Characteristics of CME- and CIR-driven ion upflows in the polar ionosphere

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Outline

1. Introduction of ion upflow on the Earth
2. Data
3. (1) Results at 66 deg Invariant lat.
   during CIR- and CME-driven storms
   (2) Results at 75 deg Invariant lat.
   during CIR- and CME-driven storms
   (3) Comparison with Weimer model
4. Summary

Background

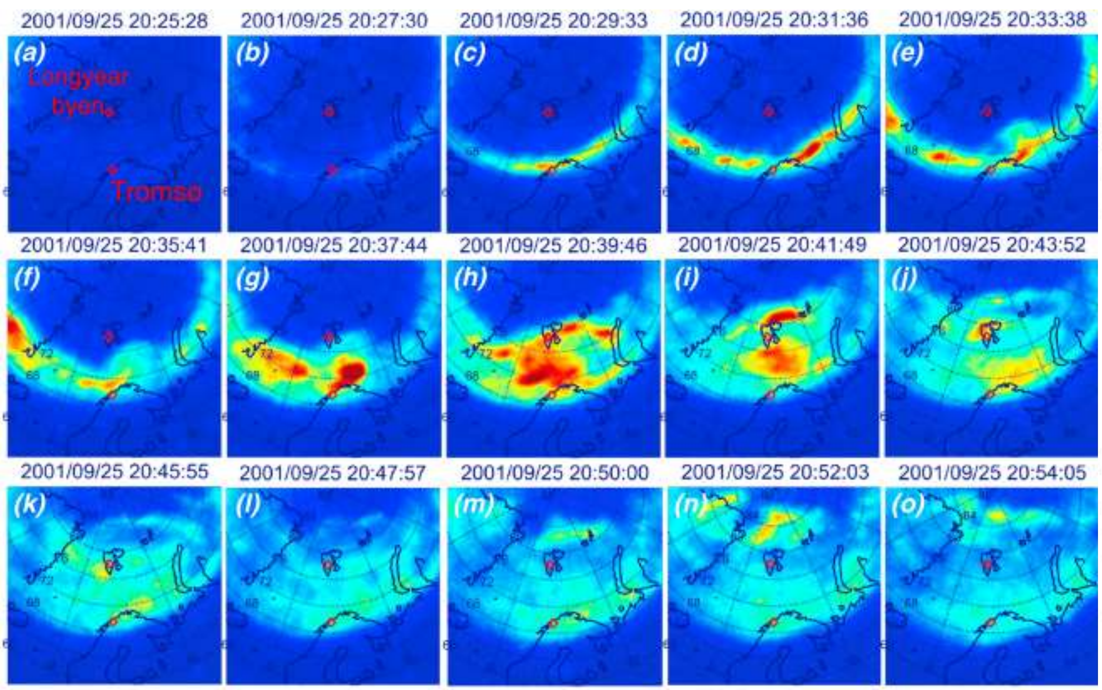
- It is well known that ionospheric ions gain kinetic energy and electromagnetic energy originating from the solar wind and escape from the polar ionosphere to the magnetosphere.

- Its escape rate has been estimated using several methods such as in-situ measurements and modeling [e.g., Seki et al., 2001; Ebihara et al., 2006; Engwall et al., 2009].

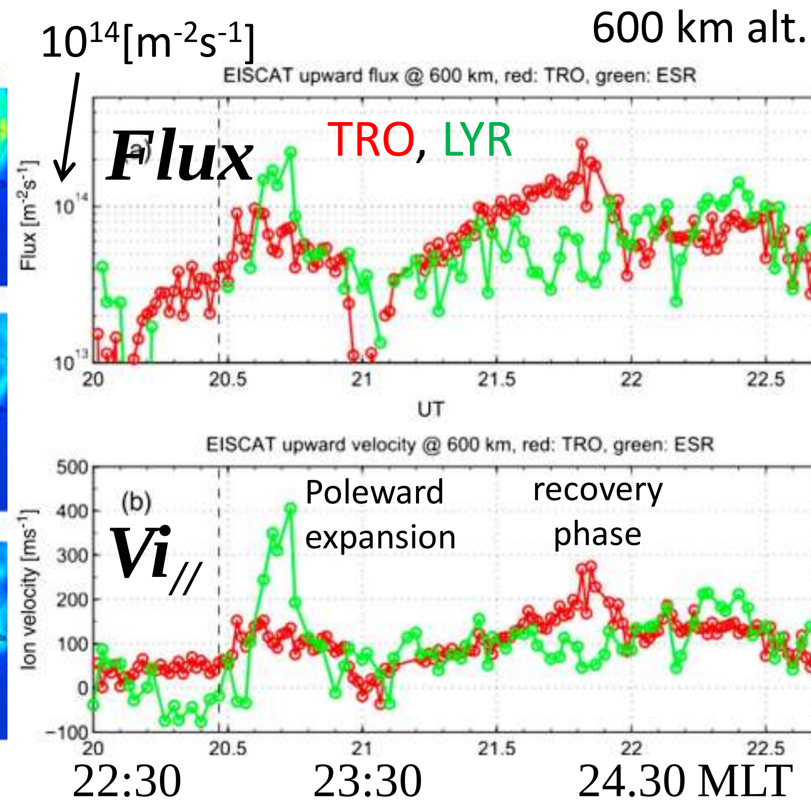
- When magnetic storms occur, velocity and flux of the escaping ions largely increase. Oxygen ions originated from the ionosphere are fed into the plasma sheet as well as the inner magnetosphere. The energy density of the oxygen ions can become dominant in the ring current [e.g., Gloeckler et al., 1985; Hamilton et al., 1988; Keika et al., 2013] and in the plasma sheet [Nosé et al., 2001, 2005] during magnetic storms.

Background

In the polar ionosphere, ion upflow is frequently seen during auroral substorm [e.g., Ogawa et al., 2013], which is most likely associated with the ion outflow measured in the bottomside magnetosphere [Wilson et al., 2004].



Aurora images (every two minutes) during a substorm obtained with the IMGE WIC on September 25, 2001.



Upward ion velocity and flux measured with EISCAT radars at two sites.

[Ogawa et al., 2013],

Background

- A typical duration of a substorm is about a few hours. Multiple substorms happen recurrently during the main phase of magnetic storms. Thus, continued, substantial ion upflow is expected during the storm main phase.

- A previous case study shows strong ion upflow associated with soft (< 500 eV) particle precipitation during the main phase and the beginning of the recovery phase of magnetic storms [Liu et al., 2000].

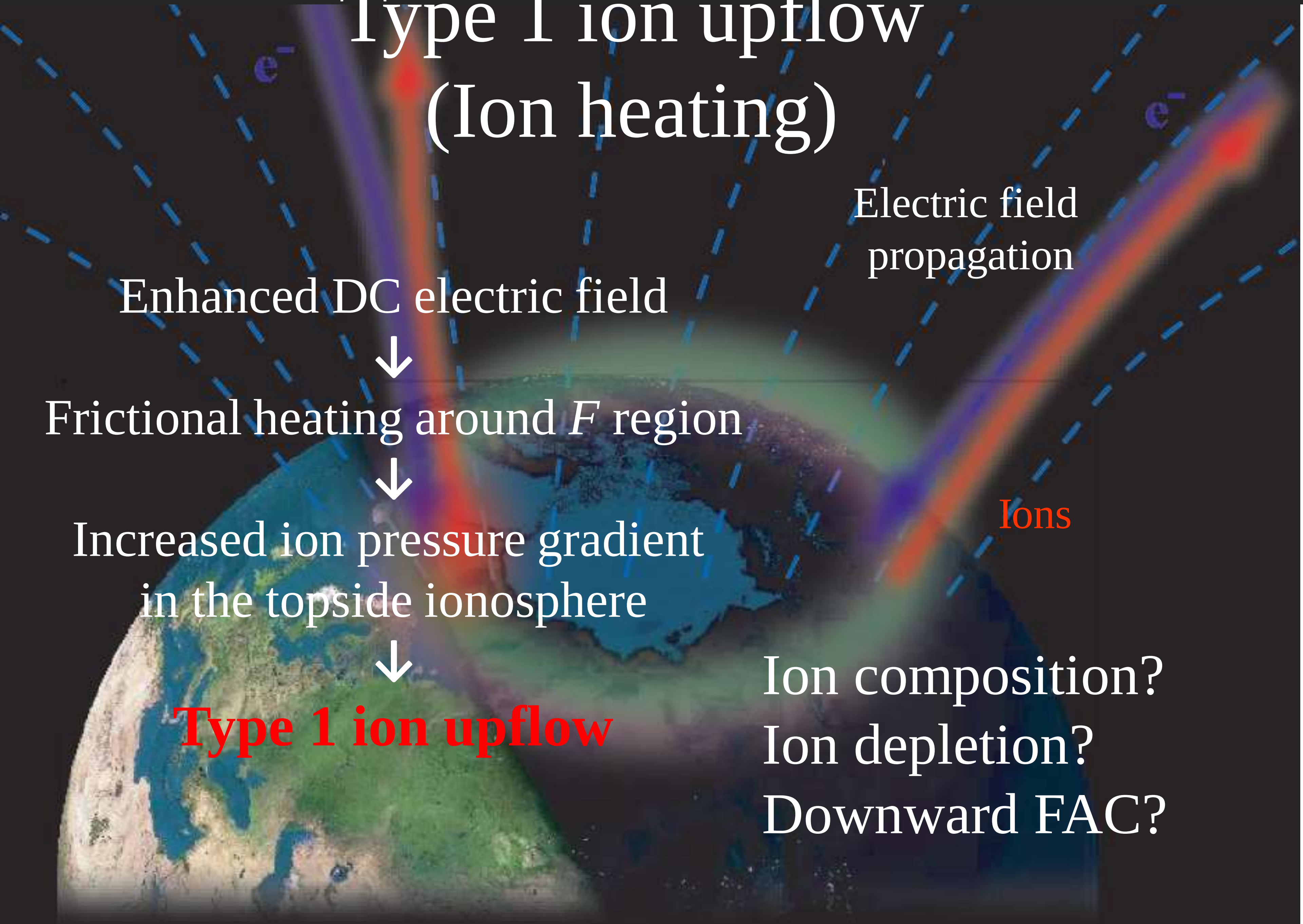
- However, effects of storms on ion upflows have not been systematically investigated because of a limited number of datasets. Thus, it had been difficult to understand long-timescale processes of ion escape from the topside ionosphere to the bottom-side magnetosphere.

Objectives

1. How velocity and flux of ionospheric ion upflows vary during magnetic storms driven by corotating interaction regions (CIRs) and coronal mass ejections (CMEs).
2. How those ion upflows are related to ion and electron heating, and also joule heating rate and field-aligned current distribution.

- This basic knowledge about the response of the Earth's atmosphere to CMEs and CIRs will contribute to understanding of the response of the atmosphere in other planets.

Type 1 ion upflow
(Ion heating)



Enhanced DC electric field

↓

Frictional heating around *F* region

↓

Increased ion pressure gradient
in the topside ionosphere

↓

Type 1 ion upflow

Ion composition?
Ion depletion?
Downward FAC?

Type 2 ion upflow (electron heating)

e⁻

Precipitations
&
heat flow

Ions

Particle precipitation and heat flow
by electrons from the magnetosphere

↓

Ionization & electron heating
in the *F* region ionosphere

↓

Increased electron pressure gradient
in the topside ionosphere

↓

Increased ambipolar electric field
(and parallel electric field
[Kagan and St-Maurice, 2005])

↓

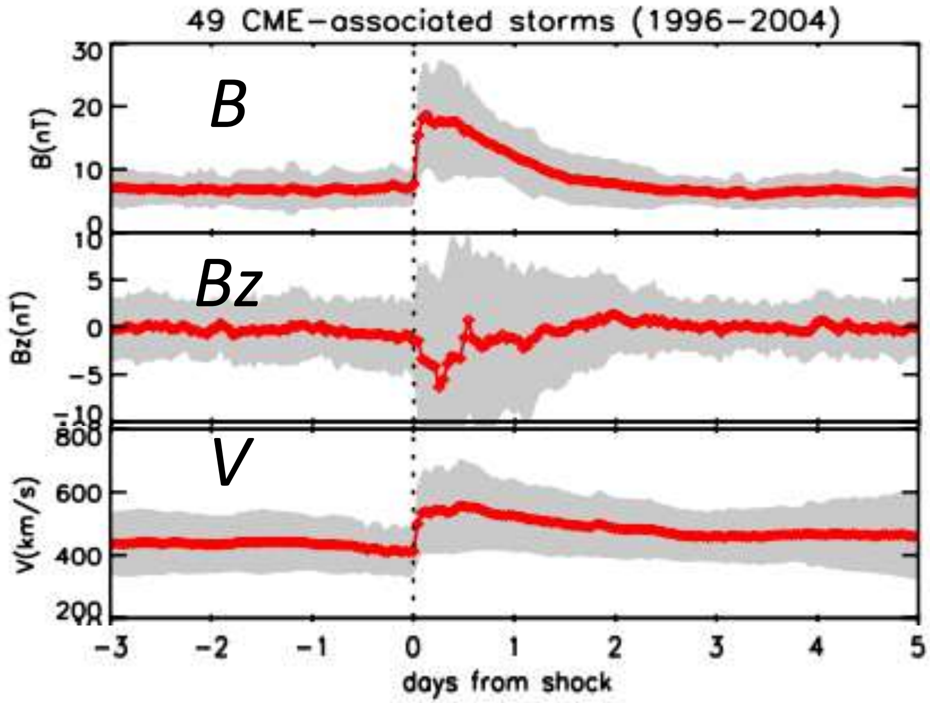
Type 2 ion upflow ←······?······→

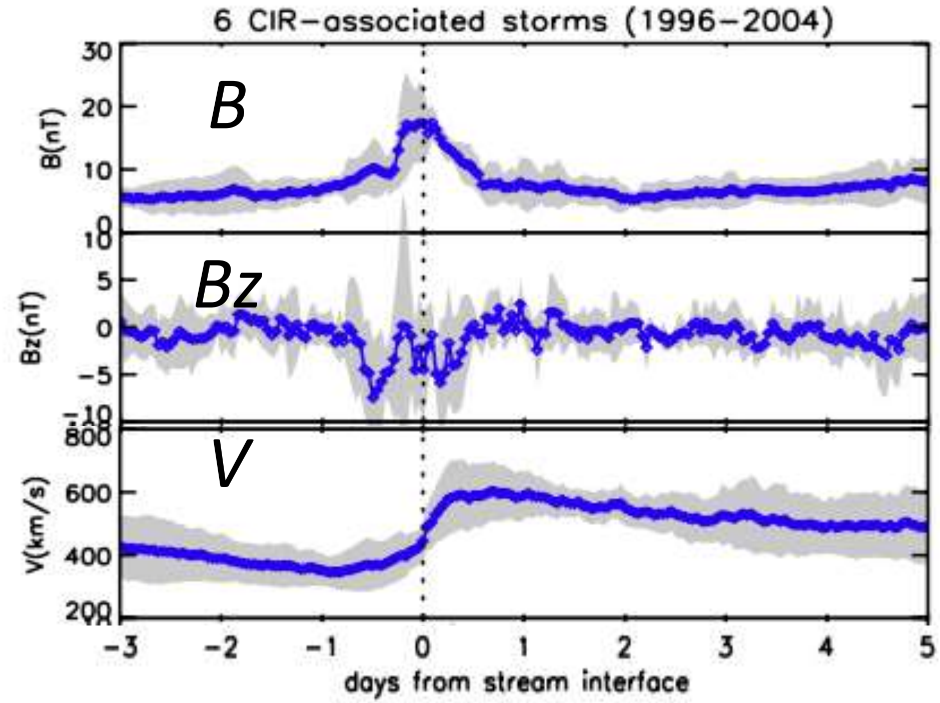
Transversely accelerated ions (TAIs)
in the lower magnetosphere

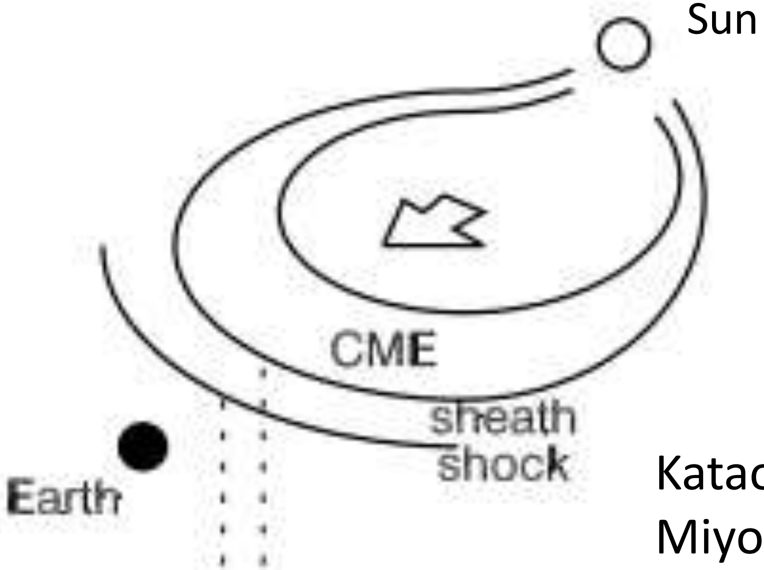
Related plasma waves:

- Electromagnetic ion cyclotron (EMIC) waves
  → Cyclotron resonance
- Lower Hybrid (LH) waves
- Broadband low-frequency waves (a few Hz)
  → Non-resonant sloshing [Norqvist et al., 1998]
- Ion-acoustic waves
  → Shear-modified Ion-Acoustic (SMIA) Instability [Teodorescu et al., 2003]
- Dispersive Alfvén waves [Chaston et al., 2004; 2007]

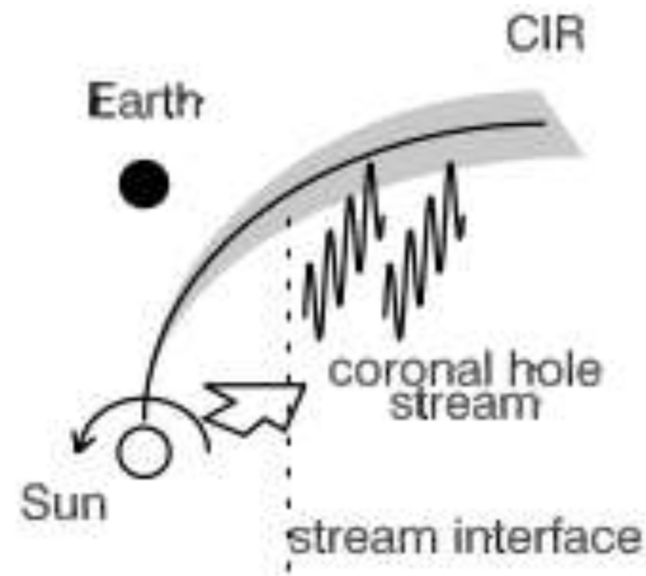
Typical characteristics of CME and CIR







Kataoka and Miyoshi, 2006



EISCAT radar observations

- Invariant lat. 66.2 deg,
  69.6 deg North, 19.2 deg East
- Observation starts since 1981.

- Invariant lat. 75.2 deg,
  78.2 deg North, 16.1 deg East
- Observation starts since 1996.

Observational parameters: *Ne*, *Te*, *Ti*, and *Vi*

In this study, we used the parameters at altitudes between 400 and 500 km during the periods between 1996 and 2015.

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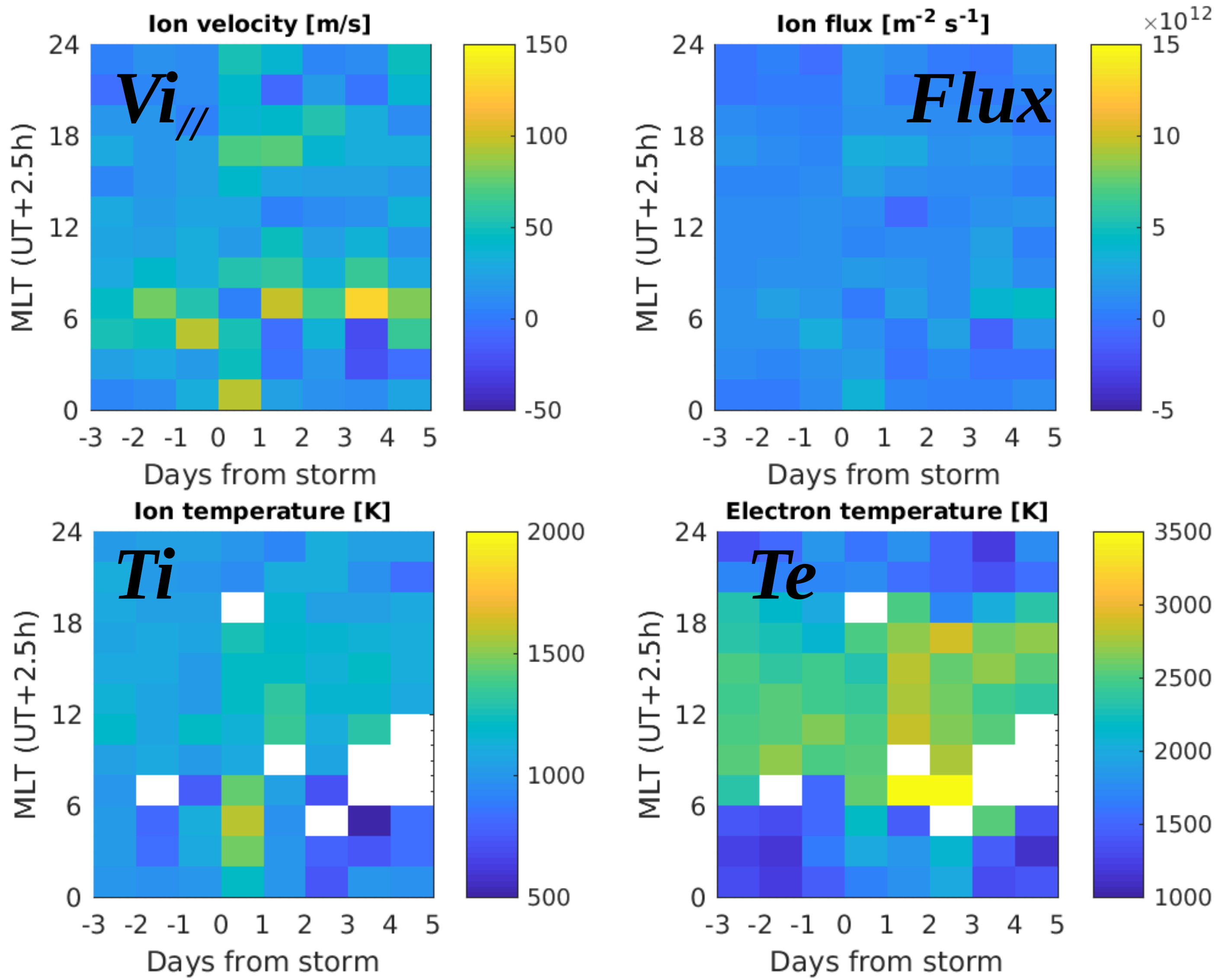
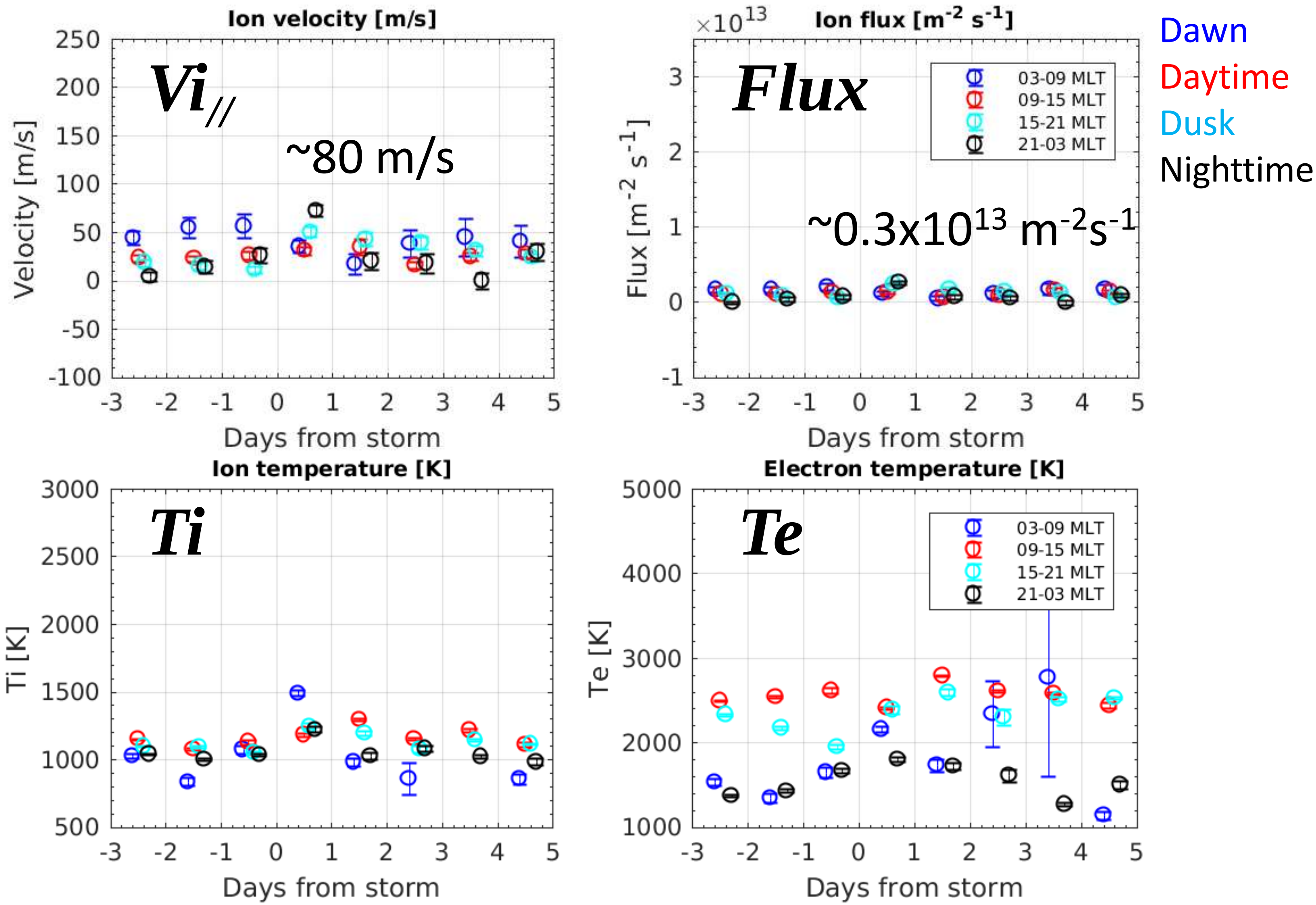
All CIR-driven storms, 66 deg mlat



Altitudes: 400 and 500 km

Upward ion velocity increases at dusk and night-side regions just after the storm onset.
Their upward ion fluxes are relatively small (~ 0.3×10^{13} $m^{-2}s^{-1}$), due to low ion density at altitudes.

All CIR-driven storms, 66 deg mlat

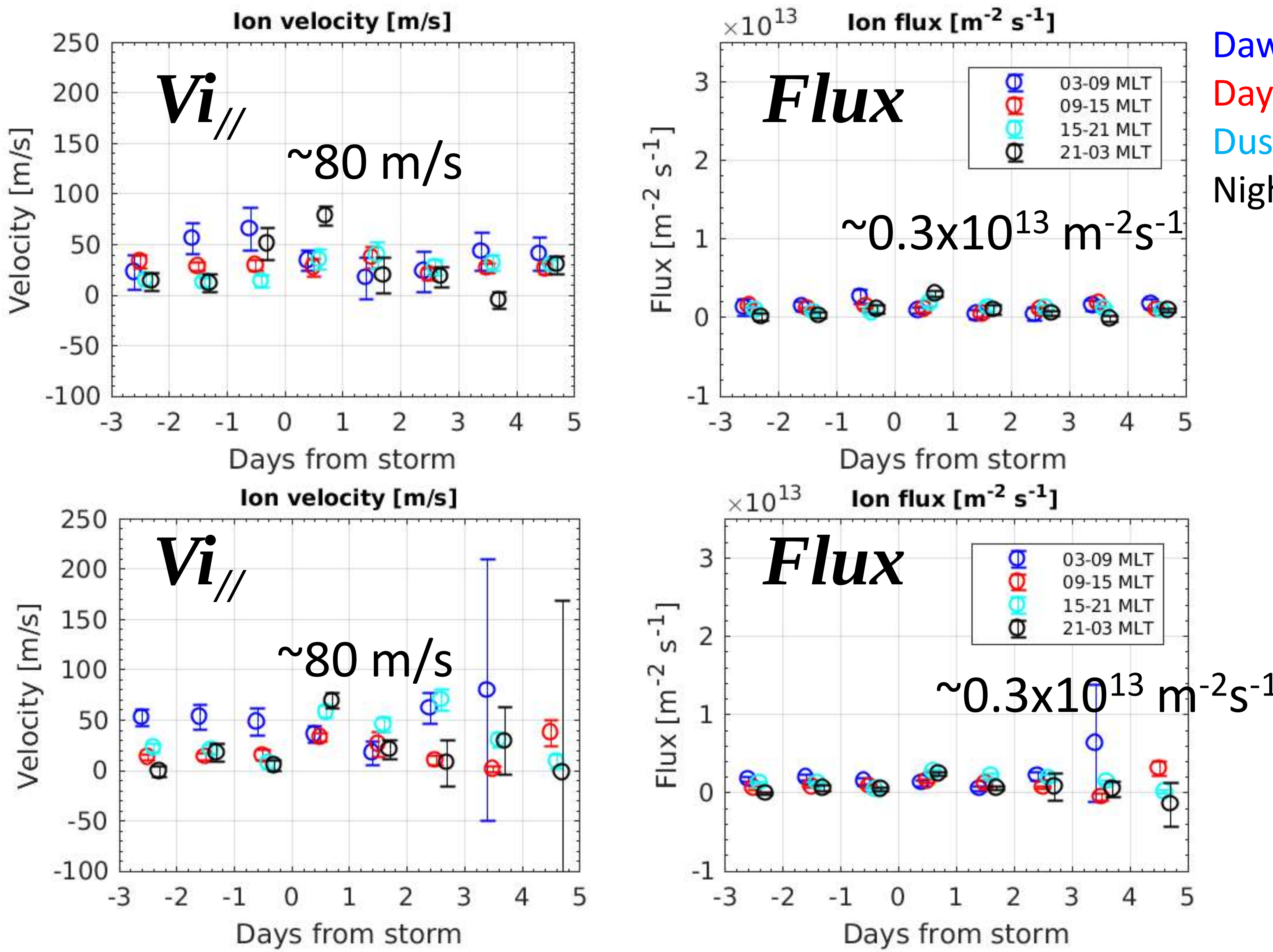


Upward ion velocity increases at dusk and night-side regions just after the storm onset.
Their upward ion fluxes are relatively small (~ 0.3×10^{13} m^{-2}s^{-1}), due to low ion density at altitudes.

Small & Large CIR storms, 66 deg mlat

Dst minimum > -60 nT

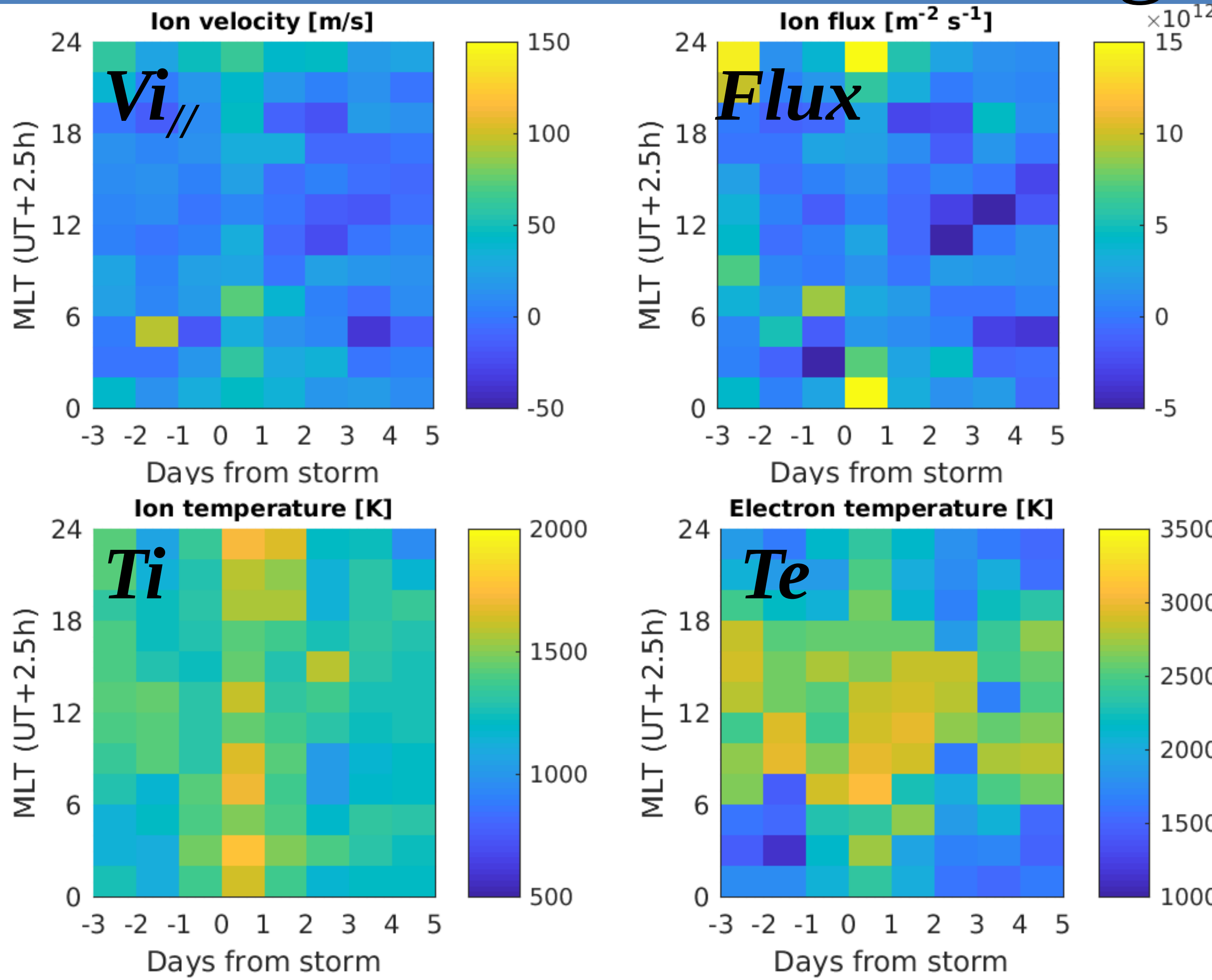
Dst minimum < -60 nT



Dawn
Daytime
Dusk
Nighttime

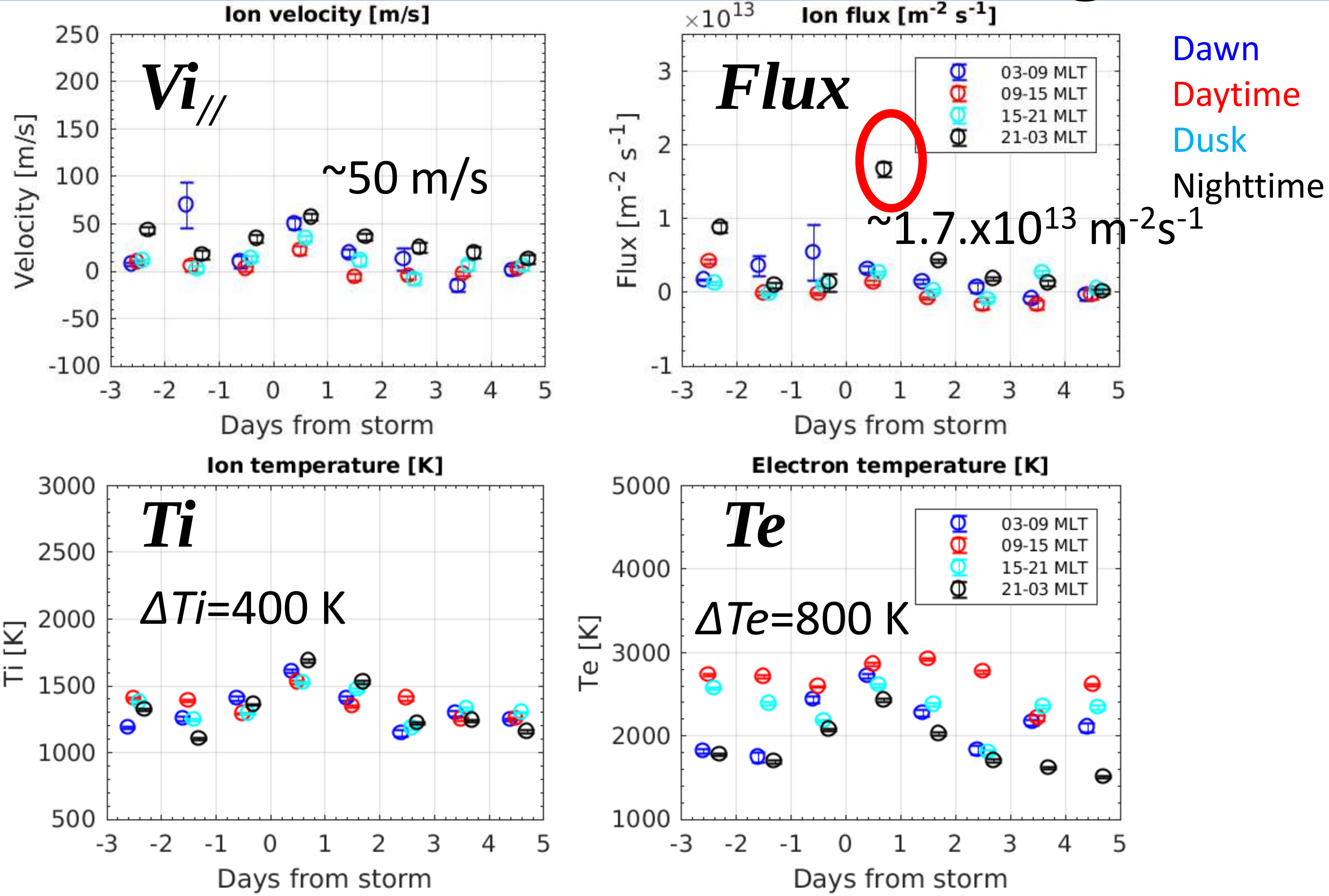
Characteristics of ion velocity and flux under small CIR-driven storms are similar to those under large CIR-driven storms. Ion upflow occurs in the nighttime on the first day of the storm onset.

All CME-driven storms, 66 deg mlat



$Vi_{//}$ becomes slightly increasing at all MLT sectors just after storm onset, and upward flux dramatically increases in the nighttime . The upward flux drastically decreases on the second and third days of storm. Ti and Te show similar characteristics of the ion velocity variations.

All CME-driven storms, 66 deg mlat

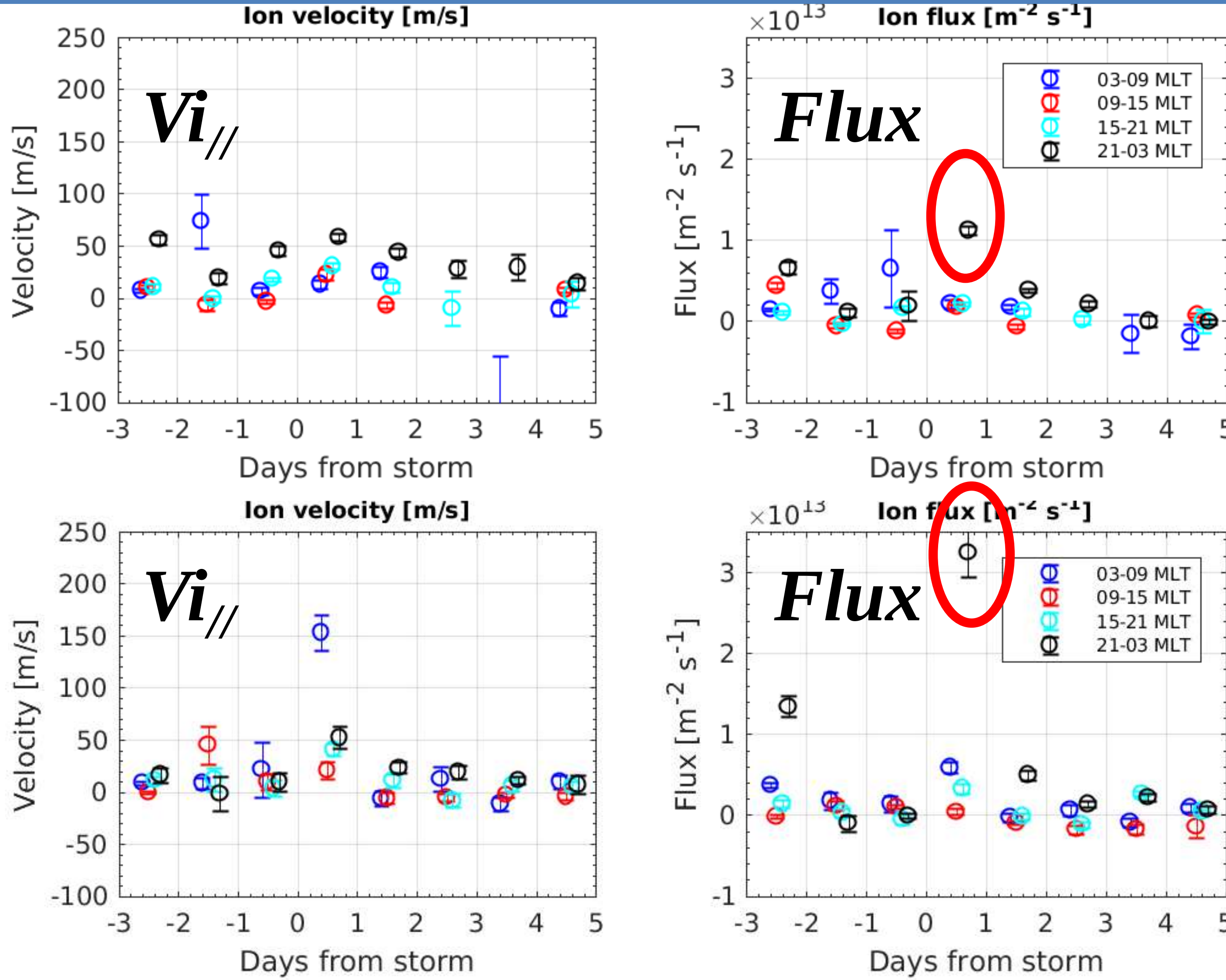


$Vi_{//}$ becomes slightly increasing at all MLT sectors just after storm onset, and upward flux dramatically increases in the nighttime . The upward flux drastically decreases on the second and third days of storm. Ti and Te show similar characteristics of the ion velocity variations.

Small & Large CME storms, 66 deg mlat

Dst minimum > -150 nT

Dst minimum < -150 nT

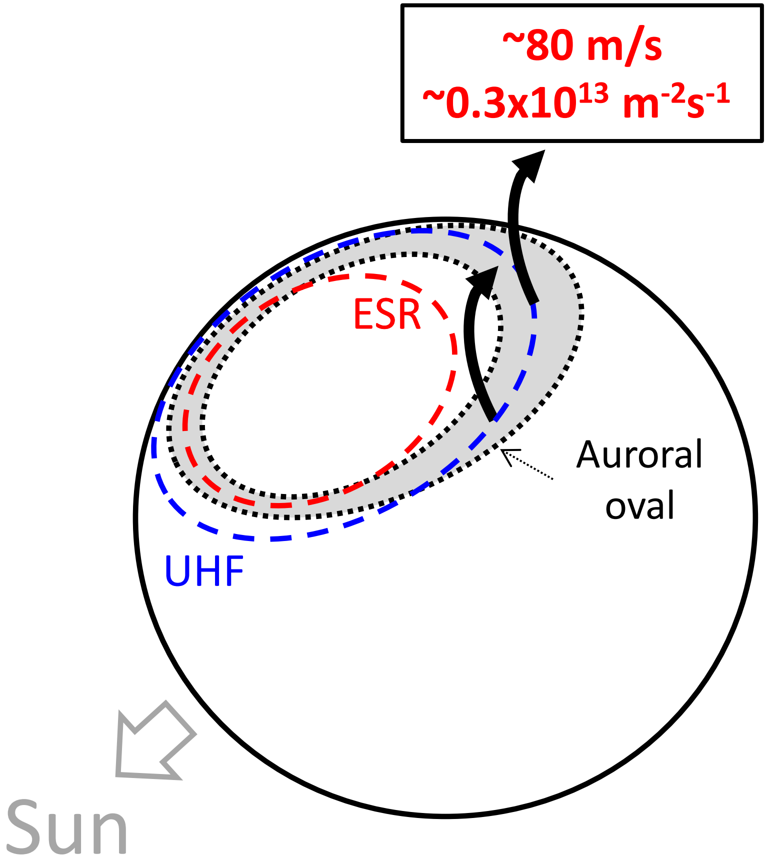


Dawn
Daytime
Dusk
Nighttime

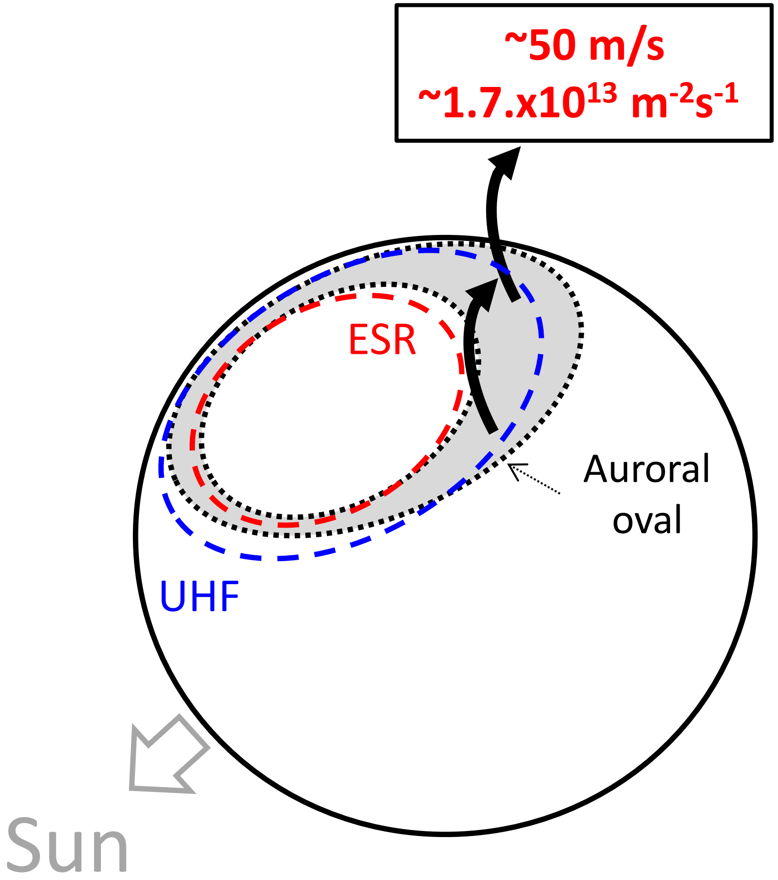
Upward ion flux in the nighttime on the first day of storm is clearly different between small and large CME storms. Under the large CME-driven storm, upward velocity also becomes large in the dawn region on the first day of the storm, but its flux is less than 1.0x10^{13} m^{-2}s^{-1} .

Summary of results at 66.2 deg mlat

CIR case



CME case



CME-driven storms have about six times larger upward ion flux than those under CIR-driven storms, although $Vi_{//}$ is comparable.

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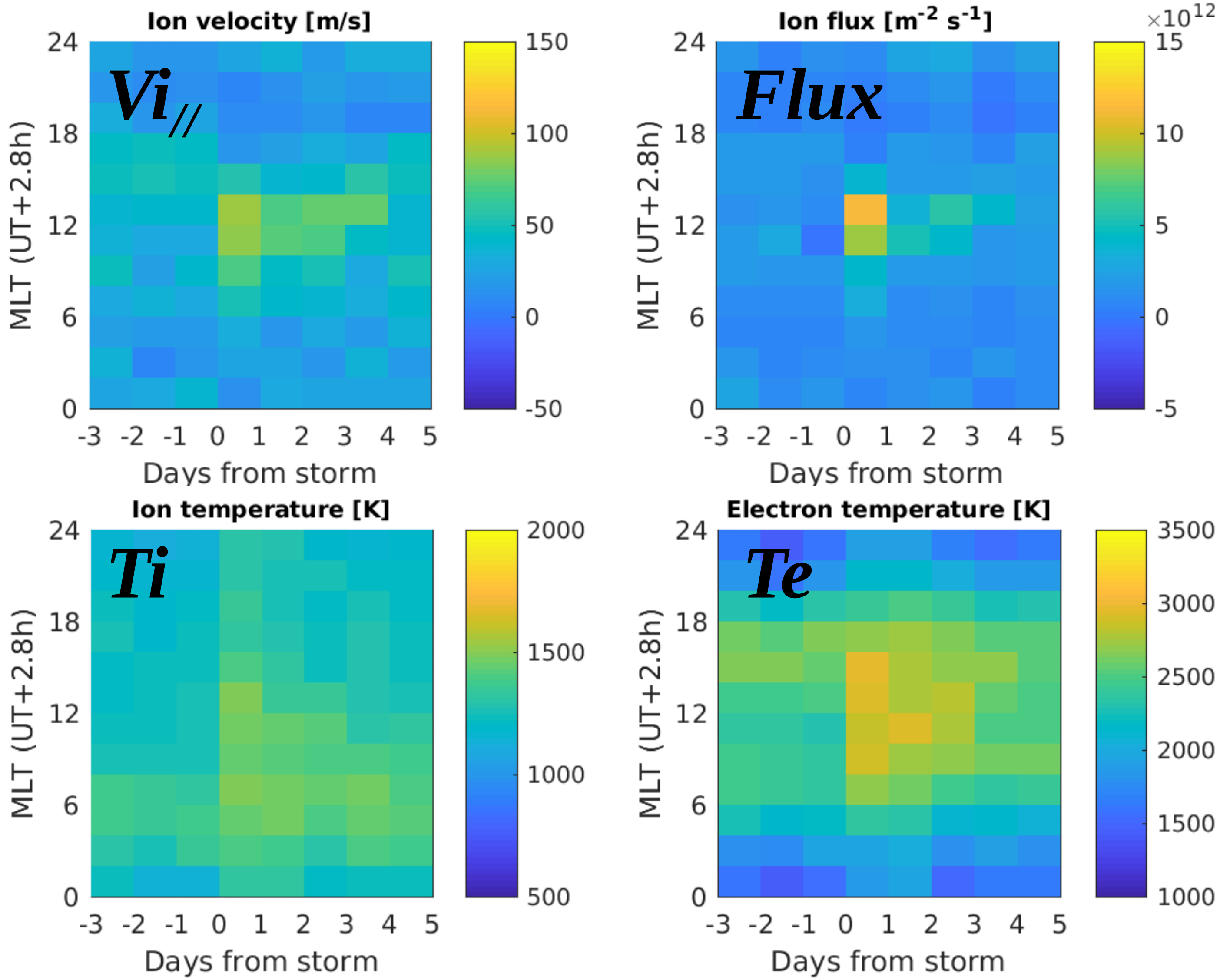
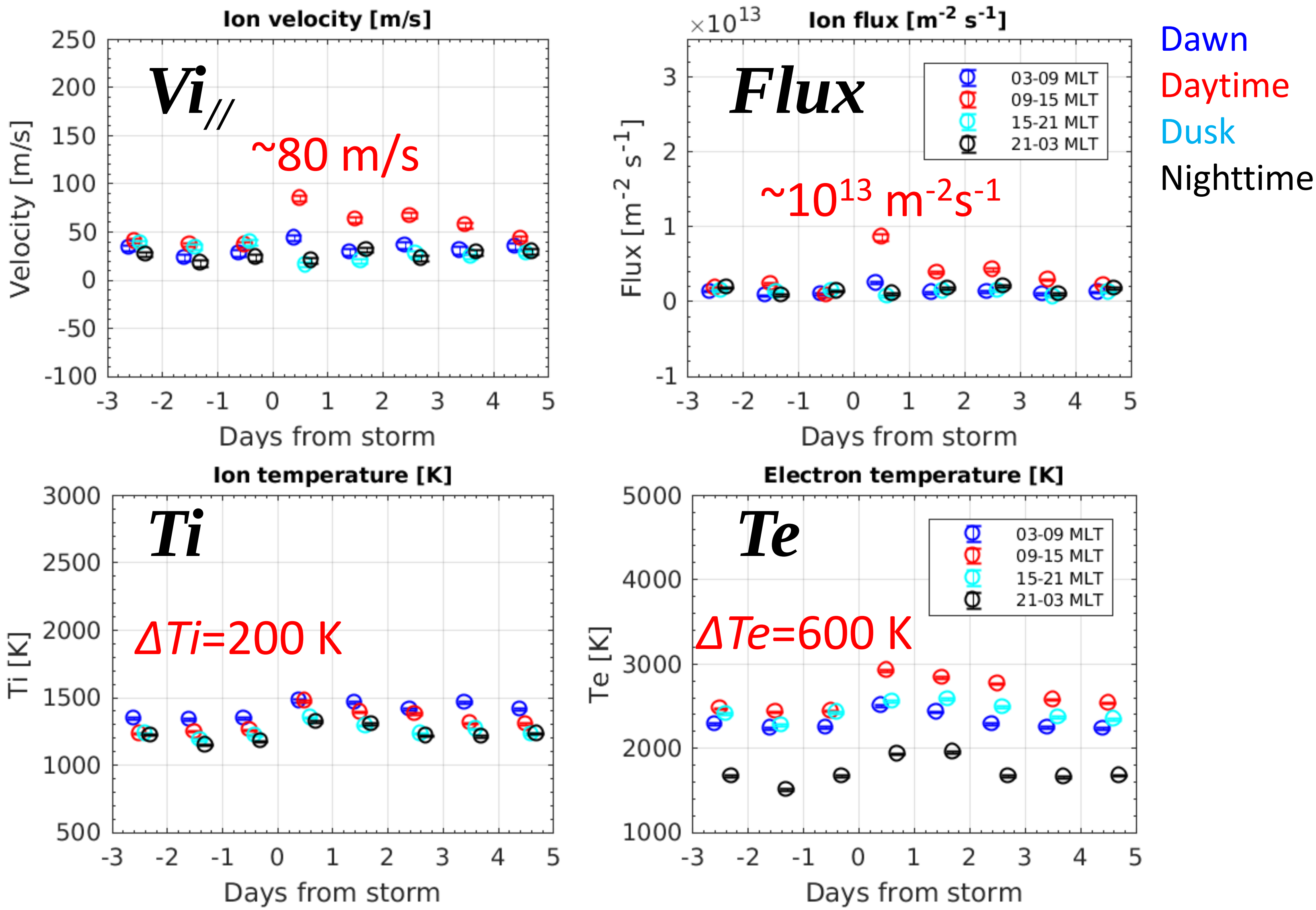
All CIR-driven storms, 75 deg mlat



Clear differences of upward ion velocity and flux between before and after CIR storms are seen in the daytime. Just after CIR storms, average ion velocity and flux in the daytime increase up to 80 m/s and 0.9×10^{13} $m^{-2}s^{-1}$ at this altitude.

All CIR-driven storms, 75 deg mlat

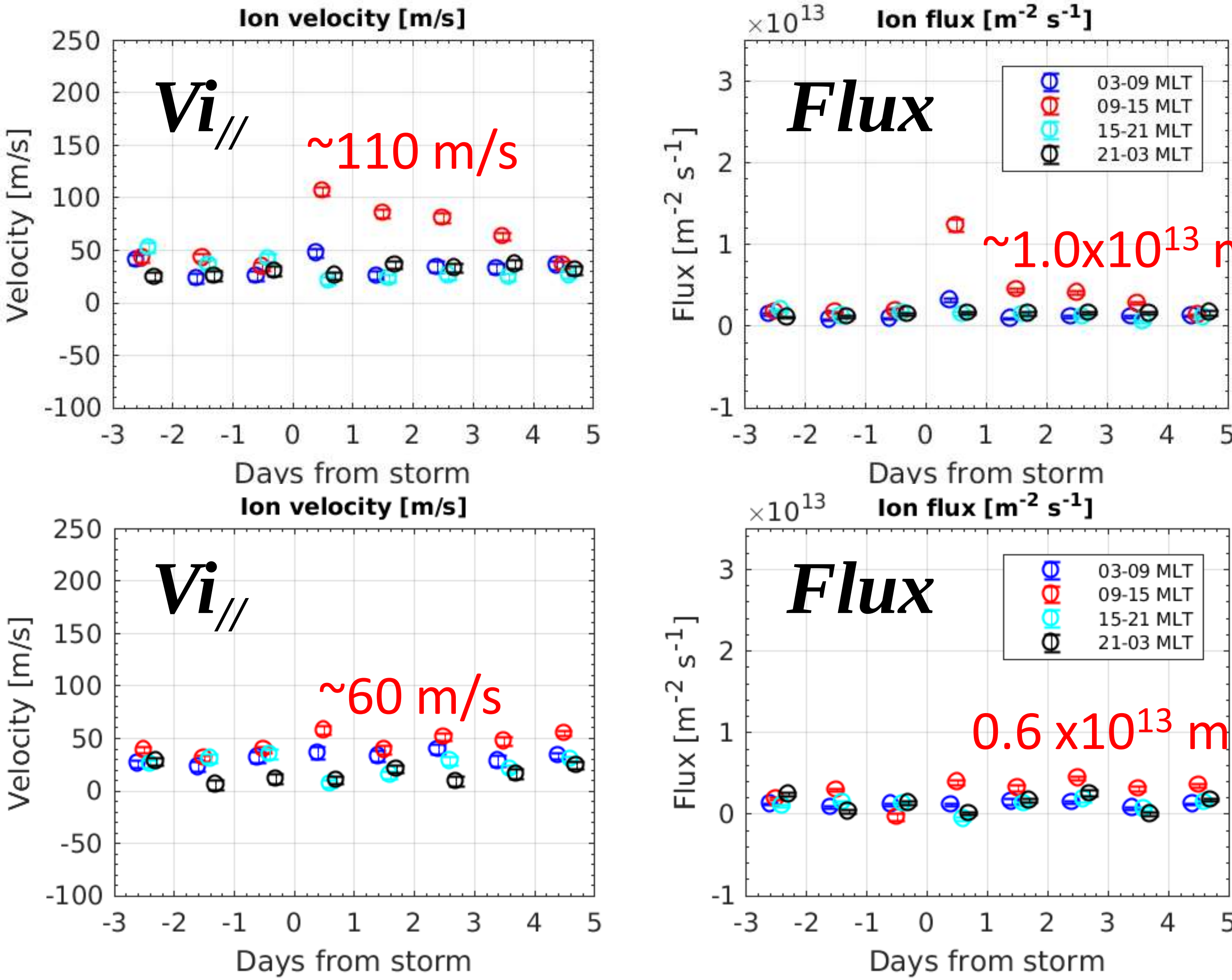


Clear differences of upward ion velocity and flux between before and after CIR storms are seen in the daytime. Just after CIR storms, average ion velocity and flux in the daytime increase up to 80 m/s and 0.9×10^{13} $m^{-2}s^{-1}$ at this altitude.

Small & Large CIR storms, 75 deg mlat

Dst minimum > -50 nT

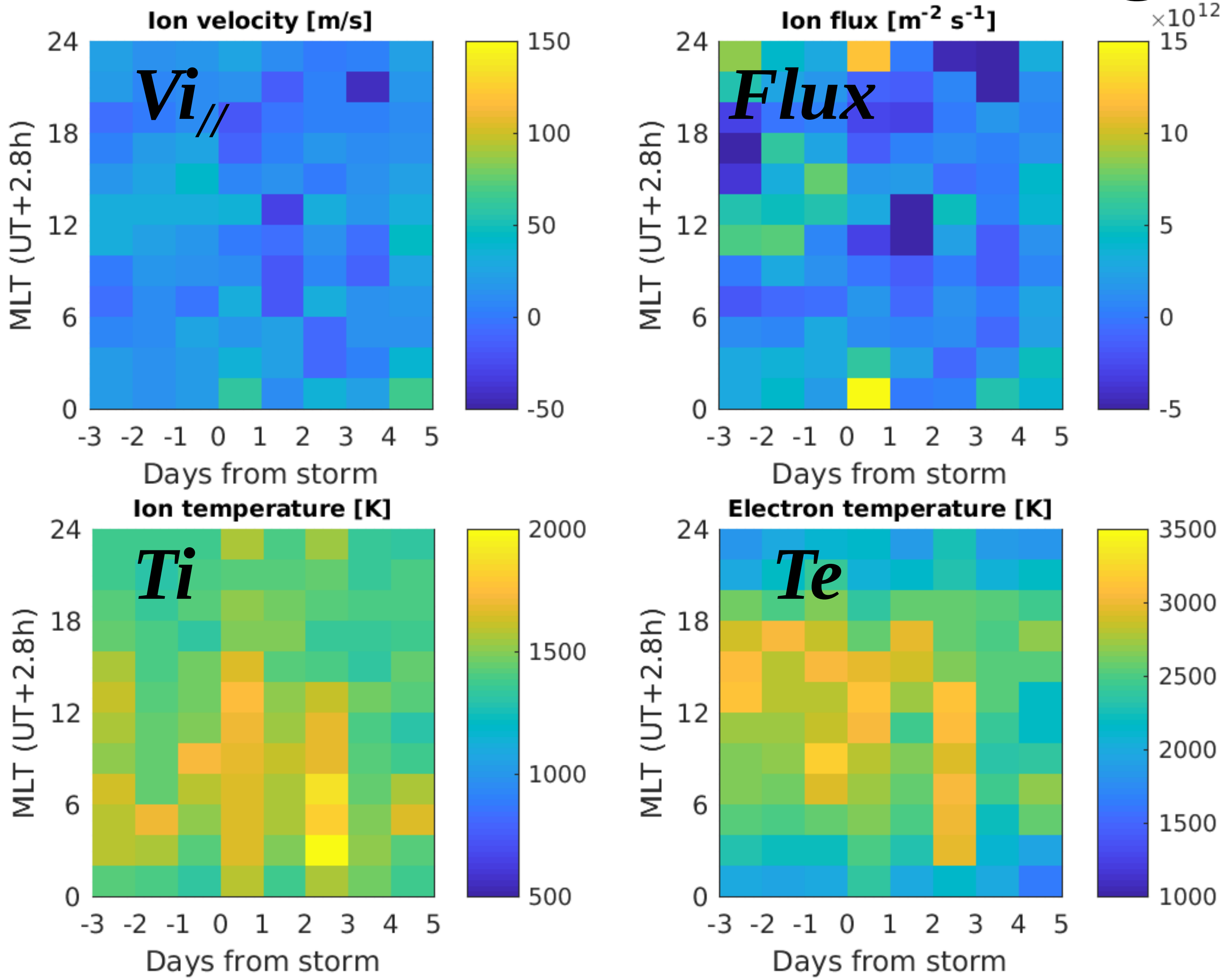
Dst minimum < -50 nT



Dawn
Daytime
Dusk
Nighttime

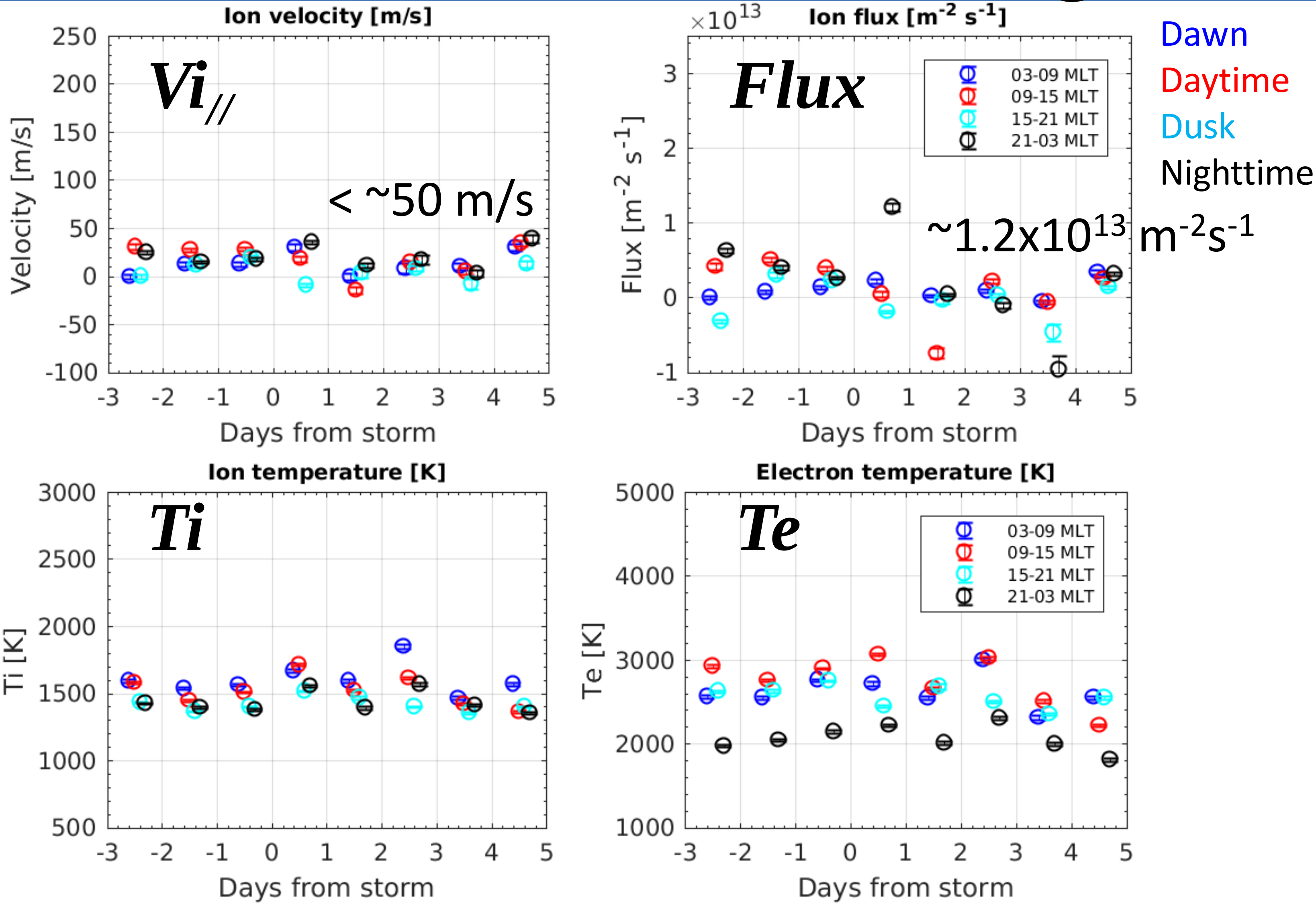
For small CIR storms, ion velocity and flux become high in the daytime just after storms.
For large CIR storms, ion velocity and flux in the daytime become slightly upward at the storm onsets. They retain their values for a few days.

All CME-driven storms, 75 deg mlat



Small upward velocities are seen before the CME-driven storms and at the storm onsets, but they become close to zero after the onsets. *Ti* becomes elevated on the whole until two days after the storm onsets. *Te* also has no apparent difference between before and after the storm.

All CME-driven storms, 75 deg mlat

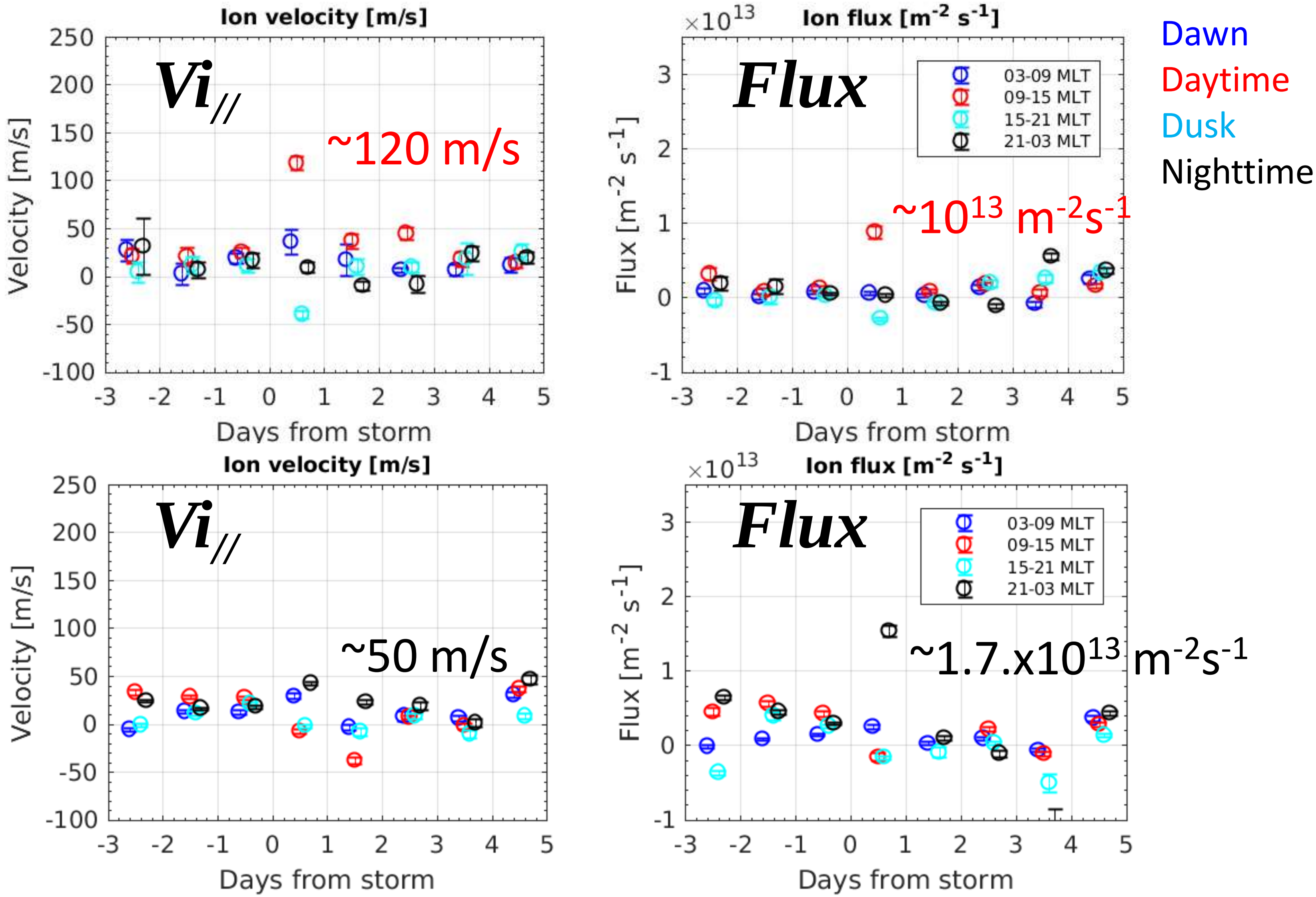


Ion fluxes are largely upward in the nighttime at the storm onsets (1.2 x10^{13} $m^{-2}s^{-1}$), but they are mostly near zero or downward after the storm onsets.

Small & Large CME storms, 75 deg mlat

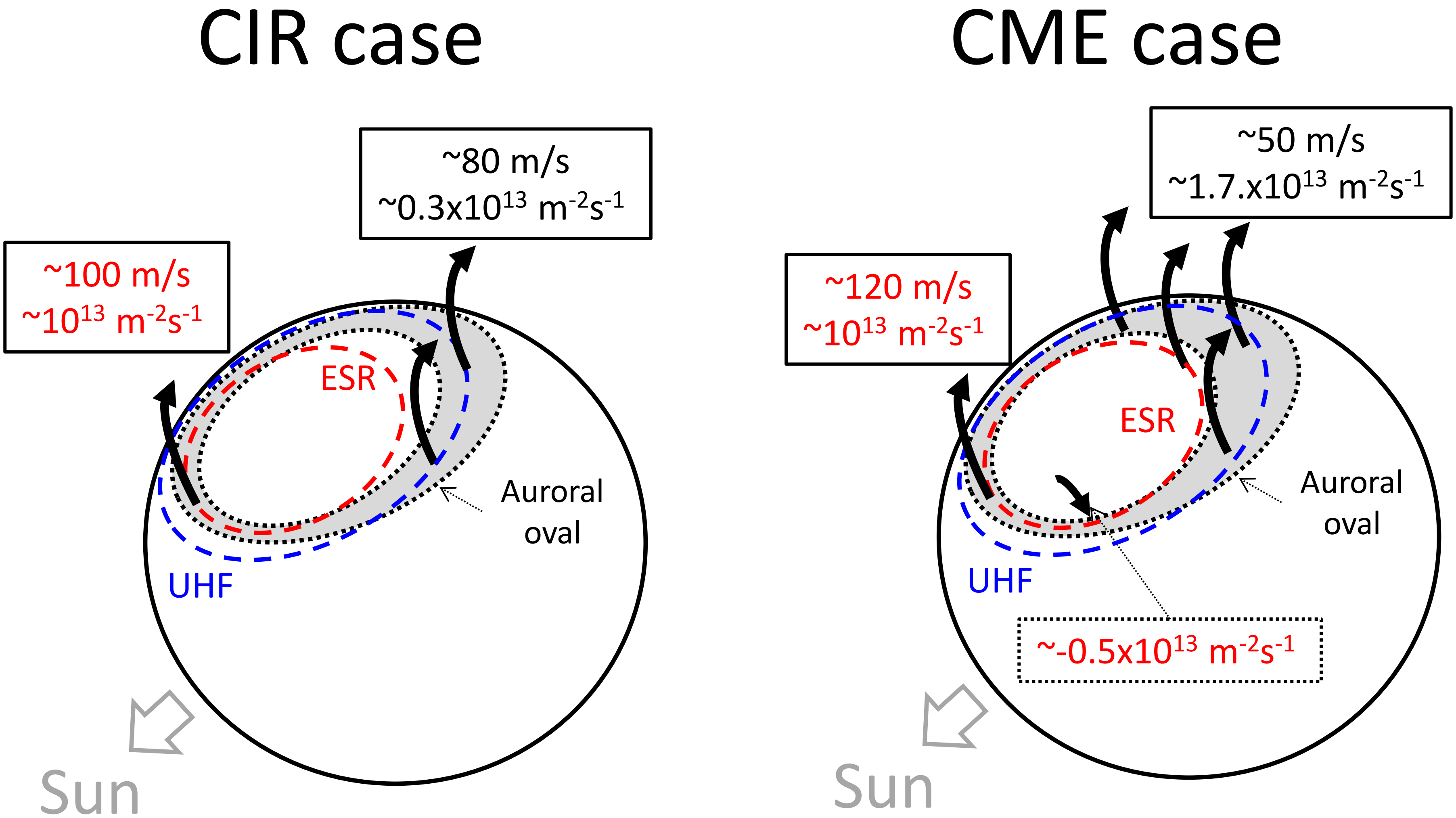
Dst minimum > -100 nT

Dst minimum < -100 nT



At small CME storm onsets, upward ion flows are seen in the daytime, and downflow in the dusk. During large CME storms, ion downflows are typically seen in the daytime. On the other hand, upward ion flux becomes extremely high in the nighttime at the large CME storm onsets.

Summary of results at 75.2 deg mlat.



Ion upflows are seen with a flux of typically 10^{13} $m^{-2}s^{-1}$ for small CIR and CME storm cases. Dayside ion upflows under small CIR-driven storms continue a few days longer than those under small CME-driven storms. Upflows in the nighttime are typically seen during strong CME.

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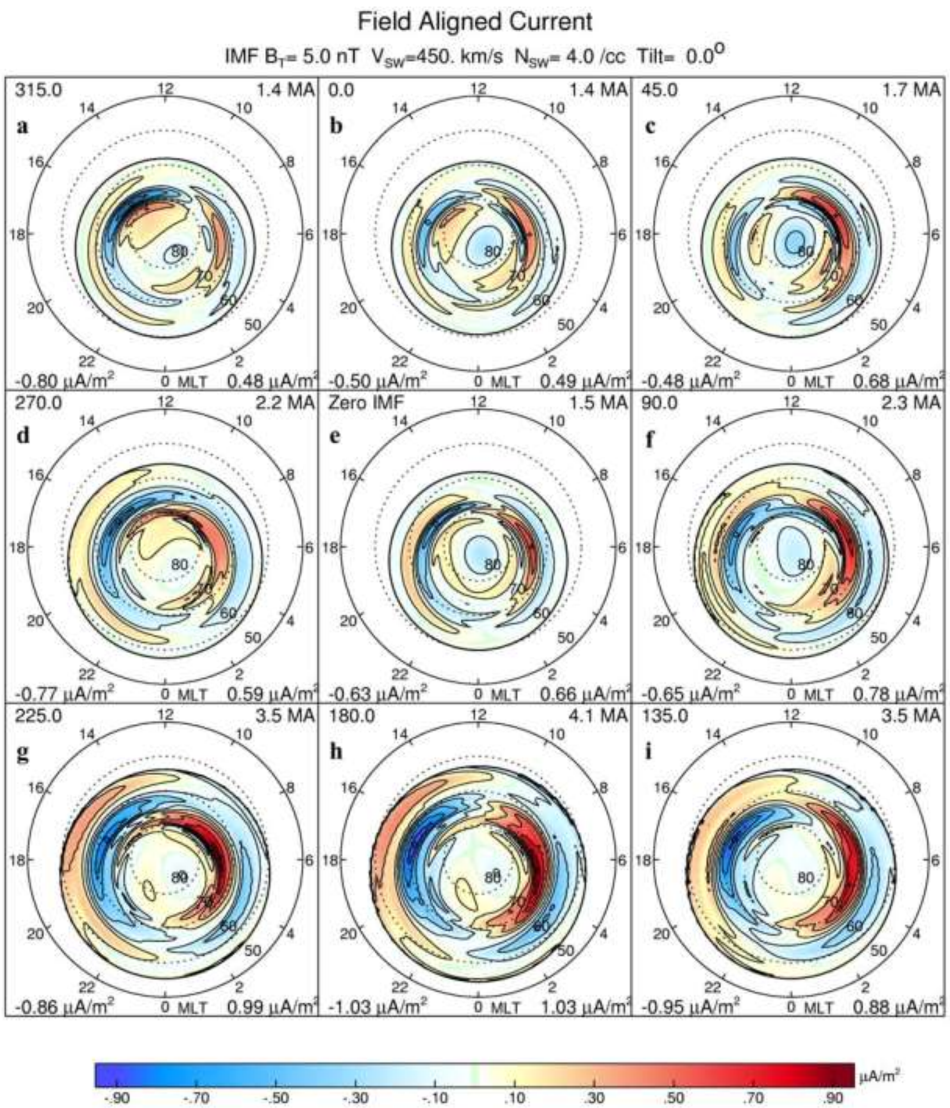
Weimer model

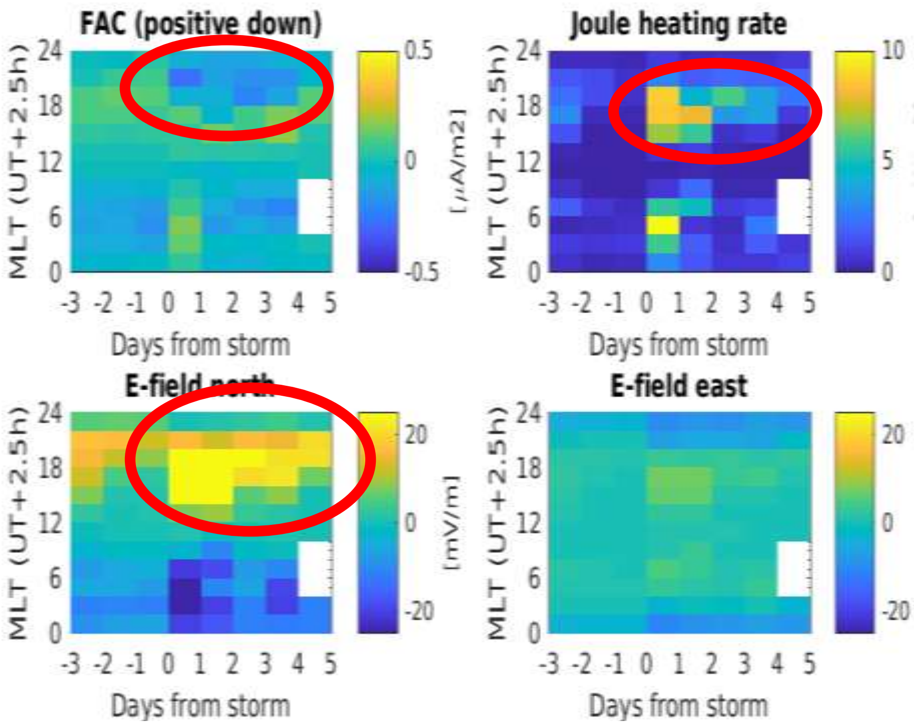


Weimer, 2005

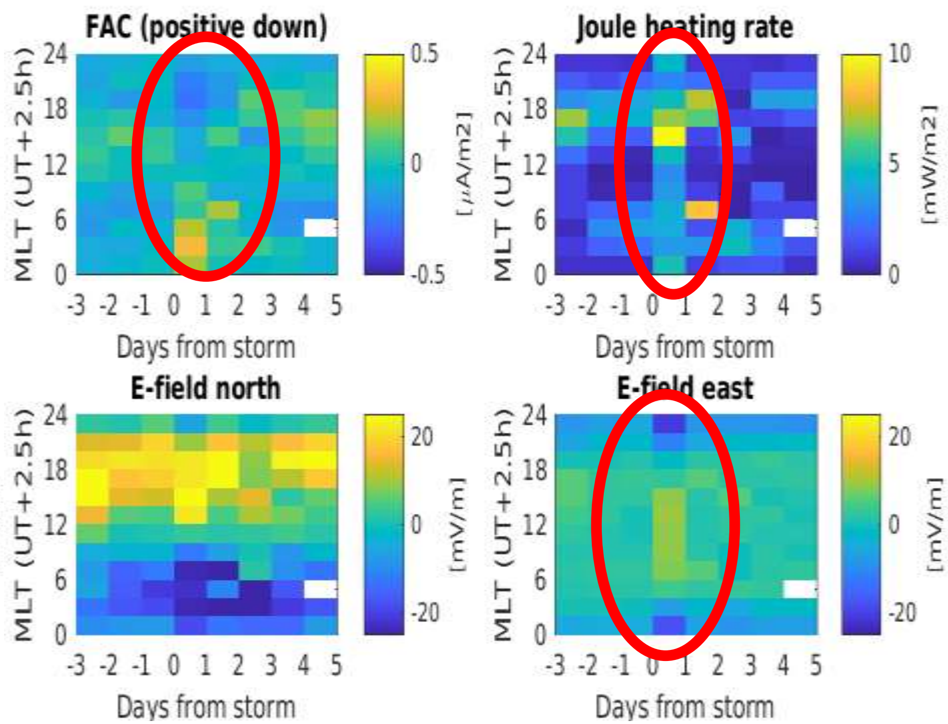
- The model provides field-aligned current (FAC), ionospheric electric field, and Joule heating rate for given magnetic local time, the magnetic latitude.
- We derived these parameters for the EISCAT radar locations at the moment when the EISCAT observation data is available

Weimer model results, 66 deg mlat

All CIR-driven storms



All CME-driven storms



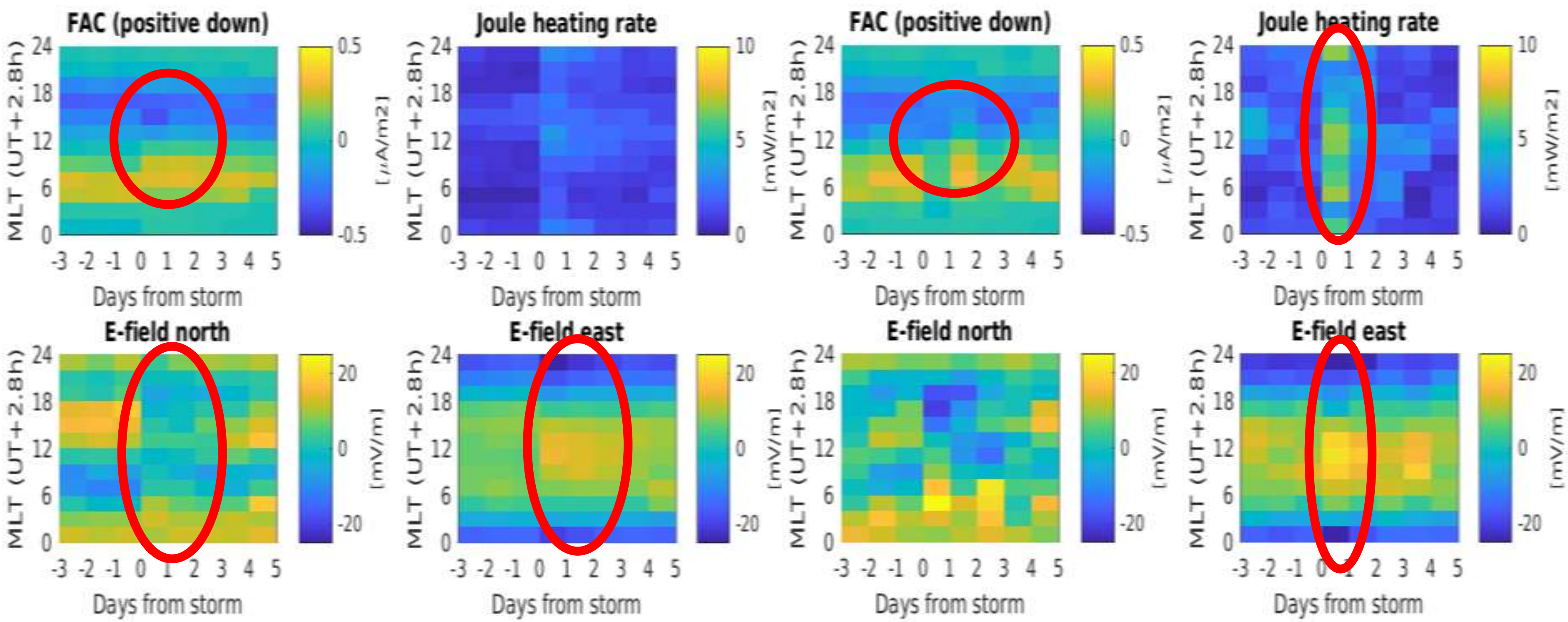
A northward electric field is enhanced in the dusk, and results in high Joule heating rate (~8 mW/m^2) at the region (associated with small ion upflows).
Slightly upward FAC is seen in the same dusk region, related to the R1 FAC current region.

The Region 2 FAC is seen before the storms, while the Region 1-sence FAC is seen on the first day of the storms.
The Joule heating rate increases in the dusk region, but is not so high in the nighttime region. → Soft particle precipitation and heat flux are more important to derive upflows.

Weimer model results, 75 deg mlat

All CIR-driven storms

All CME-driven storms

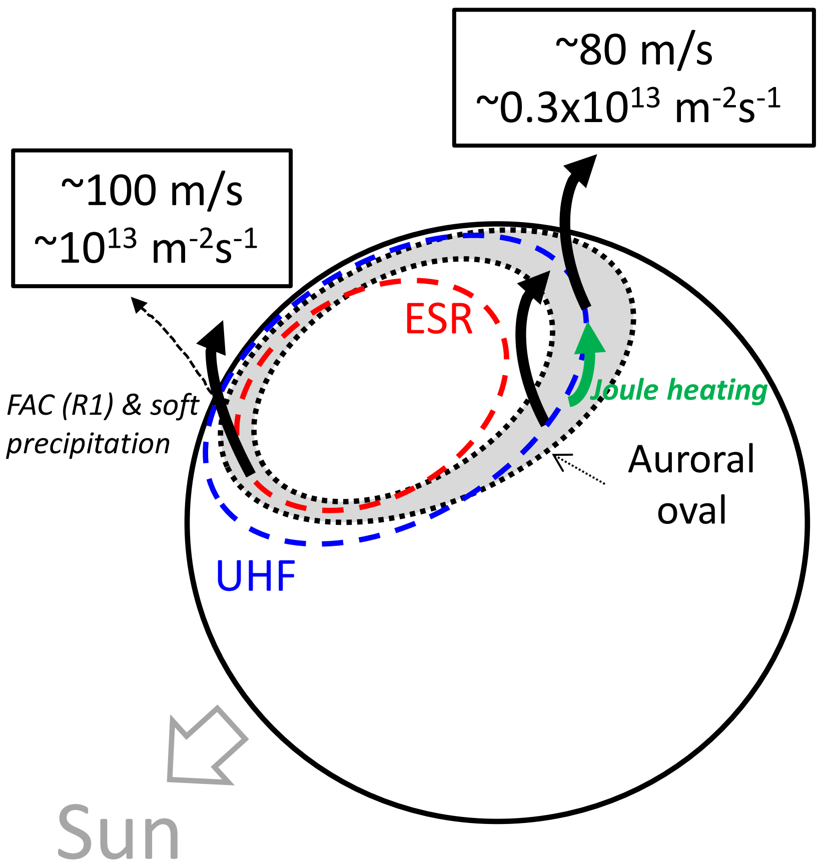


The Region 1 FACs increase and direction of the electric field suddenly changes on the dayside on the first day of storms, and the Joule heating rate slightly increases. They last for a few days, as ion upflow continues for a few days.

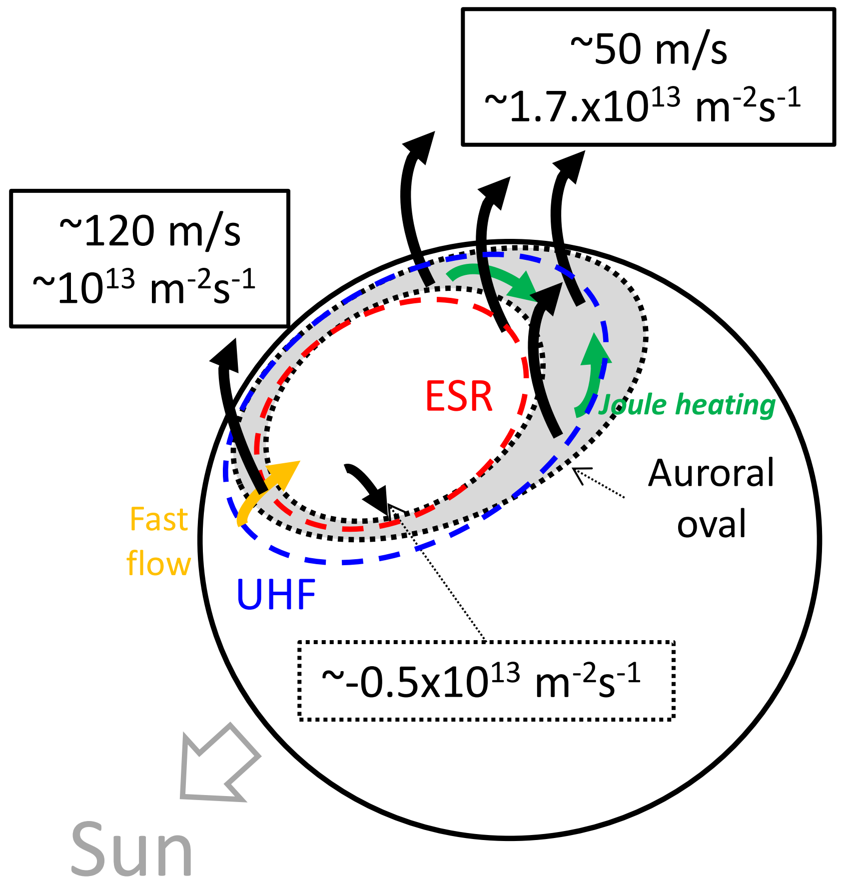
The Region 1 FACs tend to decrease.
→ The radar is situated in the polar cap.
The Joule heating rate also increase in the nighttime on the first day of storms.
→ The upflows would be mainly caused by frictional heating in the F-region ionosphere near the poleward edge of auroral oval.

Summary of all results

CIR case



CME case



- The upflows under the CIR storm associate with enhancements of the R1 FAC.
- An enhancement of the eastward electric field (corresponding to poleward plasma flow) is seen in the daytime on the first day of CME-driven storms.

Summary

- We investigated how velocity and flux of ionospheric ion upflows vary during magnetic storms driven by CIRs and CMEs, using EISCAT radars data between 1996 and 2015.

- CME-driven storms have about six times larger upward ion flux (~1.7×10^{13} $m^{-2}s^{-1}$) in the nighttime than those under CIR-driven storms (~0.3×10^{13} $m^{-2}s^{-1}$).

- In the dayside, ion upflows are seen at 75.2 degrees geomagnetic latitude, with an upward flux of typically 10^{13} $m^{-2}s^{-1}$ for small CIR and CME storm cases. The dayside ion upflows under small CIR storms continue for a few days after the storm onsets, whereas those under small CME storms have a substantial enhancement only on the first day of the storms together with an enhancement of eastward electric field.