The Variation of Ionospheric Outflow during Magnetic Storms

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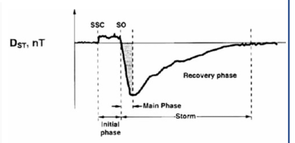
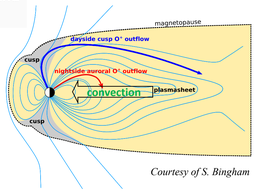
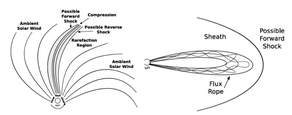
1- Introduction

Geomagnetic storms are periods, lasting from hours to days when the interplanetary medium alters the configuration of the Earth's magnetic field.
The Dst index, which is the H component of the ring current magnetic field, is widely used to numerically identify: the presence, intensity, and phases of a storm.



- The magnetospheric **plasma** originates from:
  - solar wind(H^+, He^{++})
  - Ionosphere(H^+, He^+, O^+)
- Plasma sheet:
  - Quiet time: H^+
  - Active time: O^+ increases significantly
- The only source of plasma sheet O^+ ions is:
  - ionosphere
- In the ionosphere, O^+ ions are generated in:
  - Dayside cusp
  - Nightside aurora

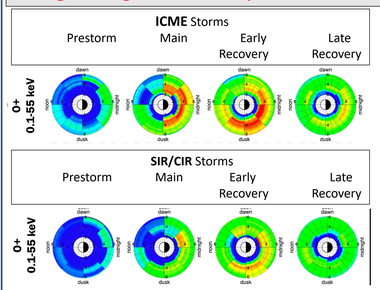




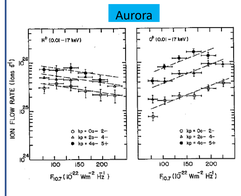
CME and SIR are two prominent structures of solar wind which produce geomagnetic storms

2- Motivation

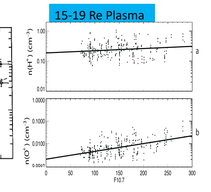
There are two factors for increasing O^+ density in the plasma sheet:
- solar EUV activity
- geomagnetic activity



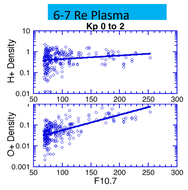
- (Mouikis et al., 2019) studied the variation of O+ pressure as a function of storm phases epoch time in the **ring current**
- Also, he showed the O+ pressure is stronger during CME storms than in SIR storms (of similar size).



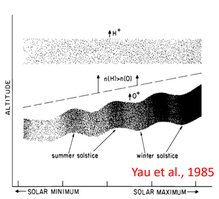
Yau et al., 1988



Mouikis et al. 2010



Kistler et al. 2016



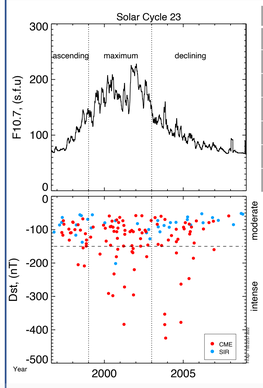
Yau et al., 1985

	ionosphere	Mid tail	Inner plasm sheet
Kp and H^+	decrease	no change	no change
Kp and O^+	increase	increase	increases
F10.7 and H^+	increase	no change	increase
F10.7 and O^+	increase	increase	increase
EUV and H^+	No change	Slight increase	Slight increase
EUV and O^+	increase	increase	increase

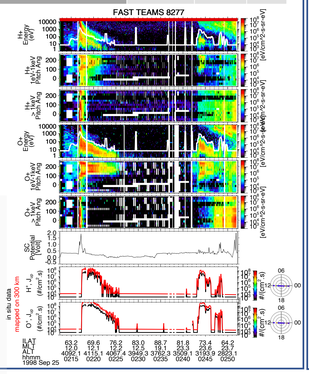
➢Questions:

1. How do O^+ and H^+ vary with storm phase?
2. How does it depend on the storm driver (CME vs SIR)
3. What is the effect of storm's intensity on O^+ and H^+ outflow?
4. How does the solar cycle affect the ionospheric O^+ and H^+ outflow?
5. How do the local seasons affect the ionospheric O^+ and H^+ outflow?

3- Data and Methodology

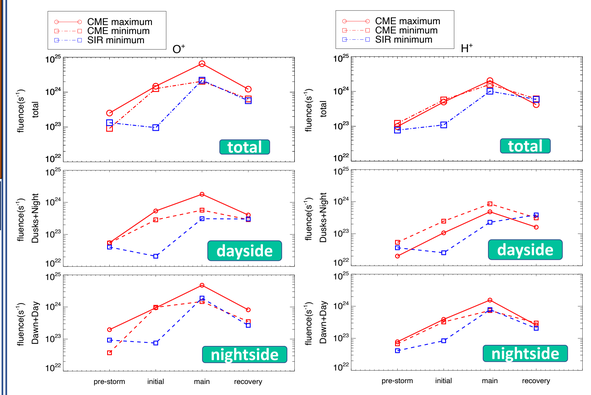


	TOTAL	CME	SIR
total storms	139	104	35
intense storm(I-storm)	27	26	1
moderate storm(M-storm)	112	78	34
M-storm, maximum phase	45	37	8
M-storm, MIN phase	67	41	26
M-storm, summer	45	30	15
M-storm, winter	69	41	17



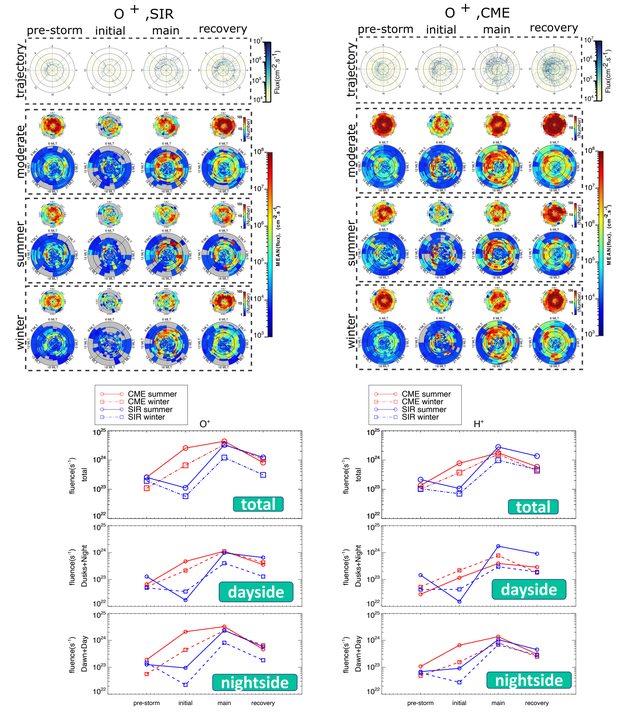
- The O^+ and H^+ outflow flux is calculated from the FAST(TEAMS) data and mapped on 300km
- The data must meet the following conditions:
  a. $Altitude > 1500\ km$
  b. $50° < Invariant\ latitude(ILAT) < 90°$
  c. $Spacecraft\ potential > -6\ eV$
  d. $7eV < data\ energy < cutoff\ energy$

5- Observations, (solar EUV)



- For CME storms, the total O^+ fluence during solar maximum is stronger than during solar minimum, except for the initial phase.
- In the (day + dawn) sector, during the solar minimum phase, the CME and SIR storm produce almost equal fluence of O^+ and H^+, except for the initial phase.
- In the (disk + night) sector, during the solar minimum phase, the CME storm produces slightly more fluence of O^+ than SIR storms in the main phase.
- For CME storms, the H^+ total fluence is the same for solar maximum and solar minimum
- For CME storms, the H^+ (dusk + night) side fluence is slightly stronger in solar maximum than in solar minimum.

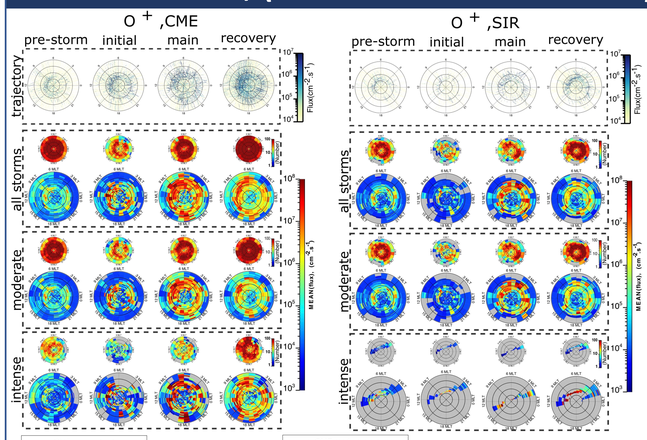
5- Observations, (seasonal effect)



➢ **SIR storms:**
- In the dayside and nightside, the O^+ fluence is stronger in the summer than in winter. In the dayside, the H^+ fluence is stronger in the summer than in winter. On the nightside, it is almost independent of the season

➢ **CME storms:**
- In the main and recovery phases, the O^+ and H^+ fluences are independent of seasonal effect

4- Observations, (storm driver and intensity)



➢ **CME storms:**
- All storms panel:

-In pre-storm, the O^+ outflow presence in the dayside

-In the initial phase, the O^+ outflow increases in the polar region with the dominance in the dayside sector.

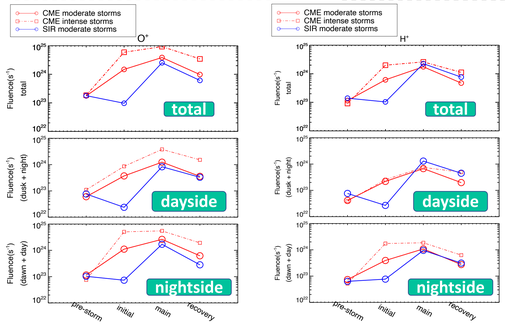
-The main phase contains the strongest O^+ outflow. The high outflow covers all MLT sectors. The dominance is still in the dayside.

-In the recovery phase The O^+ outflow significantly decreases in all MLT sectors.

- Both moderate and intense storms follow the above trend for O^+ variation as a function of storm phases.
- Although the coverage of intense storms is not as well as moderate storms, for all storm phases, it is obvious the O^+ outflow of the intense storm is more intense than the moderate storms

➢ **SIR storms:**

-In the initial phase, no meaningful increase is observed in the polar region for the O^+ outflow.
- The variation of O^+ outflow in the storm phases is similar to CME storms.



$$fluence = \sum_j \left(\left(\frac{\sum_i flux_i}{n_i} \right)_j \times A_j \right), \qquad n_i: number\ of\ data\ sample\ in\ bin\ i, A_j$$

- Intense CME storms produce more total O^+ and H^+ fluences than moderate CME storms.
- Moderate CME storms produce more O^+ fluence than moderate SIR storms.
- During SIR storms, the O^+ and H^+ fluences increase in the **main** phase and decrease in the recovery phase
- During CME storms, the O^+ and H^+ fluences increase in the **initial** phase, reach their maximum in the main phase, and decrease in the recovery phase
- The difference between SIR and CME storms in the initial phase originates from the stronger shock in CME structures which produce dayside O^+ outflow
- (Dawn + Day) side produce more O^+ outflow than (dusk + night) side, either for CME and SIR storms.

6- Conclusion

1. Effects of storm phase, solar driver, and storm intensity
- Ionospheric outflow changes significantly with storm phase on both the dayside and the nightside, with the strongest outflow in the main phase, and reduced but still significant outflow during the recovery phase.
- The main difference between CME and SIR storm outflow is that the outflow in CME storms is enhanced during the **initial phase**. This is likely because CME storms more frequently have enhanced pressure that precedes the southward turning.
- The O^+ outflow is higher during intense storms than moderate storms
- For the same sized storms, the O^+ outflow during CME and SIR storms is about the same.

2. Effects of solar cycle.
- O^+ outflow is enhanced by ~ a factor of 4-5 in solar maximum compared to solar minimum during the storm main phase. H^+ outflow is about the same.
- During solar minimum, the SIR and CME outflow is about the same.

3. Effects of season
- The O^+ outflow during CME's is not significantly effected by the season. The O^+ outflow during SIR's is stronger during summer.
- The H^+ outflow on the dayside is strongest during SIR summer. On the nightside, it is almost independent of season.

4. Implications
- Our results, in general, support the previous measurements based on KP that show both a geomagnetic activity and solar EUV impact on outflow.
- We do not find that CME's have more O^+ outflow than SIR's for the same size storm. We suggest that the reason that the ring current has a stronger O^+ response during CME's (Mouikis et al) may be because of the O^+ enhancement during the storm initial phase. The initial phase outflow allows the O^+ to populate the plasma sheet before the main phase, so that it can be injected into the ring current during the main phase.