF B_T and minimum IMF B_Z
- Ionospheric currents start to respond to the geomagnetic storm ~ 2 hours before the zero epoch, reaching maximum activity 1 hour and 10 minutes after zero epoch – 5 hours and 50 minutes prior to Dst minimum
- Maximum FAC and horizontal current activity observed at the same time
- Total integrated FAC at Dst minimum ~75% of maximum integrated FAC
- Largest FAC and variability observed in dusk and dawn sector. Largest horizontal currents observed in the dawn and midnight sector
- Maximum integrated WEJ in the dawn sector is 3 times larger than maximum integrated EEJ in dusk sector

References

- Partamies et al (2013). Statistical properties of substorms during different storm and solar cycle phases, Ann. Geophys., 31, 349-358, https://doi.org/10.5194/angeo-31-349-2013, 2013.
- Grandin et al. (2019). Properties and geoeffectiveness of solar wind high-speed streams and stream interaction regions during solar cycles 23 and 24. Journal of Geophysical Research: Space Physics, 124 https://doi.org/10.1029/2018JA026396

Data used in this study can be downloaded from:

AMPERE - http://ampere.jhuapl.edu/index.html
SuperMAG - http://supermag.jhuapl.edu/
OMNIWeb - https://omniweb.gsfc.nasa.gov/

Acknowledgement:

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