Dipolarization in the inner magnetosphere during a geomagnetic storm on 7 October 2015

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Outline

- Introduction
- A dipolarization event on 7 October 2015
- Initial part with smooth variations
- Later part with irregular variations
- Geospace localization of MMS observations
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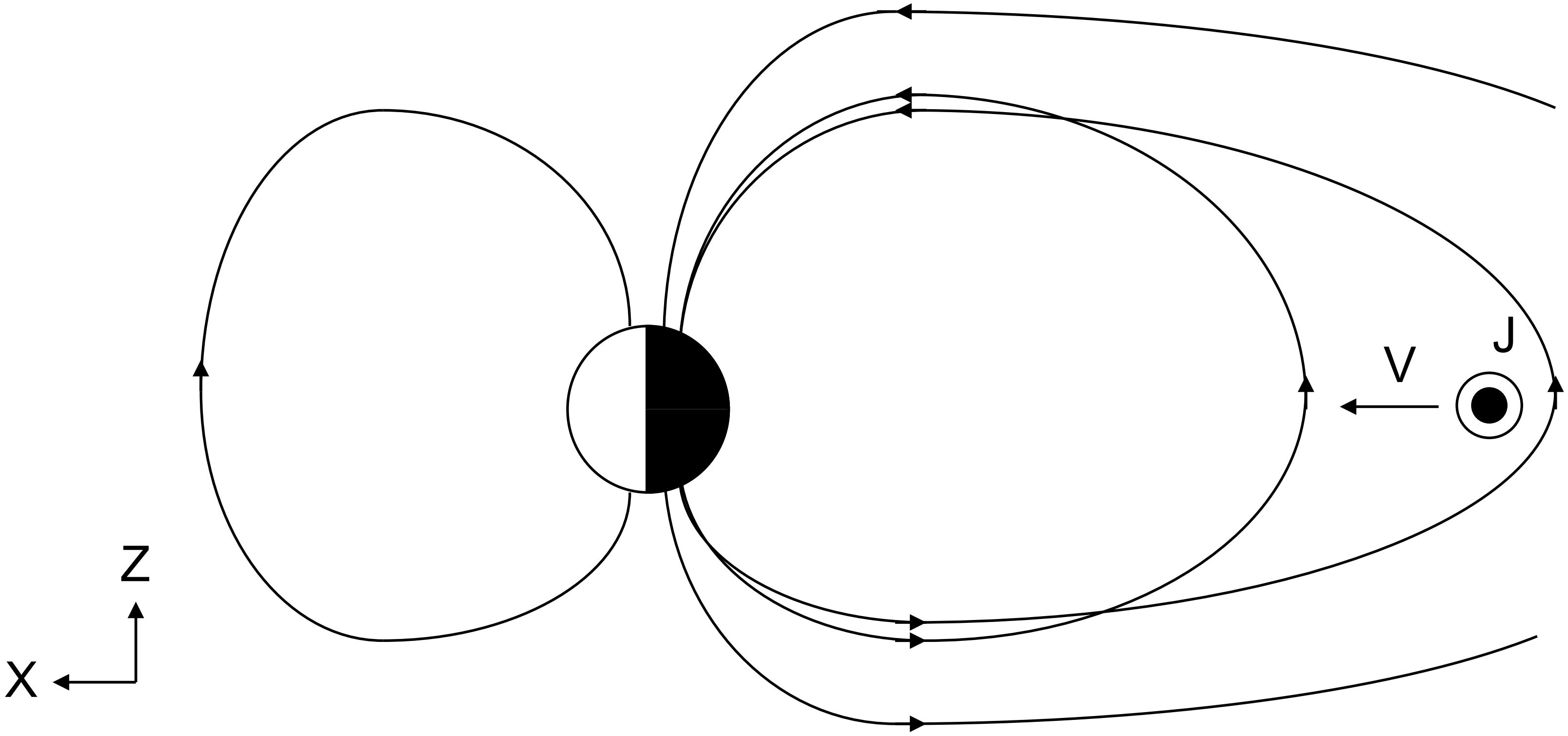
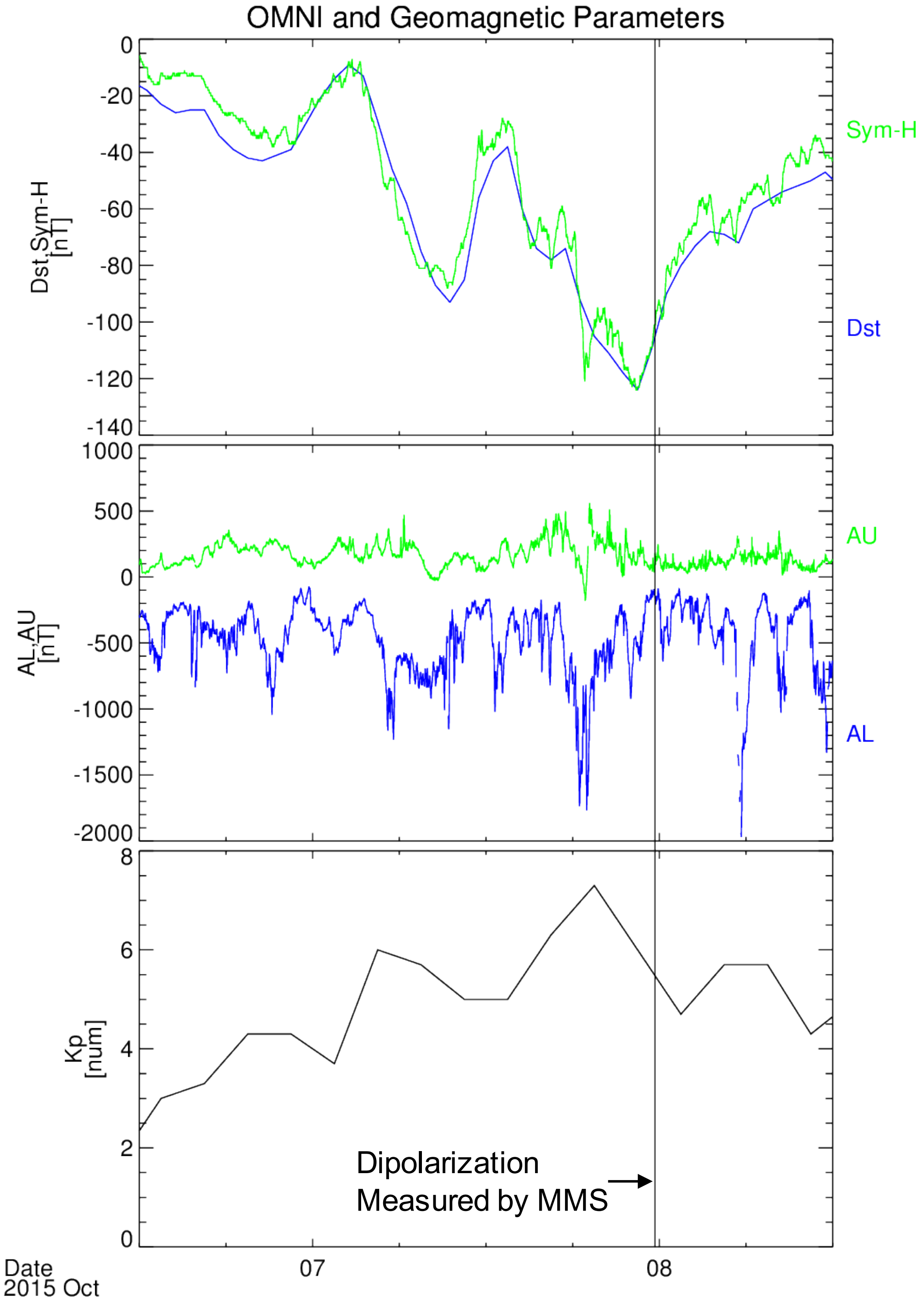
Introduction



- •Dipolarization events are characterized by increase in Bz and decrease in |Bx| in the nightside so that the magnetic field becomes dipolar from stretched configuration with large cross-tail current.
- •Injection of energetic particles are often accompanied.

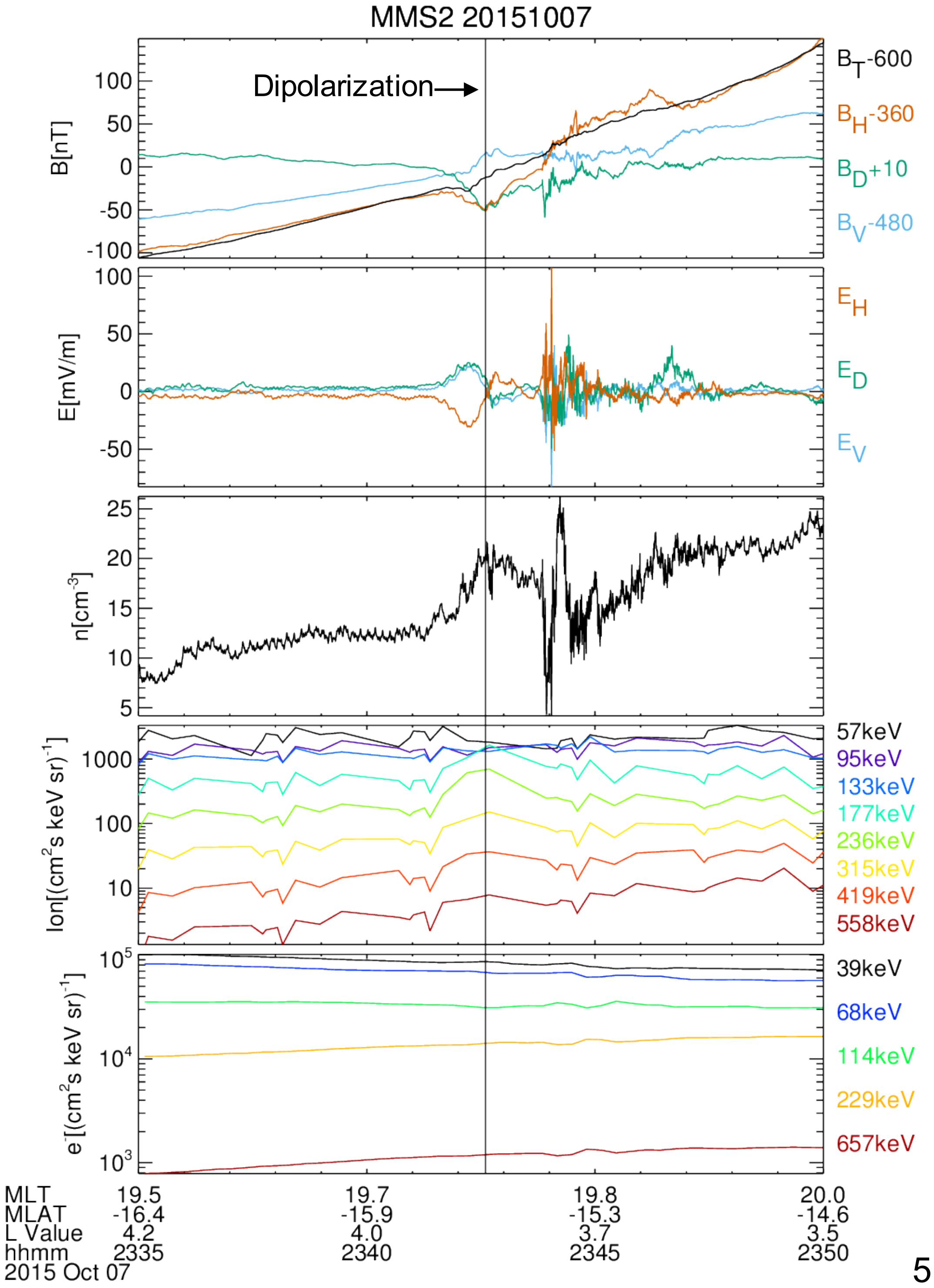
Geomagnetic Parameters

- A dipolarization event was measured by MMS 2 at L=3.8 and 19.8 MLT starting at 234236 UT on 7 Oct 2015.
- The event analyzed was measured just after the Dst value started to recover.
- There is a slight increase of the AU and AL activity beginning at ~233830-233930 UT.
- Kp index was 6, indicating that the Alfvén layer was closer to the Earth.
- We pick this event because the MMS observations were made in the inner magnetosphere where there was a conjunction measurement made by the Millstone Hill radar.



Overview of the Event

- A dipolarization event was identified by the increase of Bh(=Bz) at the time of the vertical line.
- The dipolarization event is associated with large variations of E fields with amplitudes >20 mV/m (>100 mV/m at maximum) as measured by double probes [Lindqvist et al., 2016; Ergun et al., 2016].
- The initial part consists of rather smooth variation, while the later part is irregular with large amplitudes of fluctuations.

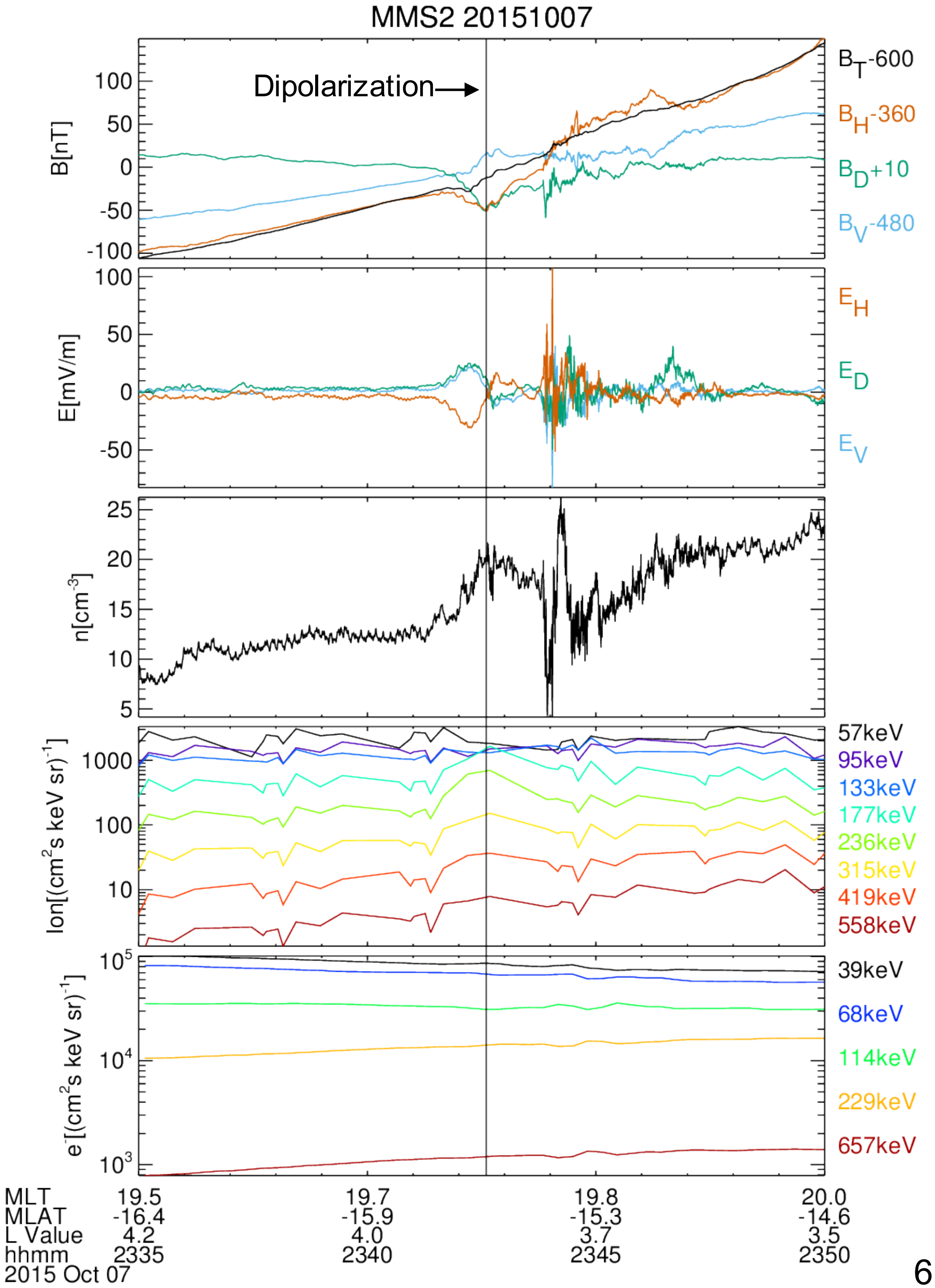


V: outward D: eastward H: northward

Overview of the Event

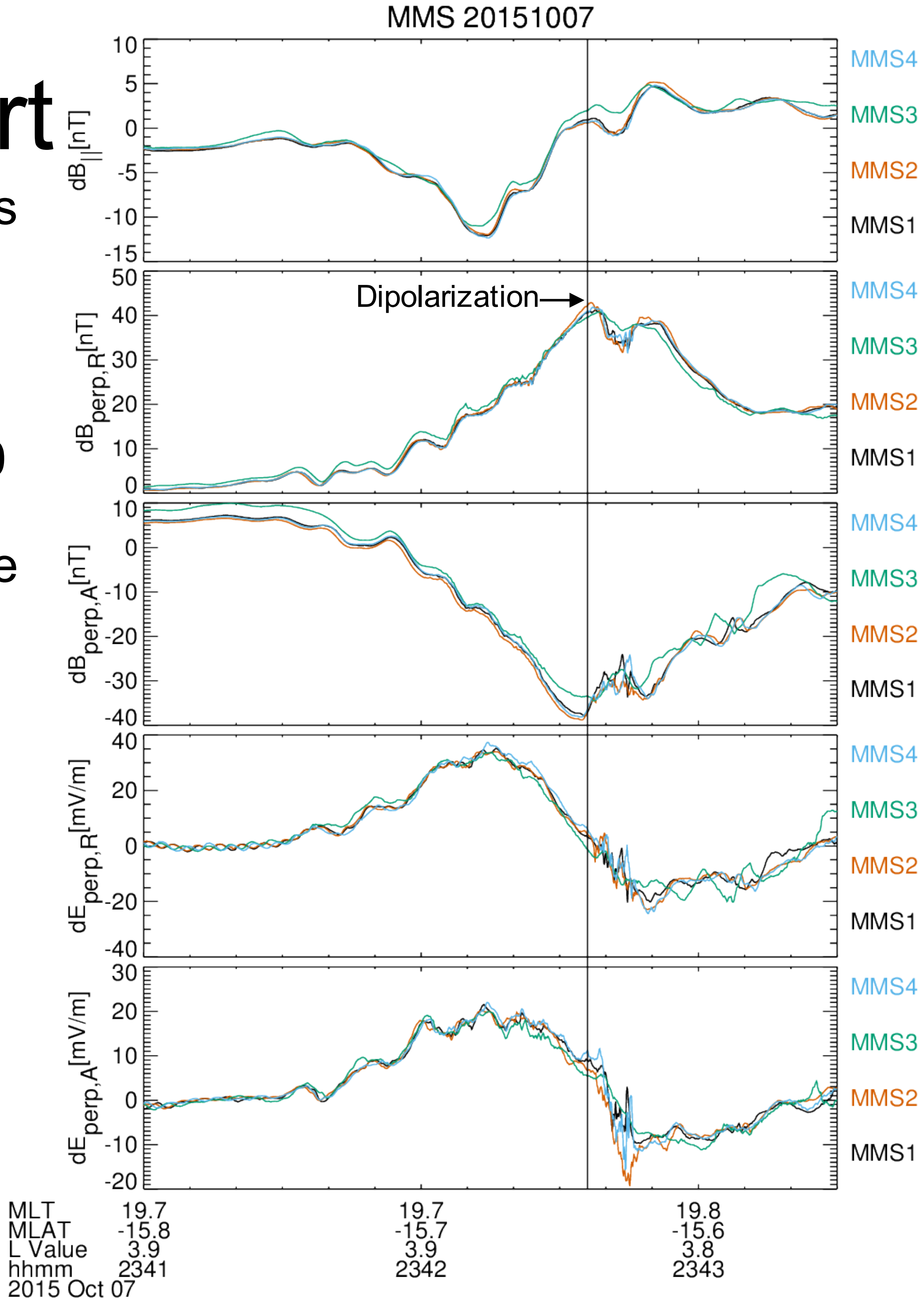
- After the Bh component starts to decrease, the Ev component becomes positive, indicating a sunward convection. There is a peak of Ev component during decrease of Bh component. Then, Bh starts to increase, that is the dipolarization starts. The sign of Ev turns to negative. After that E and B fields show some oscillating features with a mix of both longer periods of minutes and shorter periods of seconds.
- The ion flux increased at the energy ~150-400 keV concurrent with the Bh decrease.
- Electrons show few changes.

V: outward D: eastward H: northward



Initial Smooth Part

- The magnetic and electric fields showed coherent variations between spacecraft.
- The velocity fluctuation is first westward and then eastward. The maximum speed is E/B~30 mV/m/580 nT~50 km/s.
- This speed is comparable to the gradient B drift speed of energetic ions: 30 km/s.
- In this initial part, azimuthal magnetic and radial electric field variations, therefore toroidal variations, were measured.
- The phase difference between magnetic fields and electric fields are ~90 degrees, indicating that these fields are inductive [Aggson et al., 1983; Ohtani et al., 2007]. The situation is also similar to the standing waves.



Calculation of Current Density

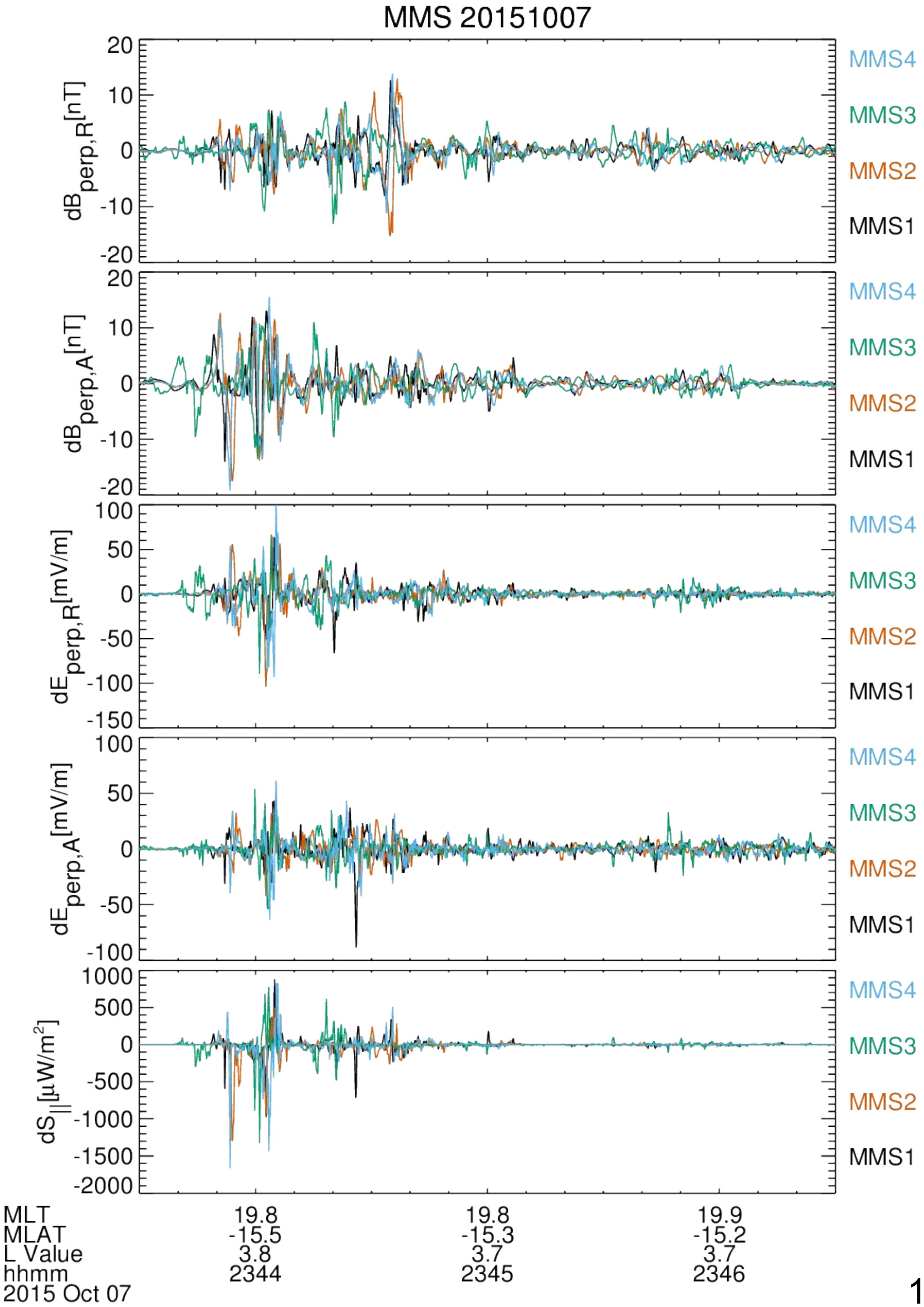
- The current density is estimated using typical magnetic field variations and spatial scales: J1para=-17 nA/m^2, and J1perp,r=-4 nA/m^2 or -3 nA/m^2. The value of J1para is not inconsistent with the one calculated with the multi-spacecraft analysis technique.
- J1para points toward the ionosphere, which is consistent with the precipitation of injected ions. The polarity of the current is the same as that of R2 current.
- We evaluate the pressure balance: $J \times B = -\mathrm{grad}(B^2/2\mu_0) + (B \cdot \nabla)(B/\mu_0)$. Note that the first term in the right side is related to the magnetic gradient, while the second term leads to the magnetic tension force. Each term is estimated as $2.4 \cdot 10^{-15}$ J/m^2 and $1.6 \cdot 10^{-15}$ J/m^2, respectively. These are comparable to the ∇p current with 0.15/cc of 180 keV protons and a spatial scale of 0.3 Re ($2.3 \cdot 10^{-15}$ J/m^2).

Possible Interpretation

- The magnetic field is stretched due to the energetic particles’ motion, its gradient, and the relevant stress balance. This motion of the magnetic field lines leads to the measured enhanced E field. At some point, the magnetic tension force is larger than the pressure gradient force so that the magnetic field line moves back. Then magnetic fields move back and forth due to the inertial motion as ULF oscillations. The ULF oscillation during substorms has been reported [Takahashi et al., 1989; Samson et al., 1992; Rae et al., 2014].
- This would explain a measurement, which is different from that typical in the magnetotail: After starting the dipolarization, the direction of convection is eastward or tailward.

Later Irregular Part

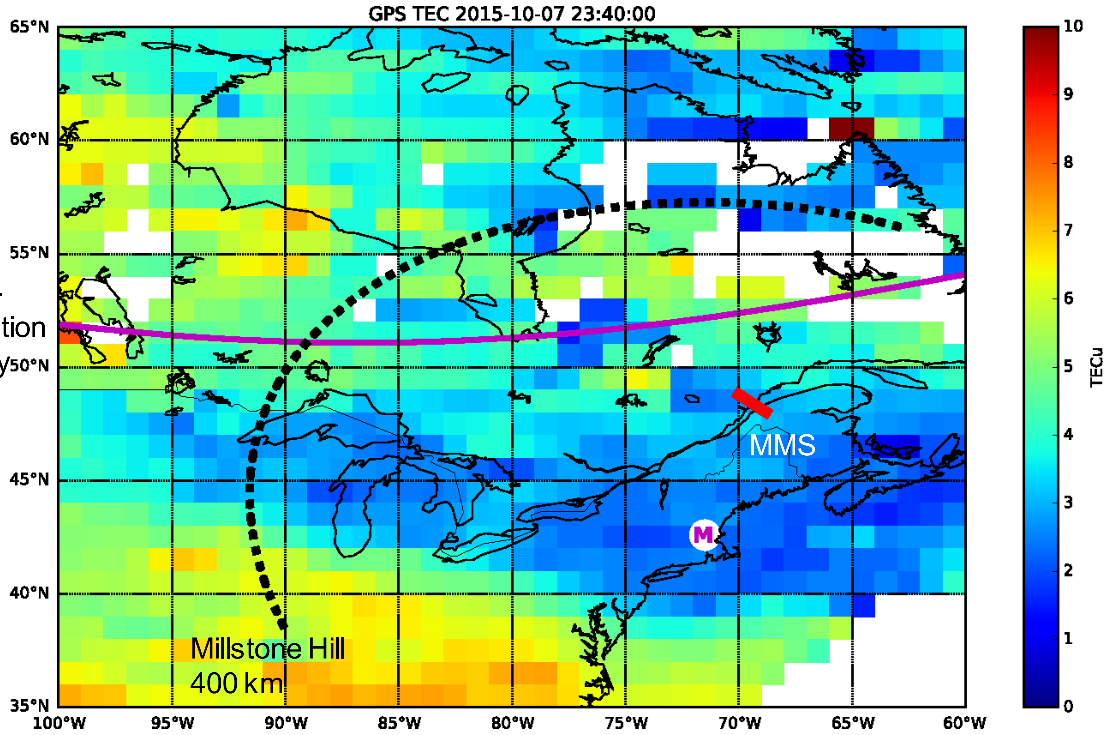
- The fields became irregular between spacecraft unlike the initial part. The spatial scales may be estimated as ~45 km for B fields and ~25 km for E fields. These scales are determined as the distances by which the correlation coefficient reduces to ~0.4.
- The ion gyroradius is of the order of ~110 km.

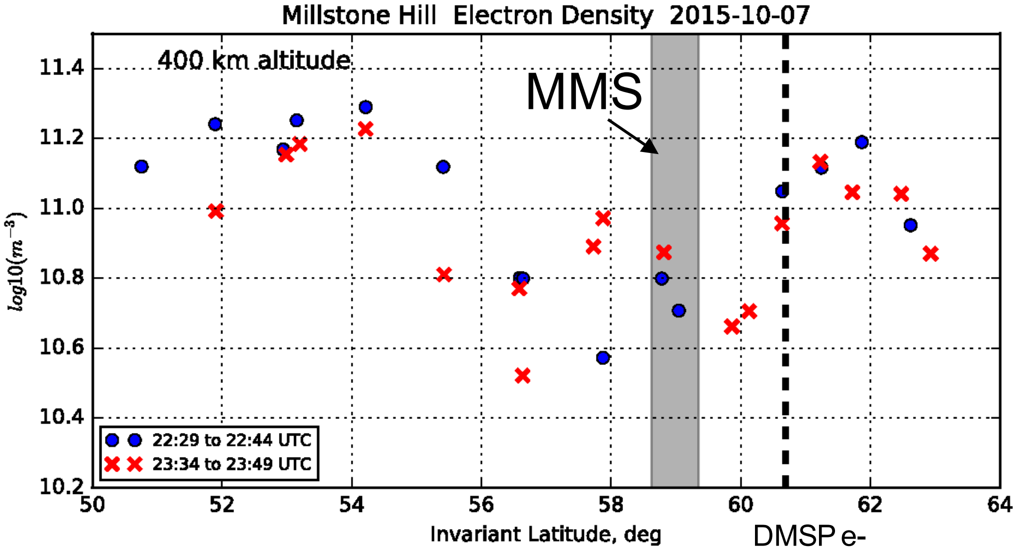


Geospace Localization

- MMS locations are mapped to the low altitude (350 km, red line) or the ground (shaded). The mapped locations correspond to the poleward edge of the stable mid-latitude density trough in the ionosphere. The location is below the latitude of precipitation boundary of plasmasheet electrons.
- This area is expected to have Region 2 field-aligned currents [Nilsson et al., 2005].

DMSP e-Precipitation boundary

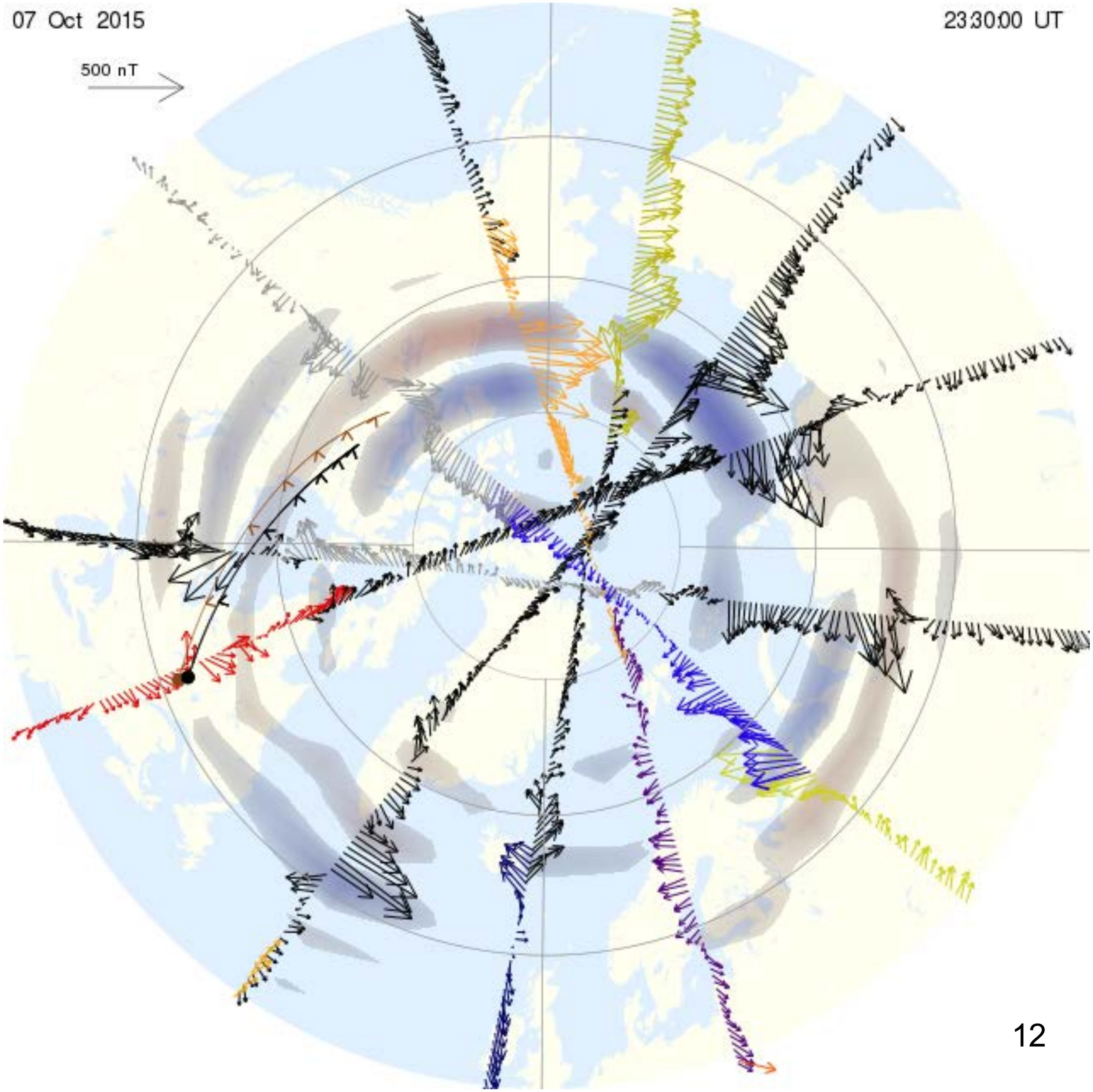




DMSP e-Precipitation boundary

AMPERE Measurements

- Indeed, AMPERE measurements recorded R2 current.
- MMS measured enhanced ions but not electrons so that Region 2 current is inferred to flow. Therefore, magnetospheric and ionospheric measurements are consistent.
- In addition, Birkeland currents associated with the onset and the dipolarization seen by MMS appeared eastward of MMS and moved westward after ~23:50 UT.



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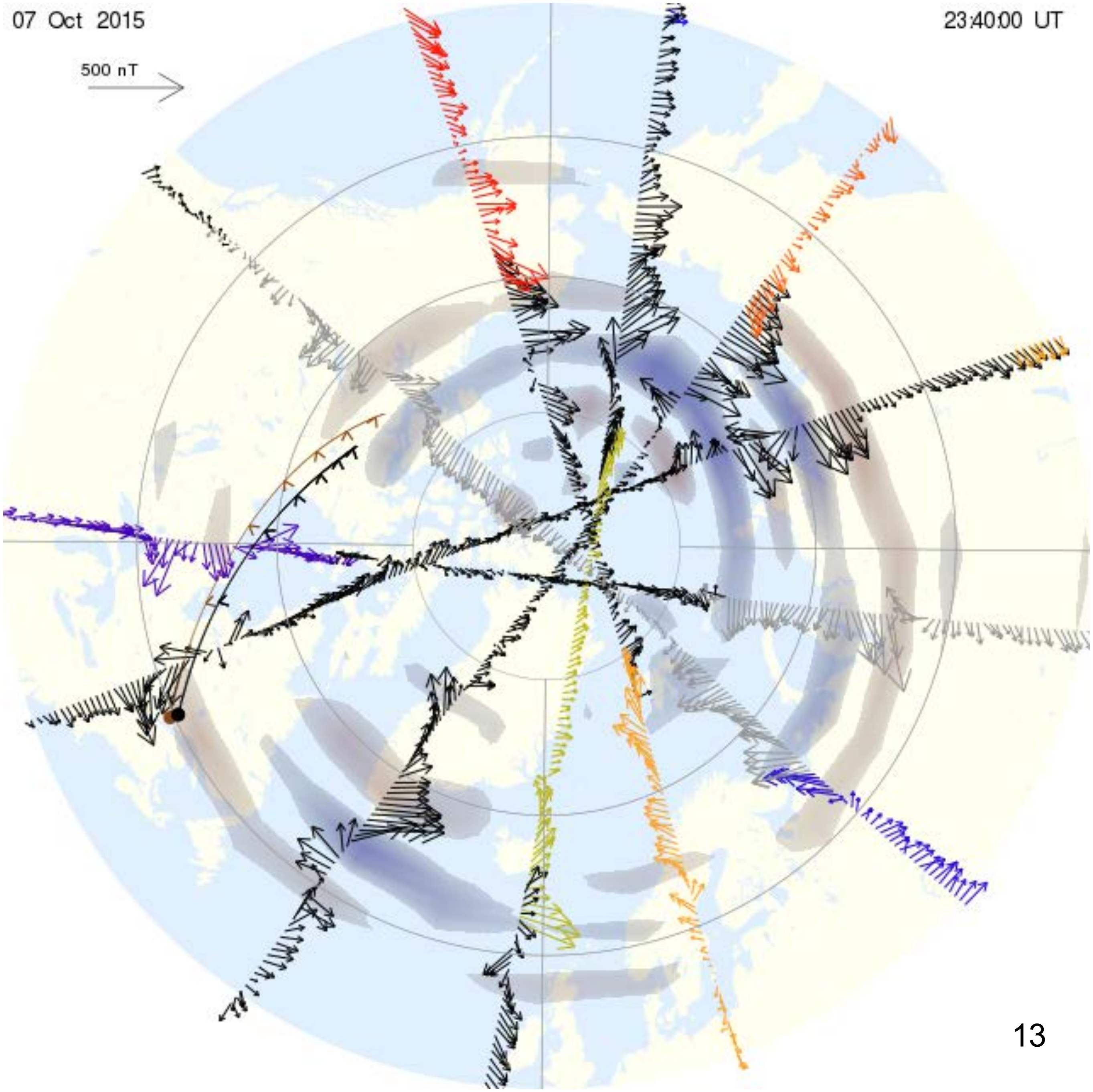

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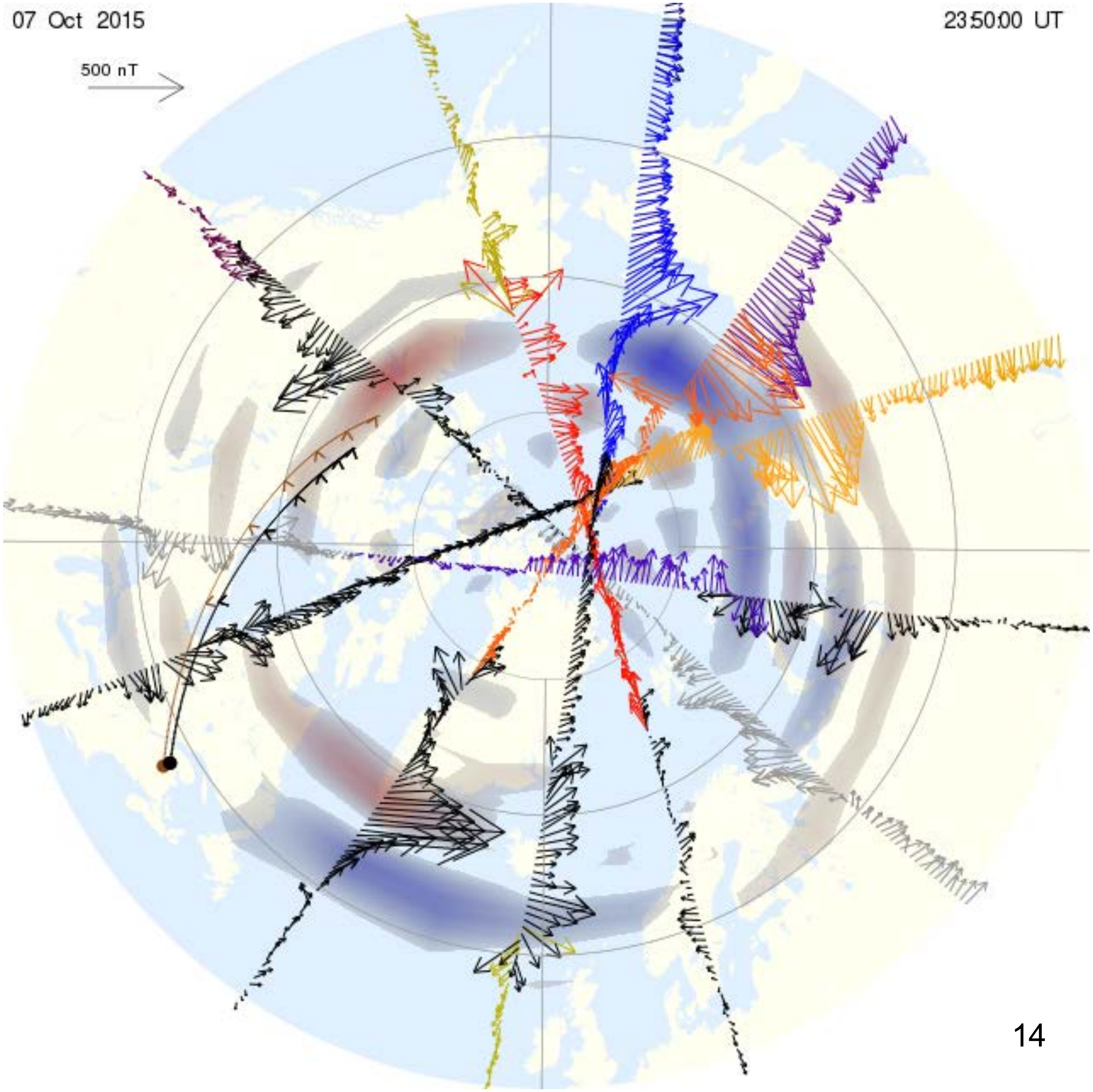

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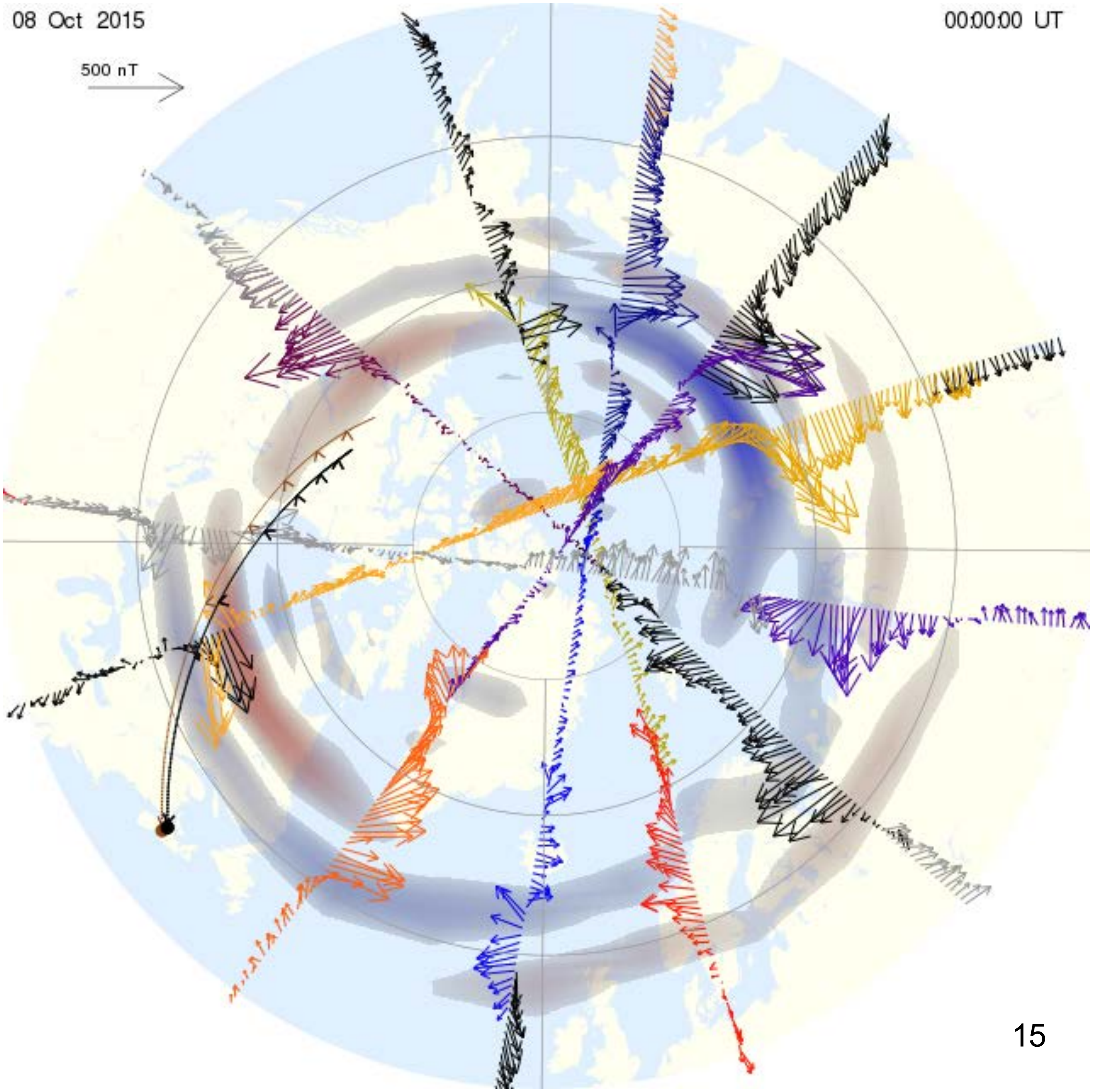

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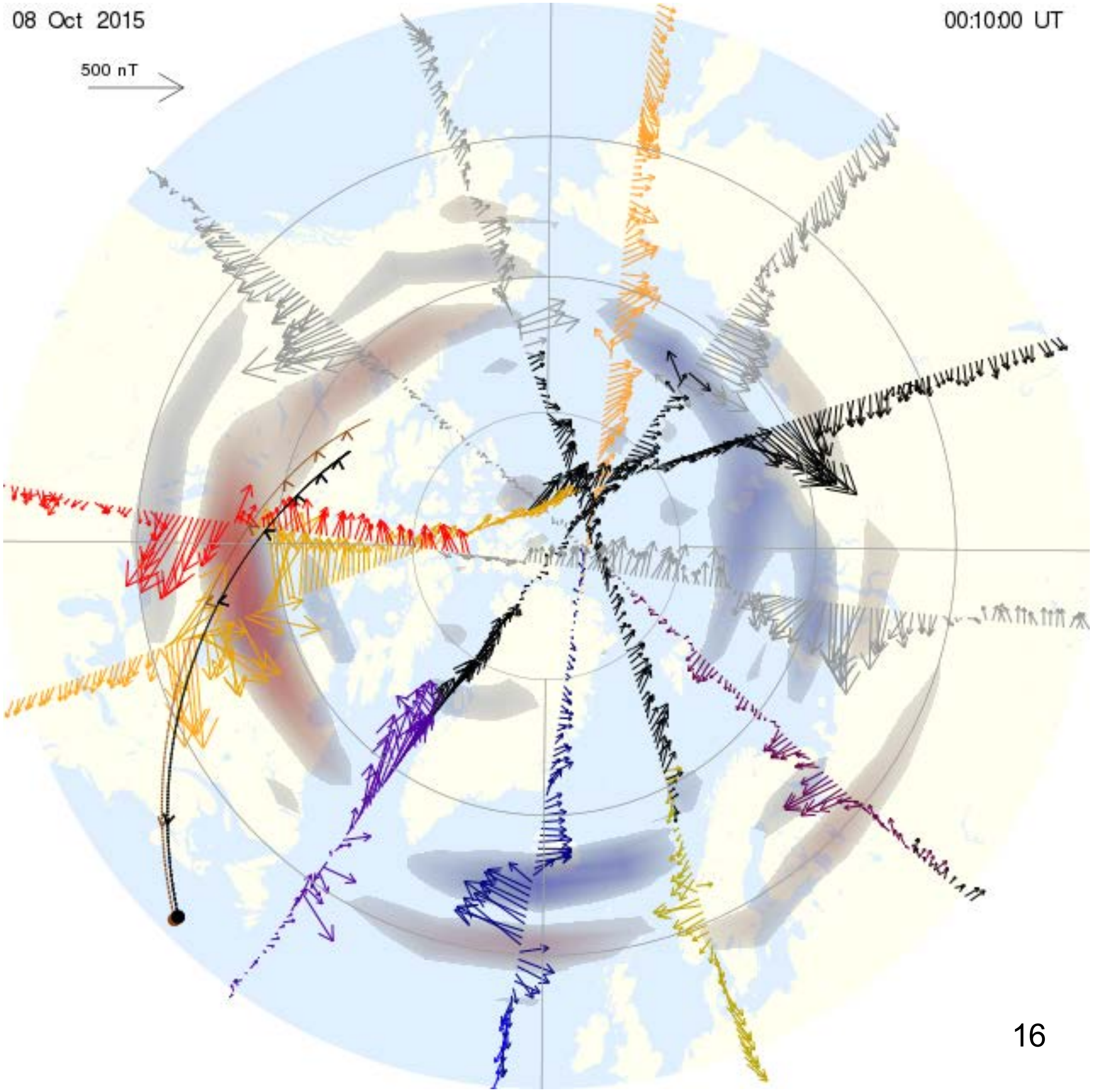

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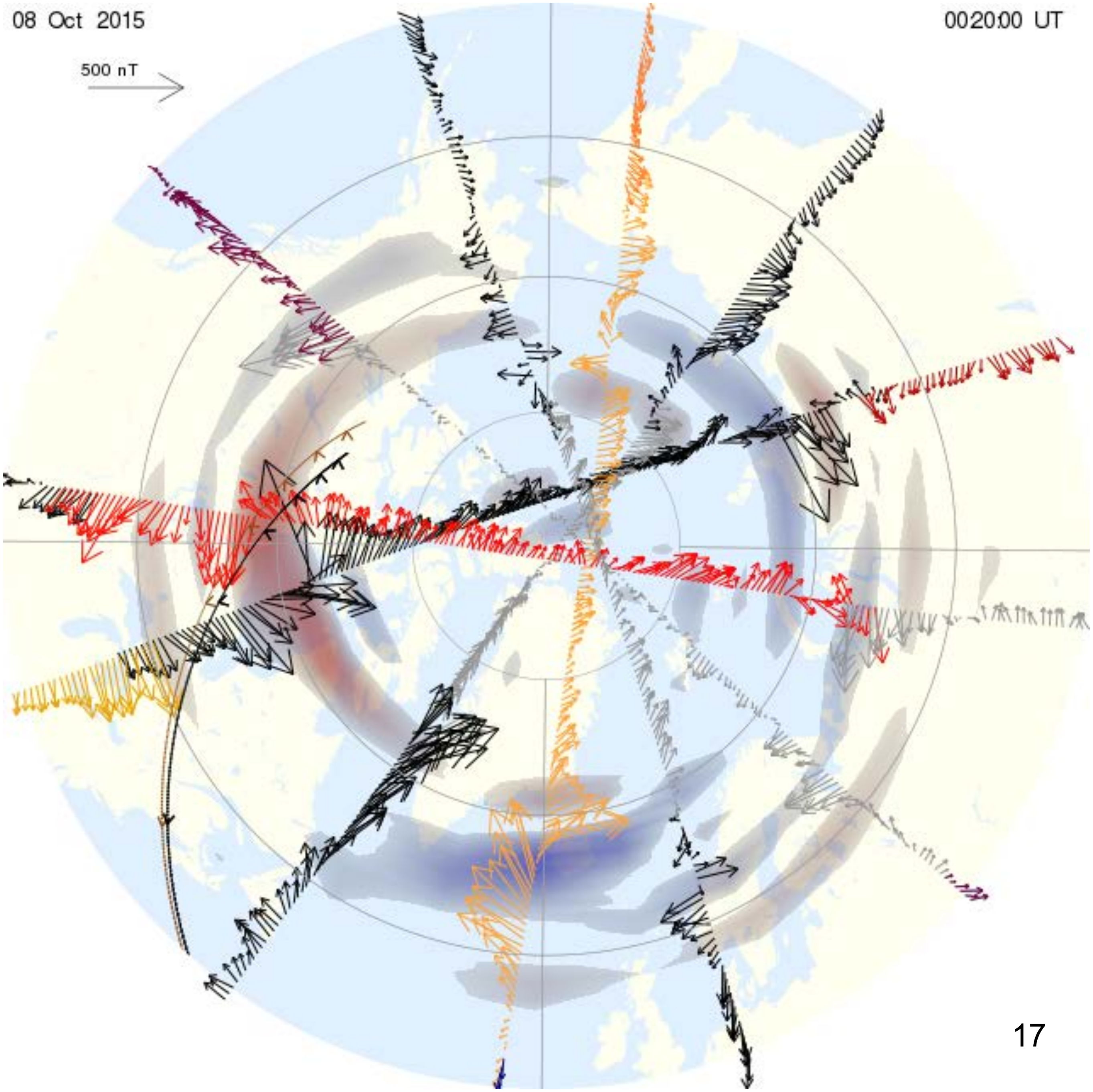

Summary

- A dipolarization event was measured by MMS in the inner magnetosphere at L=3.8 and 19.8 MLT at ~234236 UT, 7 Oct. 2015. An injection of energetic protons was accompanied. Electrons show only slight variations.
- The events consist of two parts: initial laminar part and later irregular part.
- During the initial part, the magnetic and electric fields show mostly similar variations between multiple spacecraft. The fluctuations are similar to the toroidal standing waves. The current density is estimated, which may be interpreted in terms of the pressure balance or the momentum equation. A possibility is that the JxB and grad p terms are balanced.
- During the later part, the fields are rather irregular. The scale length would be comparable to the spacecraft separation (20-120 km).
- The ionospheric observations imply that the foot point of MMS corresponds to the poleward edge of the trough where the downward Region 2 current flow.
- In the future, we would like to collect more events for the dipolarization and to examine whether the event reported here is common. A detailed analysis of the irregular fluctuations to clarify their physical mechanisms is also envisaged.
- Reference: doi:10.1002/2016GL070677.