The Variation of Cusp and night-side O+ Outflow on Storm Time-Scales for Storms with Sawtooth Events

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1. Motivation and Methodology

Sawtooth events are repeated injection of energetic particles at geosynchronous orbit. More than 94% of sawtooth events occur during storm times, so storm time conditions such as the increased density and pressure of O^+ ions in the plasma sheet may be involved in driving sawtooth oscillations. The plasma sheet is populated with energetic O^+ outflow coming from both the day-side cusp and the night-side aurora. In our recent study, we observed that both cusp and night-side O^+ outflow can be strong during sawtooth events. In this study we are going to determine:

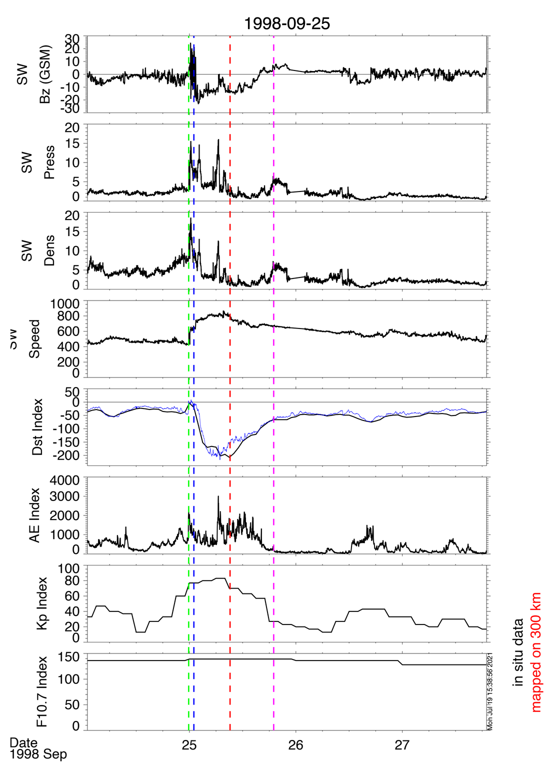
How the cusp and night-side O^+ outflow change on storm time-scales for storms with sawtooth events.

We will compare the cusp and night-side outflow during SIR and CME driven storms to determine whether the different storm drivers lead to different outflow characteristics.

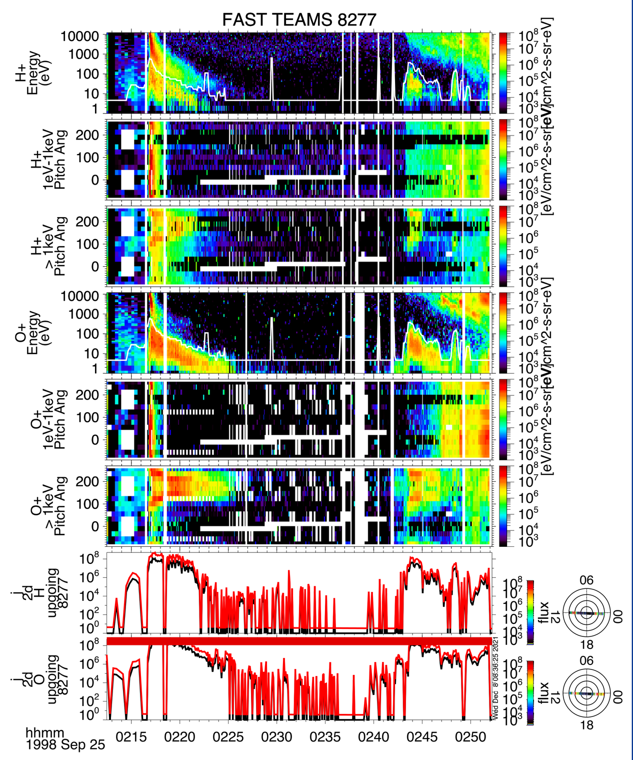
To do this in the first step:

1. We used OMNI data to determine the classical magnetic storms from 1996 to 2008. The $dst *_{minimum}$ is less than -50 nT, for a classical storm.
2. We determined the storm time scales:
- The **increase-time**, $t_{\text{increase time}}$, is when the solar wind pressure increases sharply.
- The **onset-time**, $t_{onset-time}$, is when the dst* index begins to decrease.
- The minimum dst time, $t_{dst^*_{minimum}}$, is when the dst* index reaches its minimum.
- The recovery time, $t_{recovery}$, is when the dst* index reaches $\frac{2}{3}\times dst^*_{minimum}$.
3. We determined the storm phases:
- Before-storm → $t_{\text{increaset time}} - 3\text{h} < \Delta t < t_{increase\ time}$
- Initial Phase → $t_{\text{increase time}} < \Delta t < t_{onset-time}$
- Main phase → $t_{onset-time} < \Delta t < t_{dst^*_{minimum}}$
- Recovery phase → $t_{dst^*_{minimum}} < \Delta t < t_{recovery}$

➢ A classical storm is shown on the left .The vertical lines show the storm time-scales.



Solar wind data for a classical storm



TEAMS summary plot

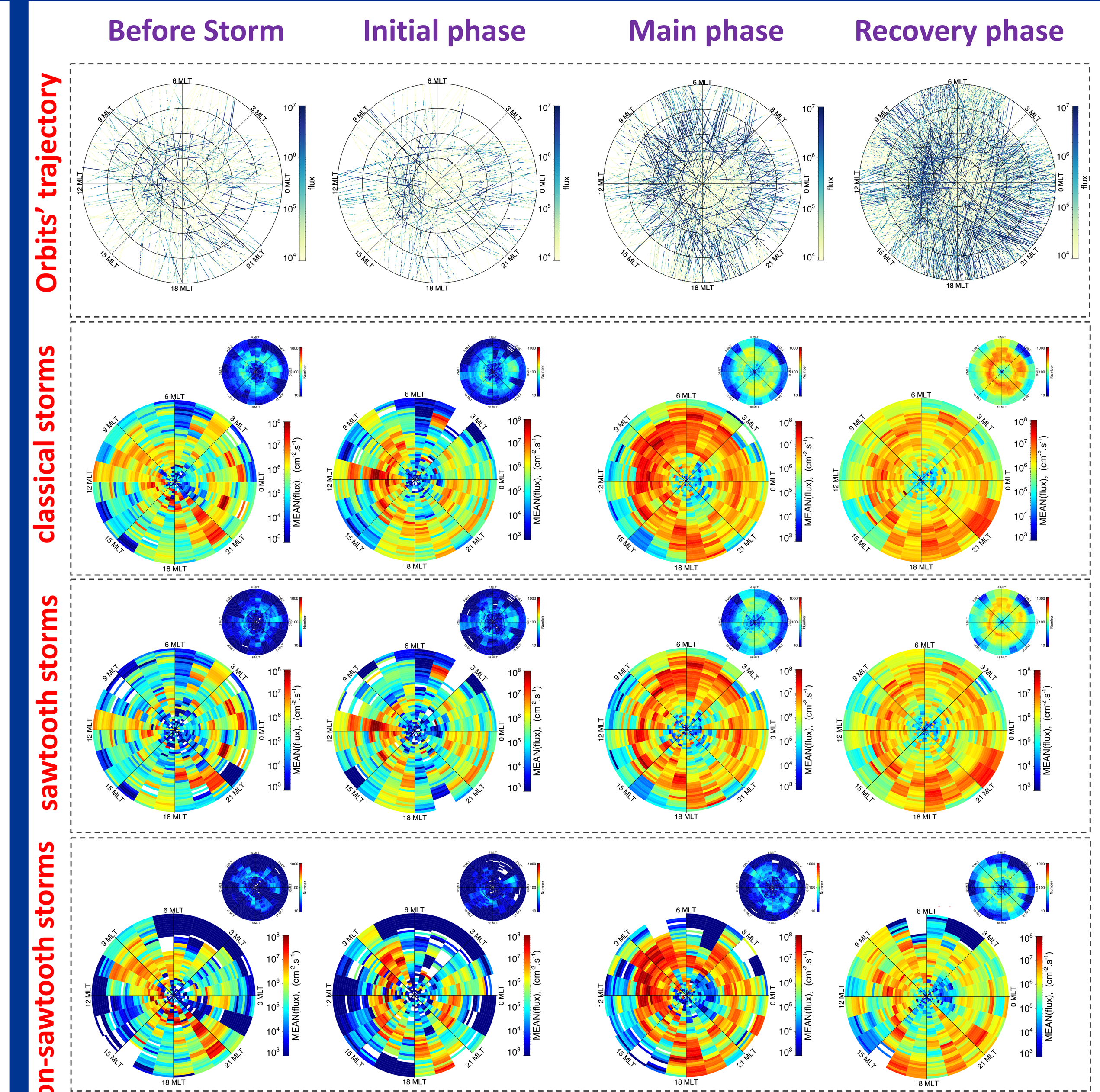
Then, in the second step:

1. We calculated O^+ and H^+ outflow from FAST(TEAMS) data.

➢ A TEAMS summary plot, which is related to the storm main phase, is presented on the right

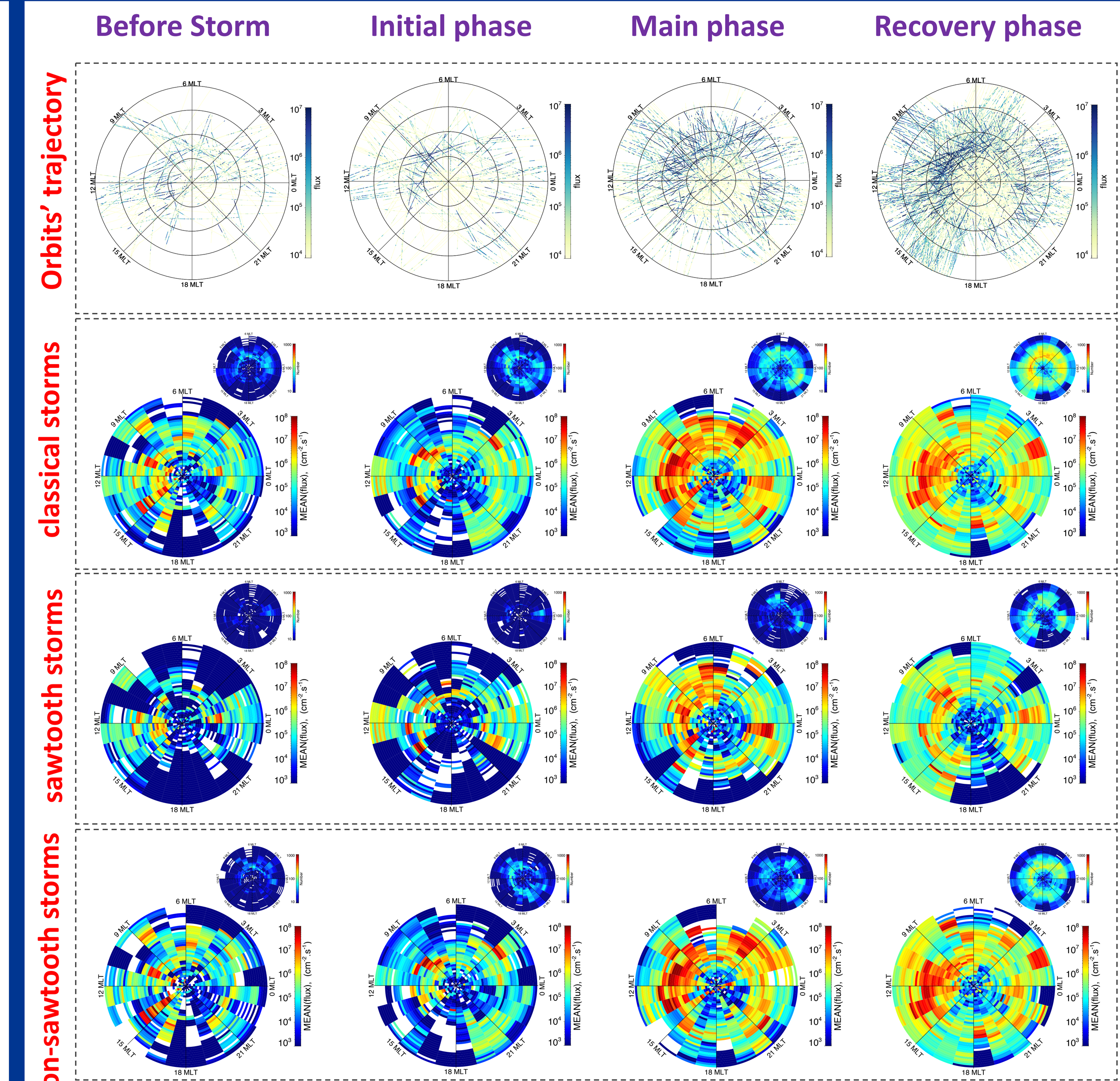
2. The data must meet the following conditions:
   $a.\ Altitude > 1500\ km$
   $b. 50° < Invariant\ latitude(ILAT) < 90°$
   $c. Spacecraft\ potential > -6\ eV$
   $d. 6eV < data\ energy < cutoff\ energy$
3. The cutoff energy is shown with a white line in the energy spectrograph panels.
4. We mapped the calculated outflow flux on $300km$ altitude and showed it along the FAST trajectory over the polar cap in in the top row of sections 2-5
5. We grouped O^+ and H^+ outflow fluxes based on:
   a. CME and SIR as the storm drivers
   b. Storm phases of **before-storm**, **initial**, **main, and recovery phases**, as storm timescales.
6. Also, we divided the classical storms into two groups of storms with sawtooth and storms without sawtooth.
7. We binned the Magnetic Local Time, MLT, and ILAT into 24 and 40 bins with resolutions of $1h$ and 1°, respectively.
8. For each storm-time and storm-type group in #4 and #5, all fluxes located in each bin are averaged. The big globe plots present the averaged outflow flux in MLT-ILAT bins.
9. The number of data points in each ILAT-MLT bin is counted and shown in the small globe plots on the top of the big dial plots.
10. Finally, the total **fluence** of data in each globe plot is calculated, and the results are plotted in section 6. $\boldsymbol{fluence_{tot}} = \sum_{j=0}^{40\times24}(\frac{\sum flux_i}{n_i}\times A_j)$

2. O^+ outflow during CME storm



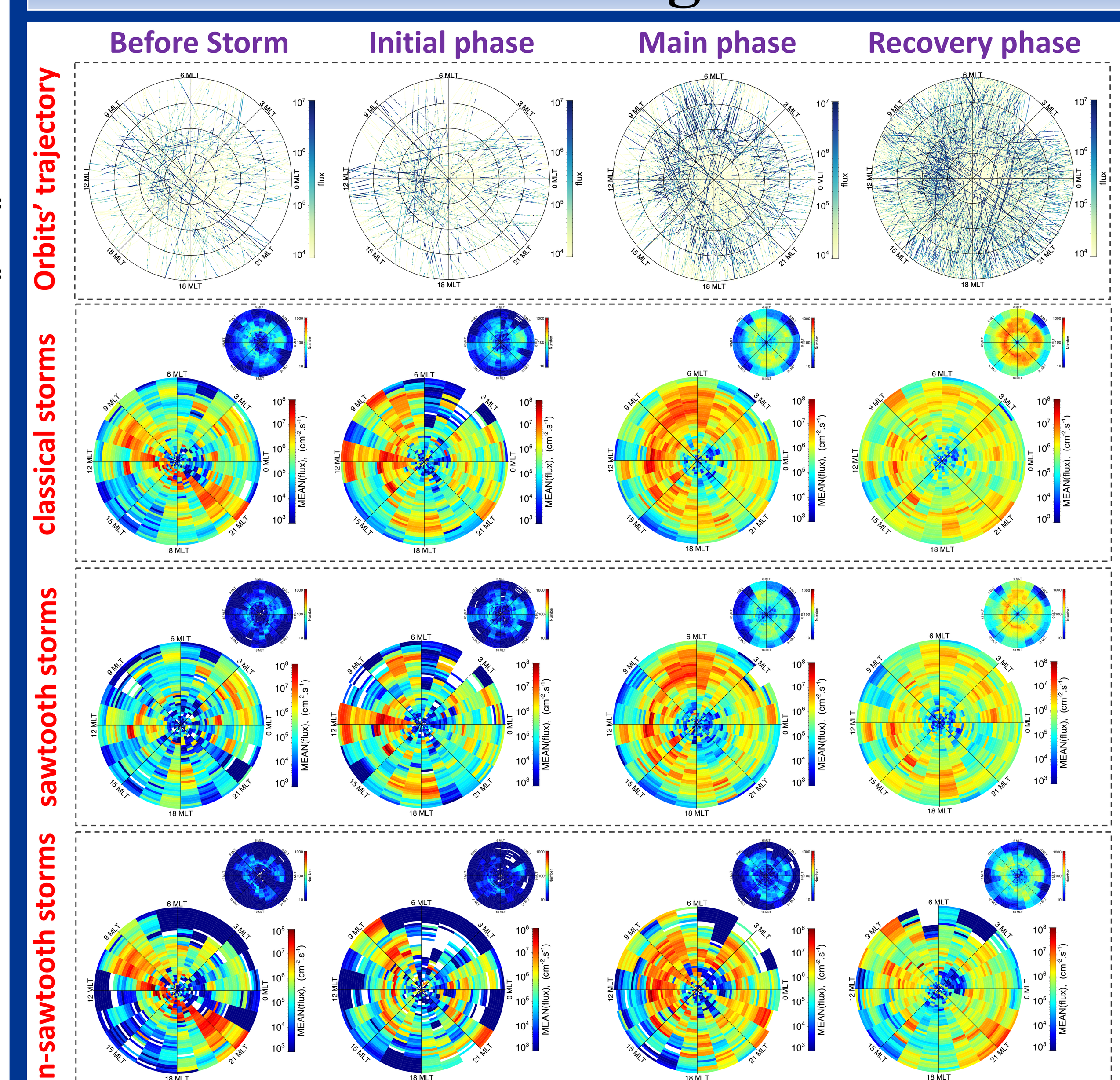
- The O^+ outflow shows an increase in the cusp day-side in the initial phase
- The O^+ outflow increases in all MLT sectors of the main phase. The dominance of flux is in the day-side and then in the dawn-side sector.
- Except for the first hours of the night-side sector, the O^+ outflow decreases in the recovery phase.
- The night-side O^+ is stronger in the main and recovery phases of sawtooth storms than non-sawtooth storms
- The non-sawtooth outflow is more poleward and centralized while the sawtooth outflow is broader and more equatorward.

3. O^+ outflow during SIR storms



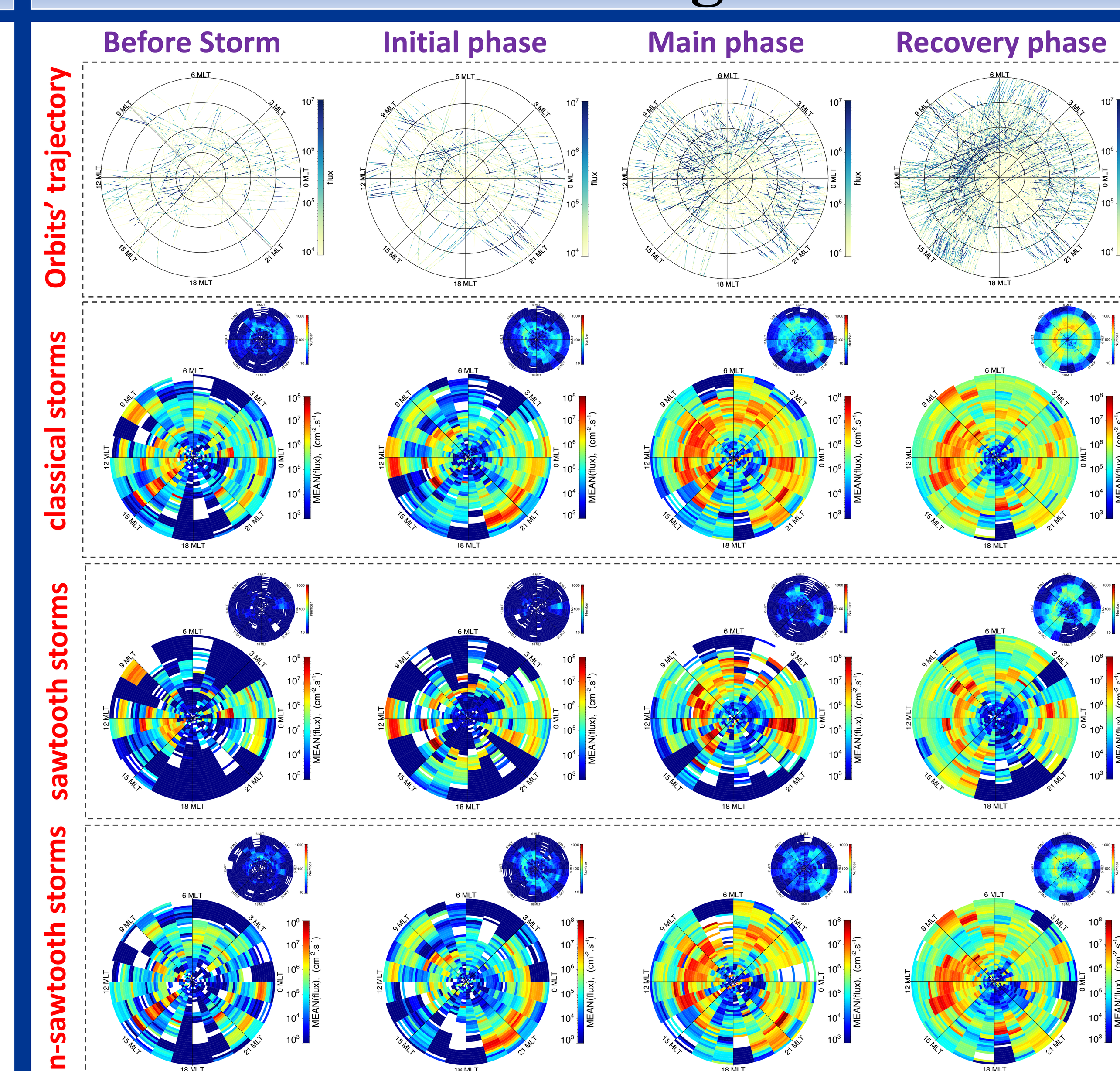
- The O^+ outflow increases in the cusp day-side and nighties, in the initial phase
- The O^+ outflow increases in all MLT sectors of the main phase. Although the dominance of flux is in the day-side, dawn-side and pre-midnight experiences an increase, too.
- The O^+ outflow decreases in the recovery phase. The cusp flux is still prominent
- In the main and recovery phases, the night-side O^+ flux, only near midnight, is stronger for sawtooth storms than non-sawtooth storms
- In all storm phases, the cusp day-side O^+ is stronger for non-sawtooth storms than sawtooth ones.

4. H^+ outflow during CME storm



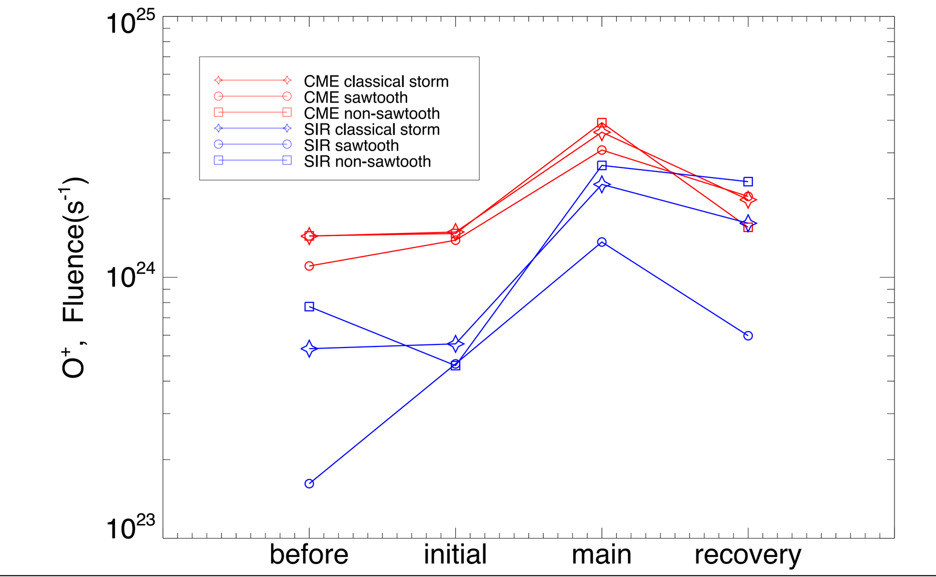
- The H^+ flux increases in the cusp day-side and dawn-side in the initial phase.
- The H^+ outflow in the dawn-side and day-side increases in the main phase and stretches to all the MLT sectors
- H^+ flux decreases in the recovery phase.
- In the main phase, the equatorward H^+ outflow in the dawn-side is significant in sawtooth storms. Nevertheless, the non-sawtooth storms show more outflow for the cusp and night-side.

5. H^+ outflow during SIR storms

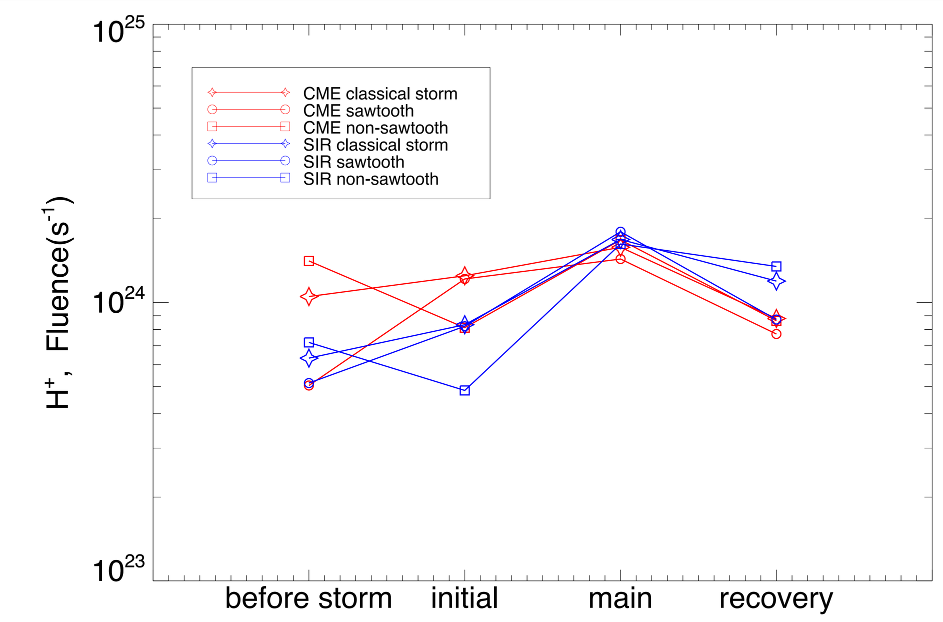


- The H^+ outflow increases in the cusp day-side and after dusk, in the initial phase
- The H^+ outflow increases in all MLT sectors of the main phase. The dominance of flux is in the day-side sector and then pre-midnight.
- The H^+ outflow decreases in the recovery phase. The dominant flux is in the day-side in the recovery phase.
- In the main and recovery phases, the H^+ flux in the night-side and near midnight is stronger for sawtooth storms than non-sawtooth storms
- In all storm phases, the cusp day-side H^+ is stronger for non-sawtooth storms than the sawtooth storms.

6. FLUENCE



- O^+ fluence in CME storms is stronger than SIR storms in all storm phases, even before starting the storms.
- For recovery and main phases of SIR storms, the fluence of non-sawtooth storms is stronger than sawtooth storms.



- In the initial phase, the H^+ fluence in CME storms is stronger than SIR storms
- In the main phase, the H^+ fluence of SIR storms is very close or even more than CME storms.
- In the recovery phase, the H^+ fluence of SIR storms is higher than CME storms

7. Summary

- ✓Using OMNI data, 153 classical storms are identified from 1996-10 to 2008-10
- ✓For that period, FAST(TEAMS) data is used, and the O^+ and H^+ outflow is measured.
- ✓The variation of O^+ and H^+ outflow fluxes are studied for storm time scales and storm drivers, CME and SIR.

❑ Our study shows that
- ✓after initiating the storm, the cusp day-side increases. This increase is more in the sawtooth storms than in the non-sawtooth storms.
- ✓For all storms, the main phase contains the highest outflow flux over the polar region.
- ✓The dominant H^+ and O^+ outflow flux are in the dawn-side for sawtooth-storm and on the day-side for non-sawtooth storms.
- ✓The outflow flux in the recovery phases reduces.
- ✓For all phases of CME and SIR driven storms, O^+ outflow is stronger than H^+ outflow, either in sawtooth or non-sawtooth storms.
- ✓O^+ outflow flux is more during CME storms than SIR storms.

8. References

- *Cully et al. 2001,* 10.1029/2002JA009457
- *Lund et al. 2018,* 10.1002/2017JA024378
- *Mouikis et al. 2019,* 10.1029/2019JA026695
- *Kistler et al. 2019,* 10.1029/2019JA027061