Global evolution and propagation of electric fields during sudden commencements based on multi-point observations

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- ☐ Typical SC event on 17 March 2013
  - Response in the magnetosphere & ionosphere
  - Poynting fluxes
- ☐ Statistical study
  - Response time
  - Evolution of the magnetospheric electric field

[ERG science center]

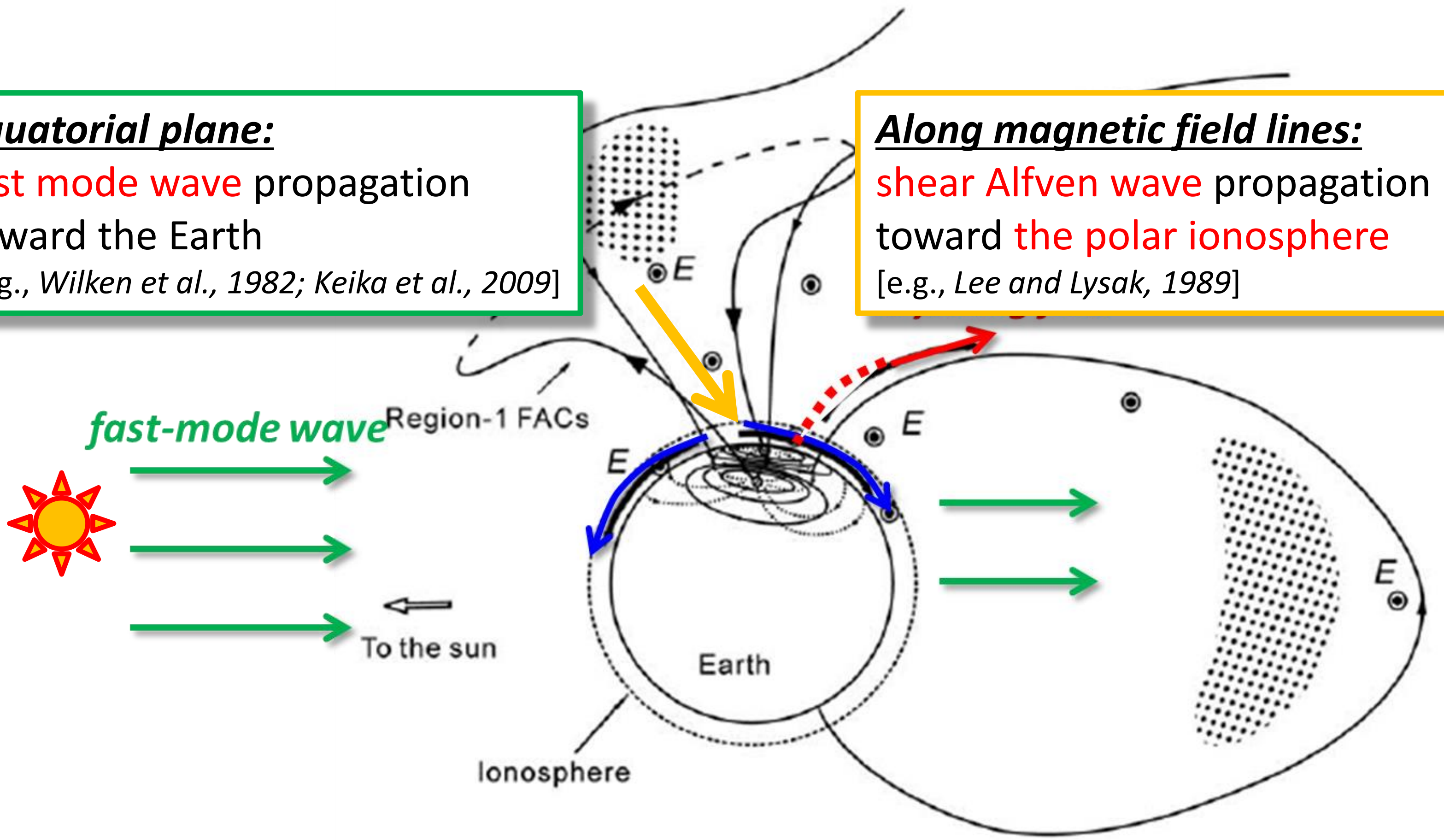
Propagation process in the M-I coupled system

Sudden Commencement (SC)

- solar wind dynamic pressure enhancement
  -> Compression of the dayside magnetopause

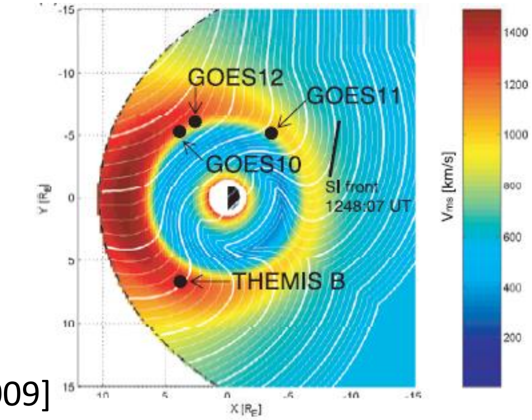
Equatorial plane:
fast mode wave propagation toward the Earth
[e.g., *Wilken et al., 1982; Keika et al., 2009*]

Along magnetic field lines:
shear Alfven wave propagation toward the polar ionosphere
[e.g., *Lee and Lysak, 1989*]



[adapted from *Hashimoto et al.*, 2002]

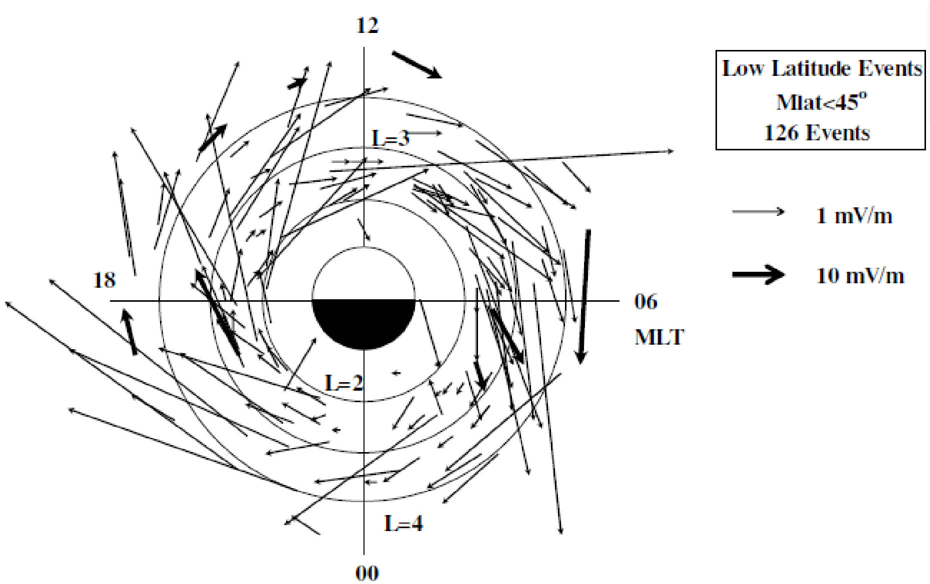
Evolution of electric fields: magnetosphere



Electric field = key parameter of plasma transport

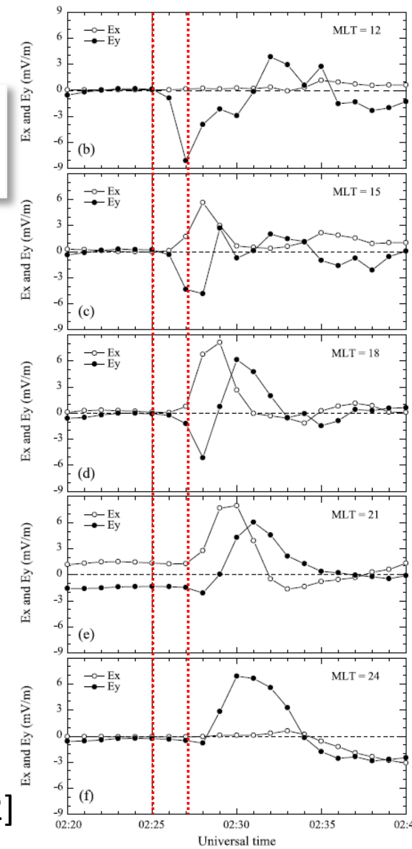
- At the onset of SC, westward electric fields respond quickly.
- Propagation speed of the SC disturbances:
  300-1000 km/s (~fast mode wave)
  [e.g., *Wilken et al.*, 1982; *Araki*, 1994; *Keika et al.*, 2009]

[*Keika et al.*, 2009]



[*Shinbori et al.*, 2004]

Black dot: Ey (east-west)



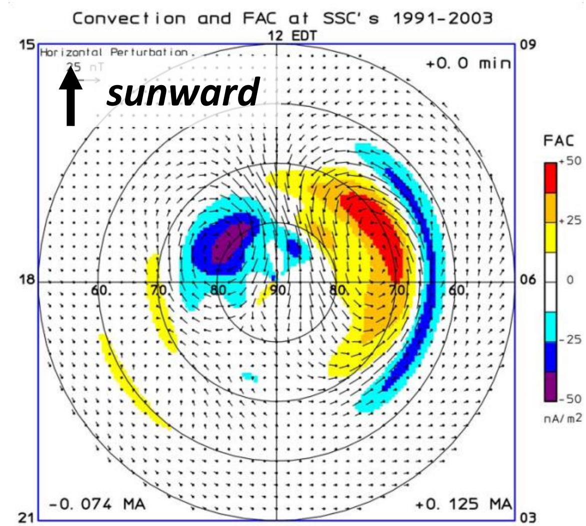
MLT=12
MLT=15
MLT=18
MLT=21
MLT=24

[*Kim et al.*, 2012]

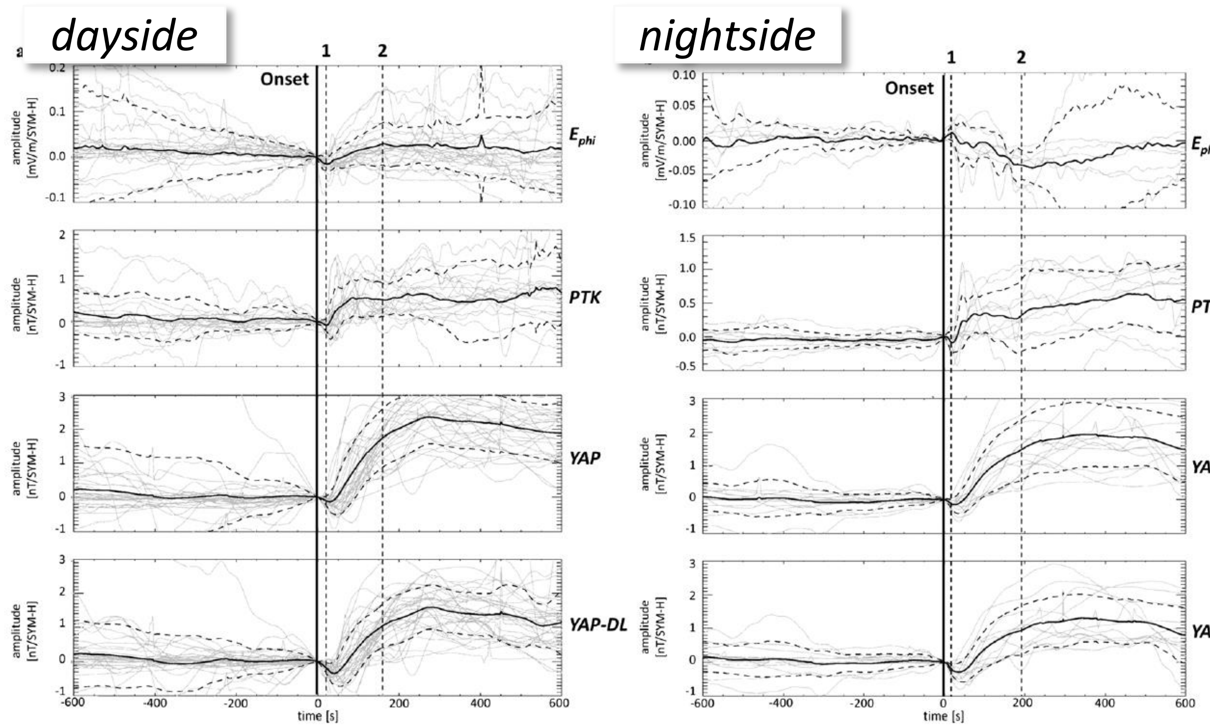
Evolution of electric fields: ionosphere

- The field-aligned current flows toward the polar ionosphere.
  -> The ionospheric electric field is formed.

- The dawn-dusk electric field transmits from polar toward low-latitude ionospheres at speed of light [e.g., *Kikuchi and Araki*, 1979b].



[*Stauning and Troshichev*, 2008]



Ephi

PTK

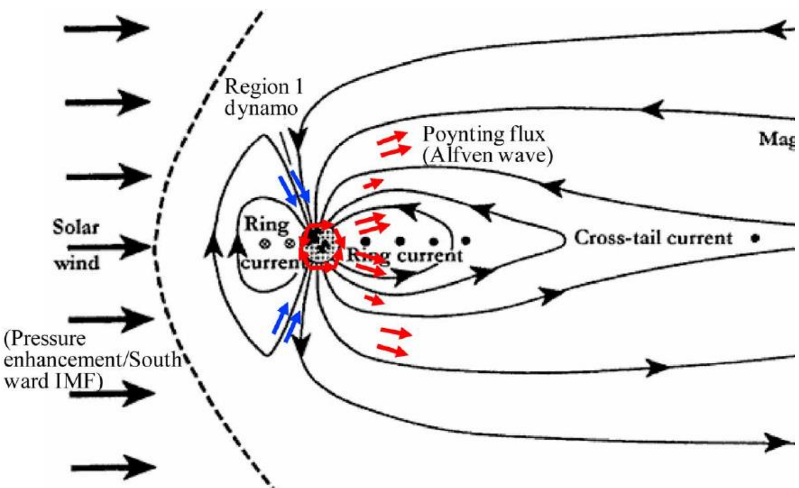
YAP

ionospheric current

[*Takahashi et al.*, 2015]

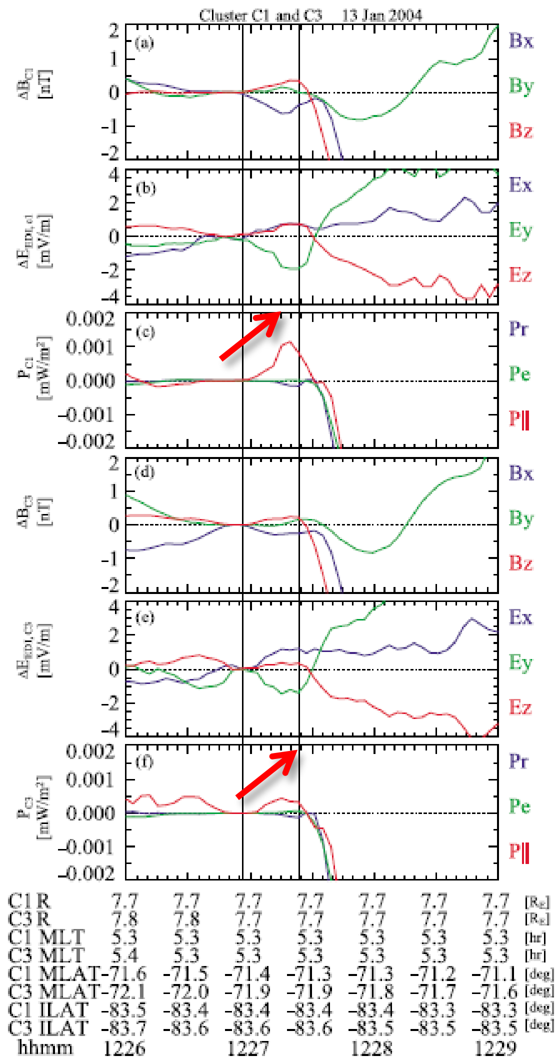
Energy transport process

- The field-aligned component of Poynting flux ($P_{||}$) is dominant at the onset of SC.
- The electromagnetic fields are associated with Alfvén wave propagating along field lines rather than fast mode wave.

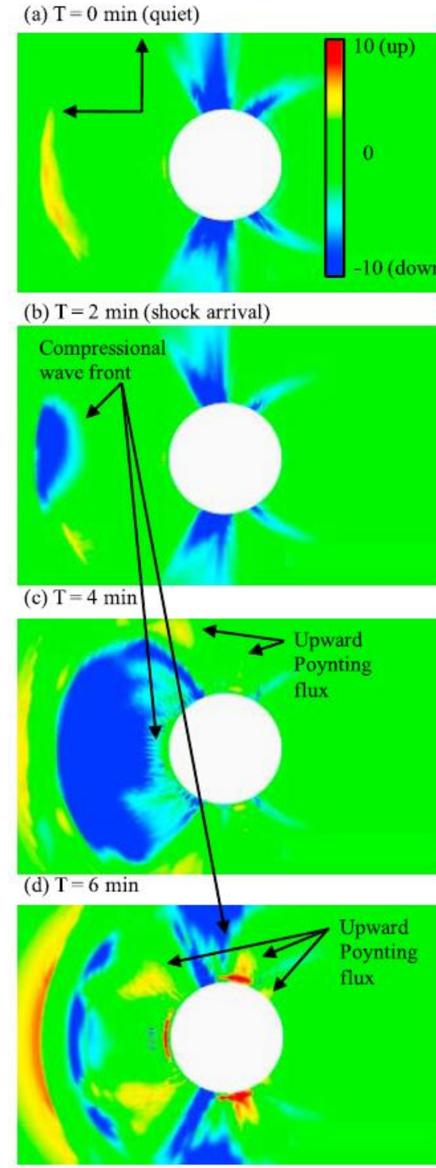


[*Nishimura et al.,* 2010]

Cluster satellite



MHD simulation



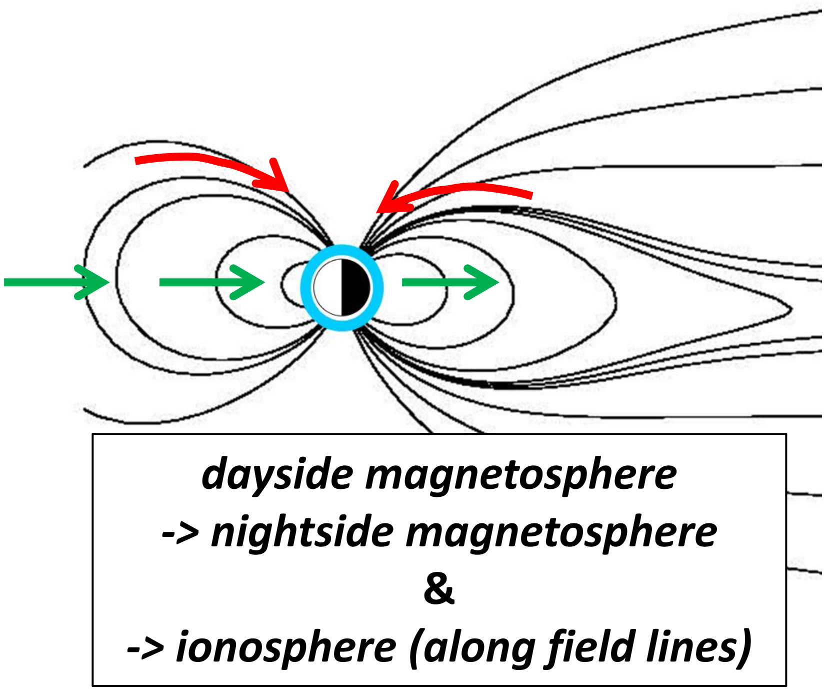
Open issues

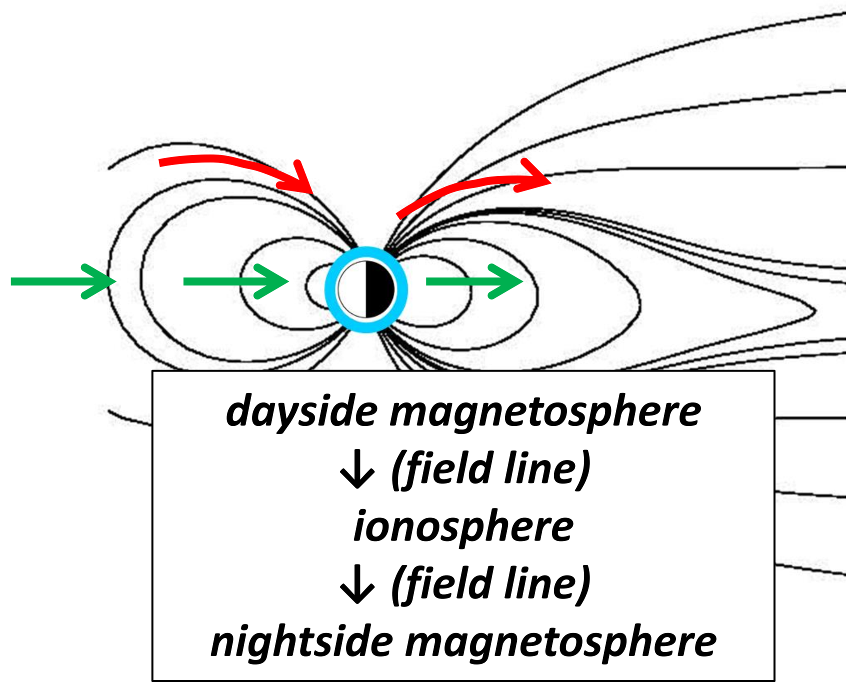
Question 1: Time response

- How do electric fields evolve in time?
  - The precise response time lag has not been deeply discussed yet.

Question 2: Propagation Process

- What is the propagation path in M-I coupled system?
  - particularly the connection between magnetosphere and ionosphere





Purpose of this study

- The electric field is a key parameter to understand the propagation process in the M-I coupled system, but there are few reports that focus on the electric field.

Using multi-point observations, we investigate

1. **the spatial and temporal variations of electric fields**
2. **the propagation process in the M-I coupled system**

during SCs.

- In order to understand the propagation process between magnetosphere and ionosphere, **multi-point observations that locate in the M-I coupled system are needed**.

  -> Now is a good time!

Ionosphere:
SuperDARN, **C/NOFS**, HF Doppler radar, SWARM, DEMETER, etc…

Magnetosphere:
THEMIS, **RBSP**, **GOES**, ETS, MMS, ERG (2016-), etc…

[*NASA/ESA SOHO Mission*]

Data set

Data set

- **THEMIS (5 probes; mainly use -A, -D, and -E)**
  E-field (3 s)/B-field (3 s)/electron density (potential)
- **Van Allen Probes (RBSP, 2 probes)**
  E-field (< 10.9 s)/B-field (4 s)/electron density (potential & f_{UHR})
- **GOES (-13, -15):** B-field (0.512 s)

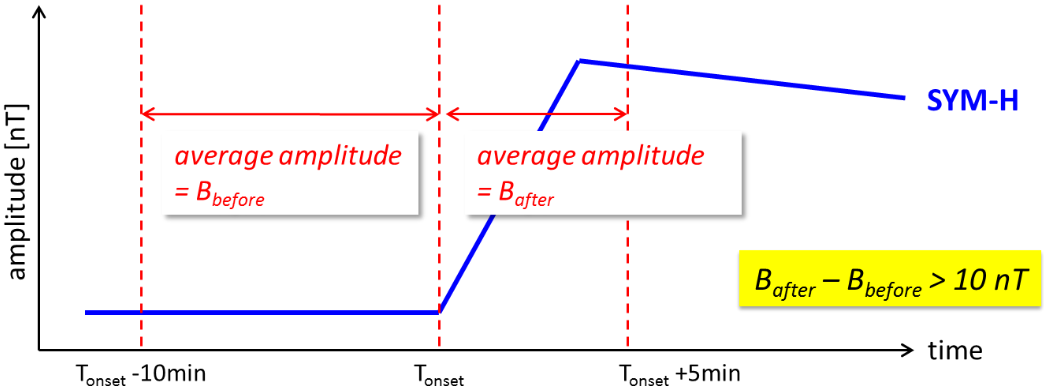
- **C/NOFS**
  ion velocity (0.5 s)/B-field (1 s) **-> We derive E (= $-V \times B$).**
- **SuperDARN (SD, near spacecraft footprints)**
- **Ground magnetometers**: 1-s resolution (THEMIS-GBO, WDC, etc.)

Event Criteria -> SYM-H index

- amplitude: > 10 nT
- rise time: < 5 min

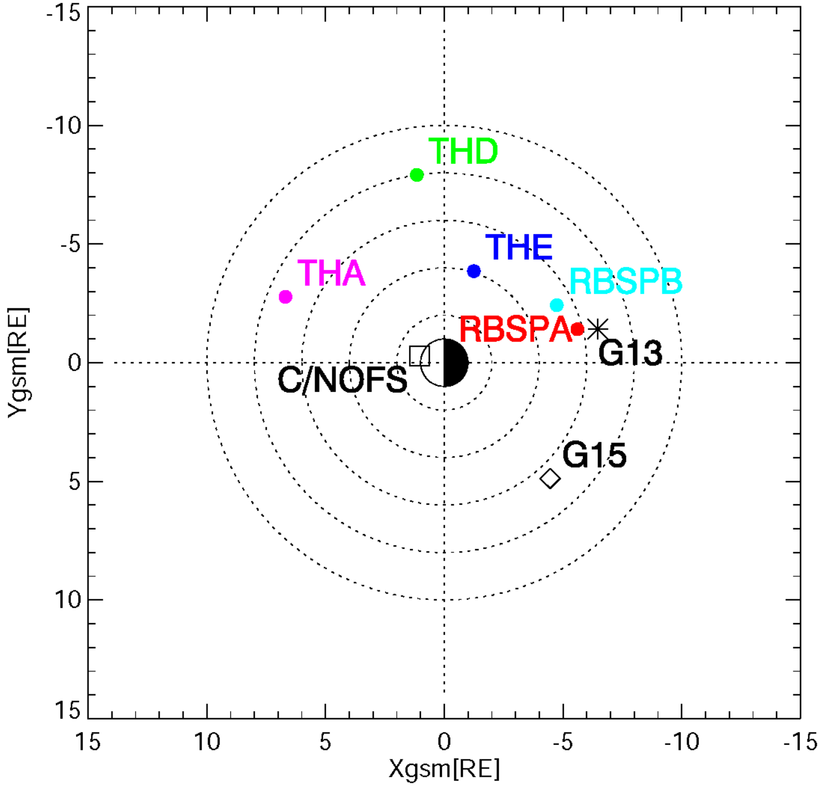
January 2013 ~ December 2014

130 events



2013-03-17 event: overview (onset = 0600 UT)

Observation geometry



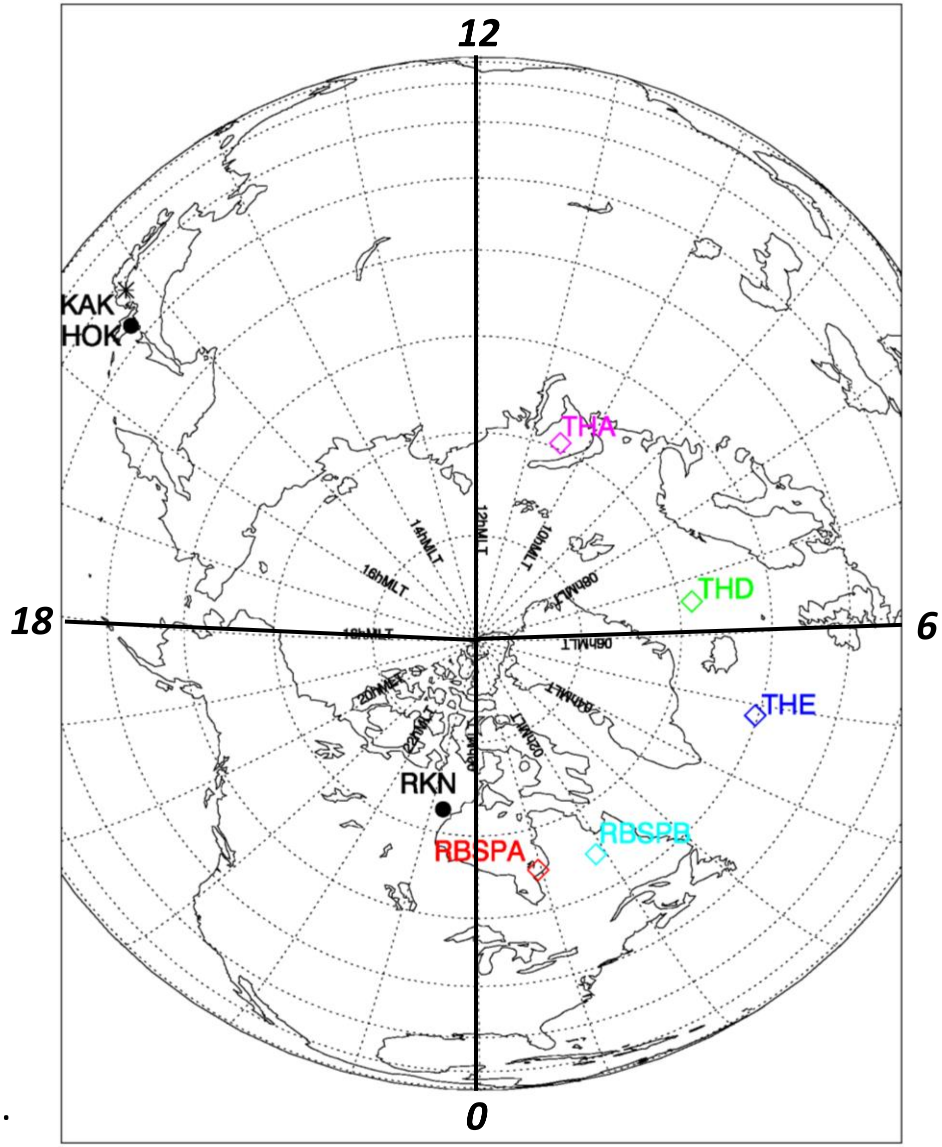
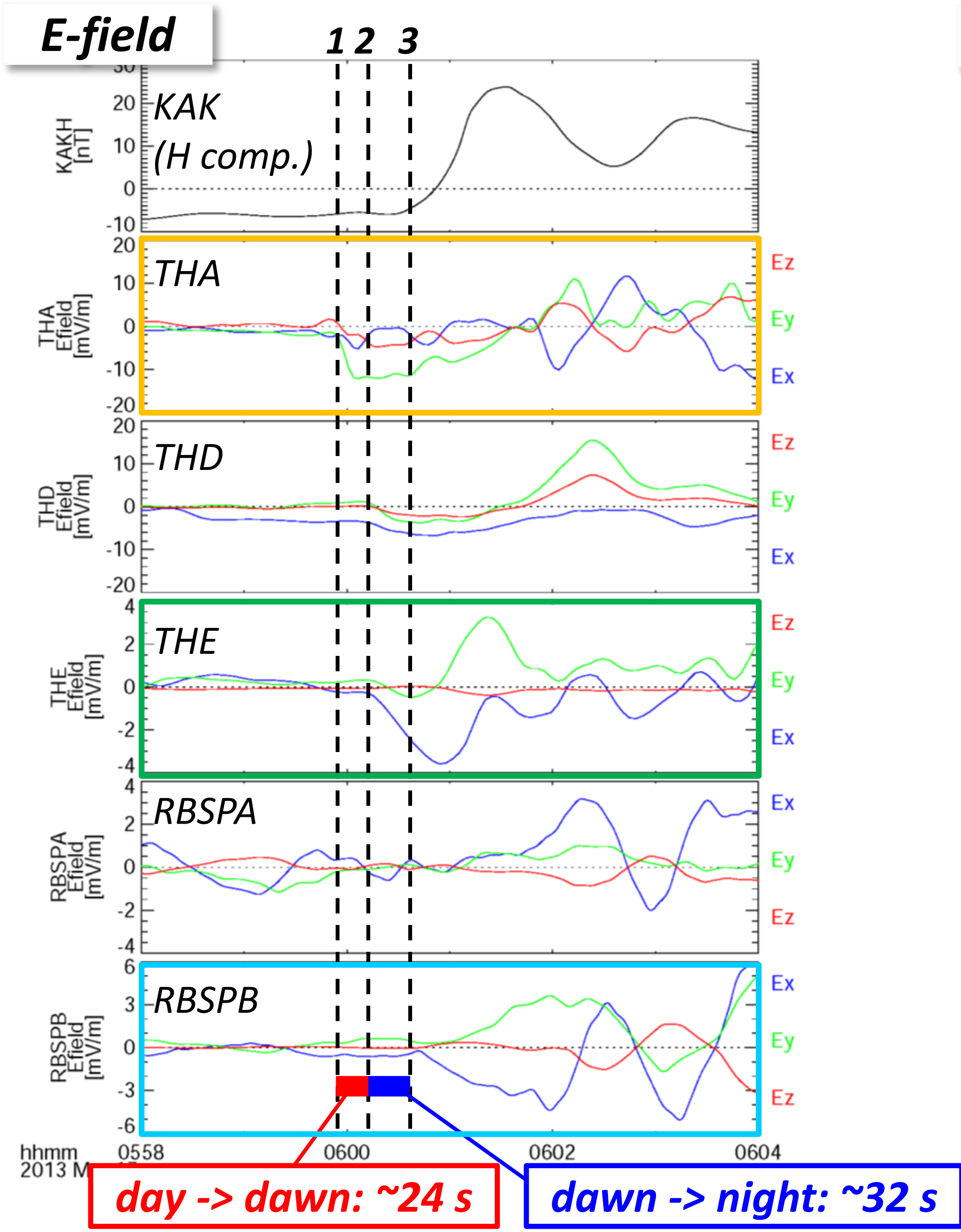
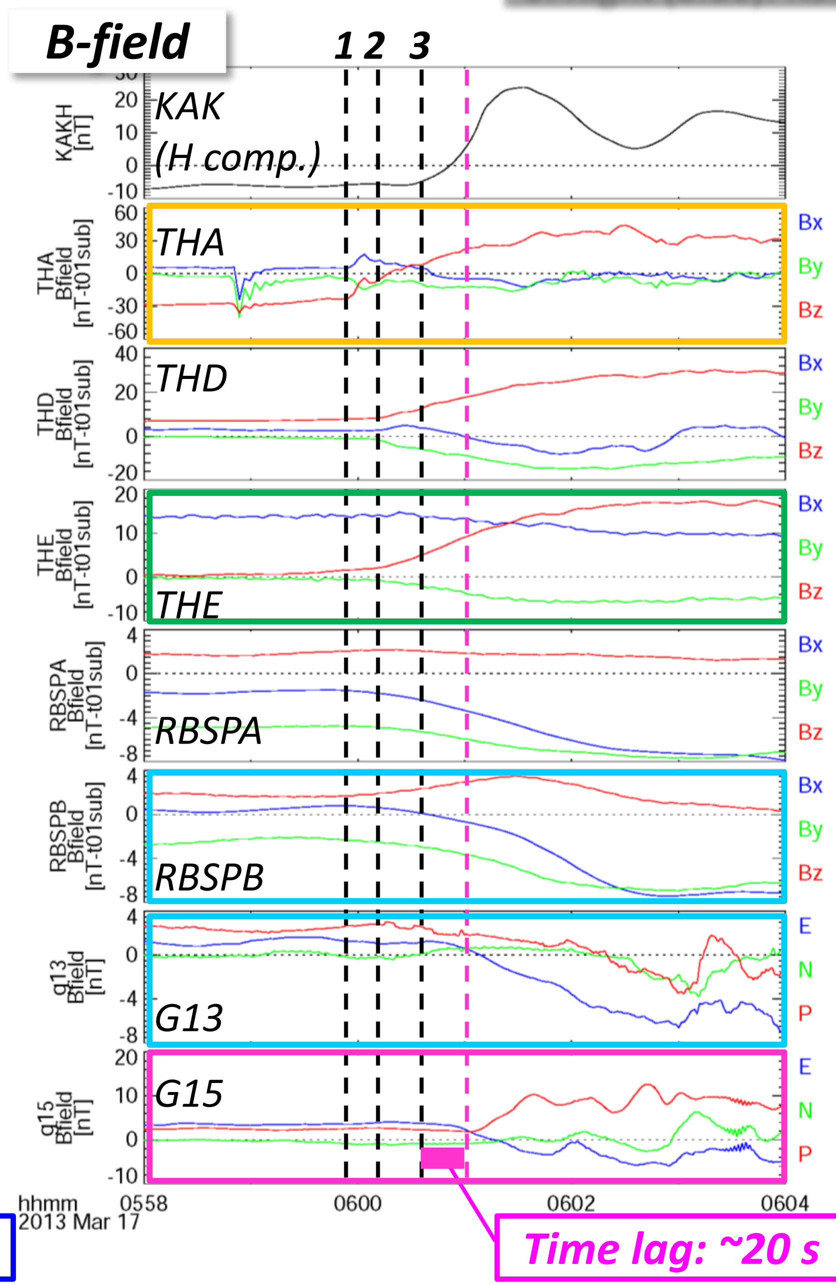


Fig.
(left) Satellite location on the equatorial plane in GSM coordinate.
(right) Footprint of satellites and locations of radars and a magnetometer in AACGM coordinate.

2013-03-17 event: magnetosphere

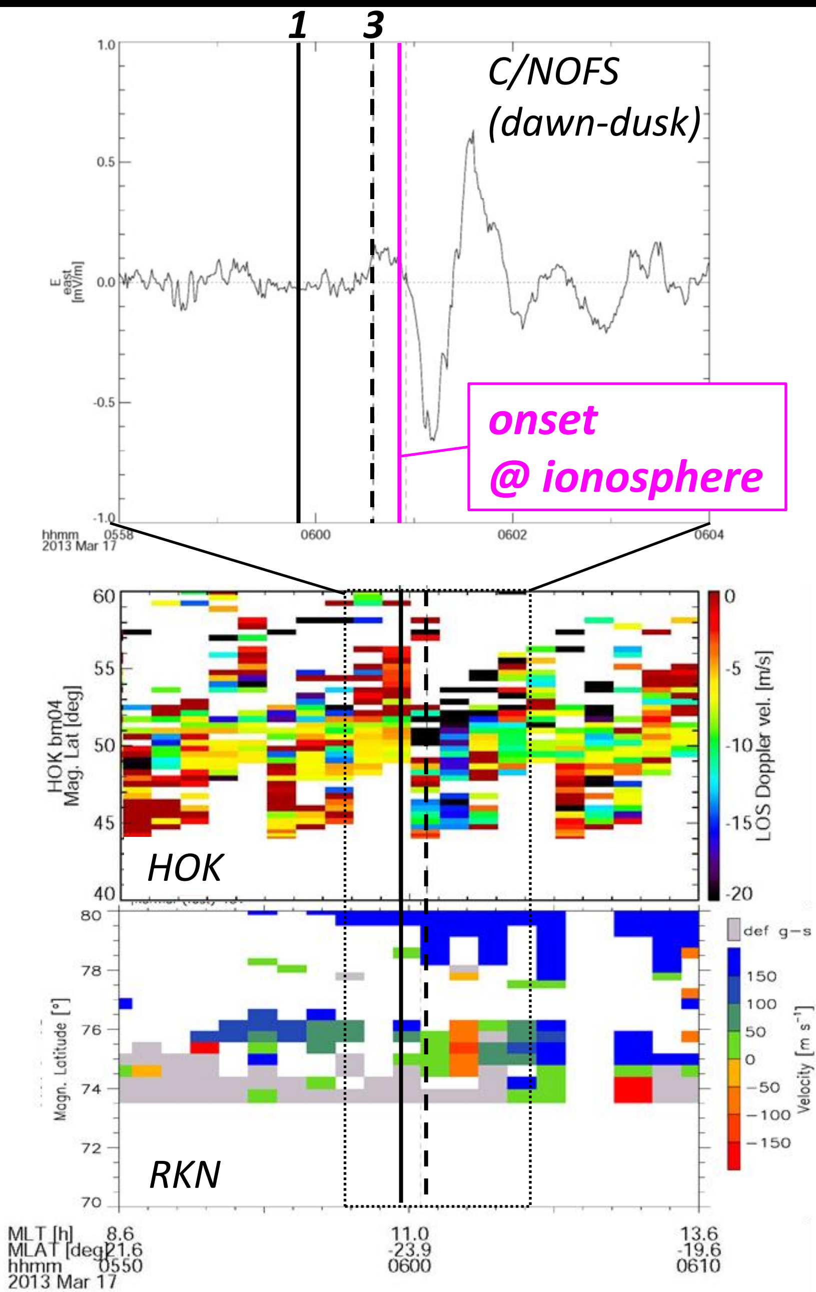
1. day (orange): THA
2. dawn (green): THE
3. night (blue): RSPB





2013-03-17 event: ionosphere

1. day (orange): THA
2. dawn (green): THE
3. night (blue): RSPB

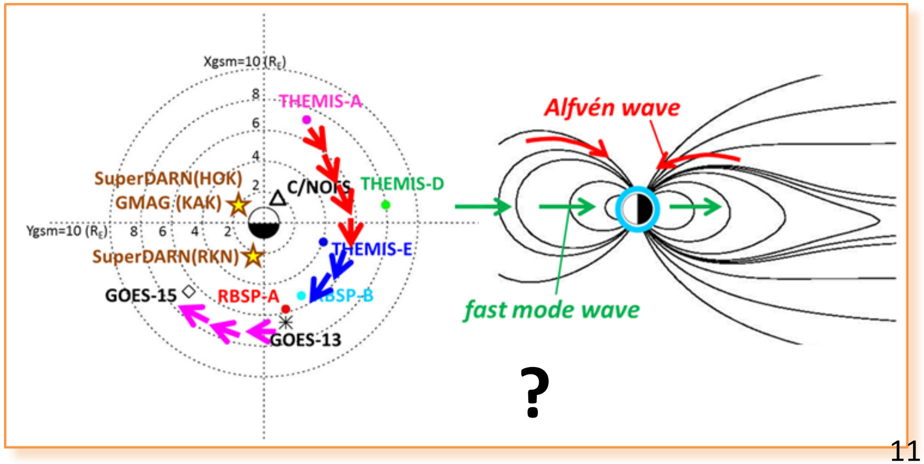


C/NOFS (~11 h LT)

- ☐ dusk-to-dawn electric field (Ey) at 0600:55 UT
  -> 19 s later than midnight E-field (line 3).

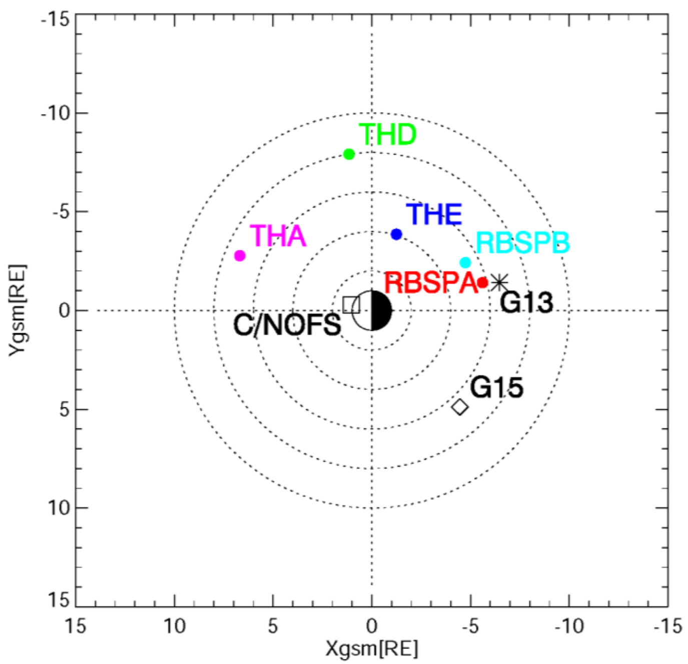
SuperDARN
(Hokkaido: 15 h LT, Rankin Inlet: ~23.5 h LT)

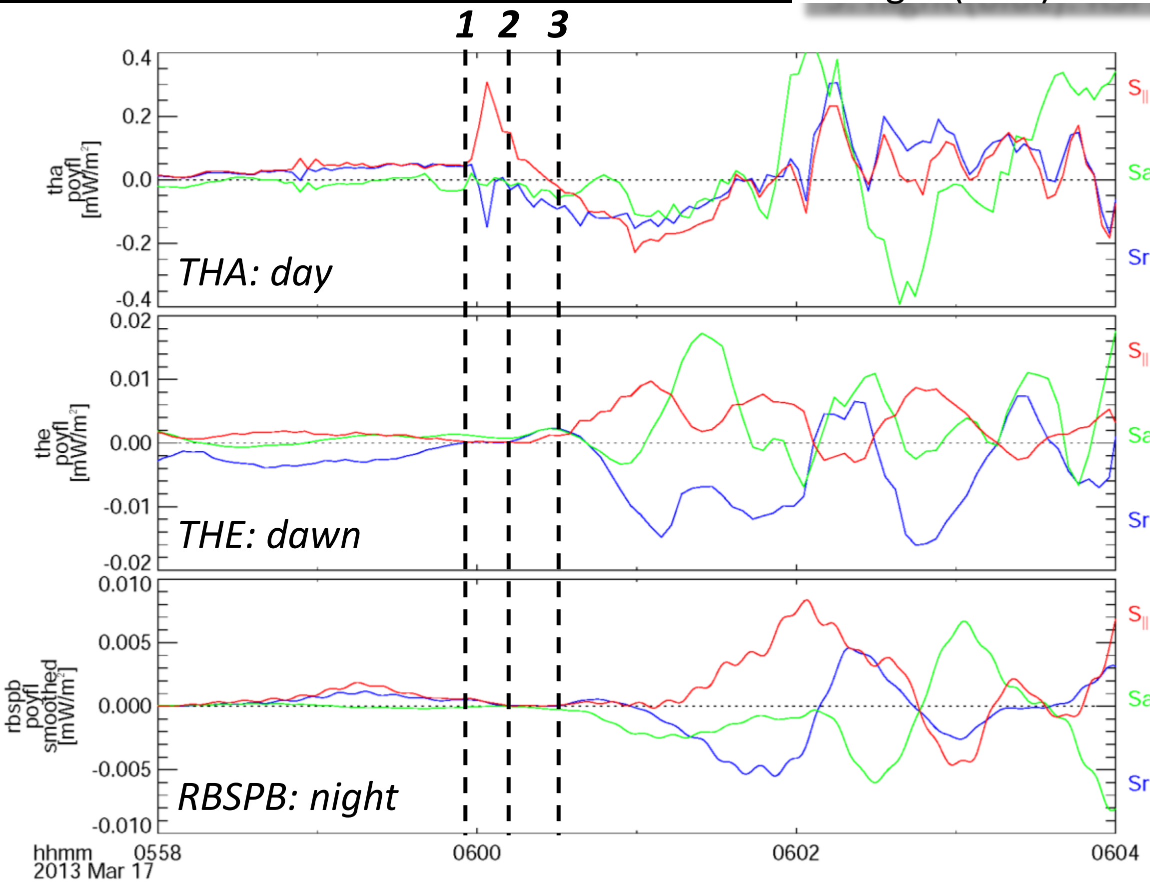
- ☐ 1-min resolution
- ☐ Both radars detect negative flows.
  (= **dusk-to-dawn E-field**)
- ☐ Ionospheric electric fields propagate globally and simultaneously.
  [e.g., *Kikuchi*, 2014; *Takahashi et al.*, 2015]



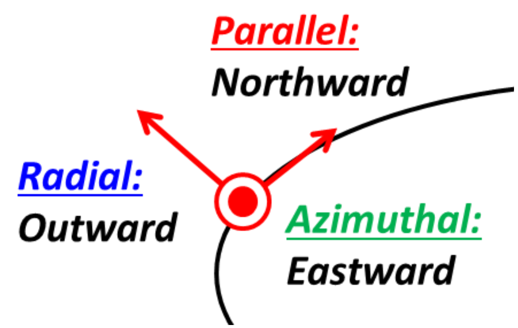
Poynting fluxes (= δE x δB/μ)

1. day (orange): THA
2. dawn (green): THE
3. night (blue): RSPB





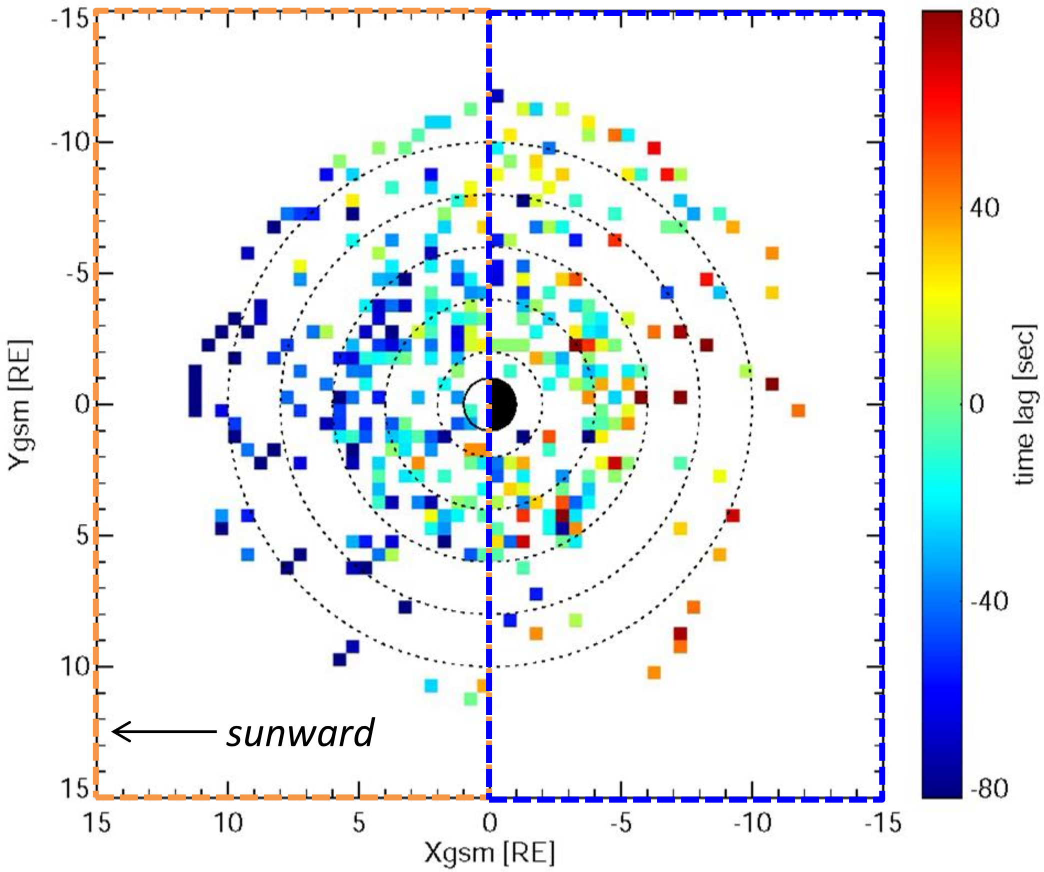
- day: $S_{||} > 0$
  -> toward the ionosphere
- dawn: *Sr* is dominant.
  -> earthward propagation
- night: *Sr* >0, $S_{||} > 0$
  -> **compressional waves**
  + toward the ionosphere

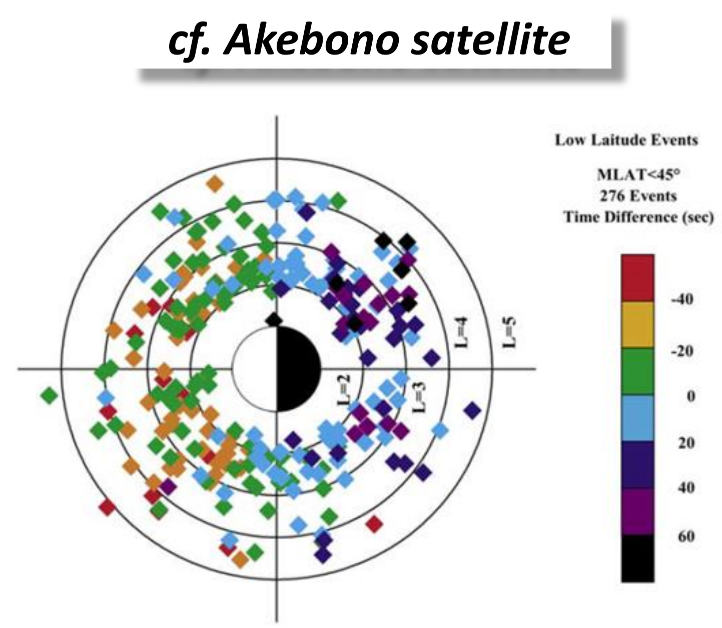


Statistical study: response time

- color counter: time lag from KAK = (PI onsets at satellites) – (PI onset at KAK)
  -> <u>cool color = The magnetospheric electric field responds faster than KAK.</u>

- Dayside (Orange frame): can be explained by fast mode wave propagation
- Nightside (Blue frame): dawn- dusk asymmetric distribution
  -> due to the asymmetry of plasmapause location?





[*Shinbori et al.*, 2003]

Statistical study: response time

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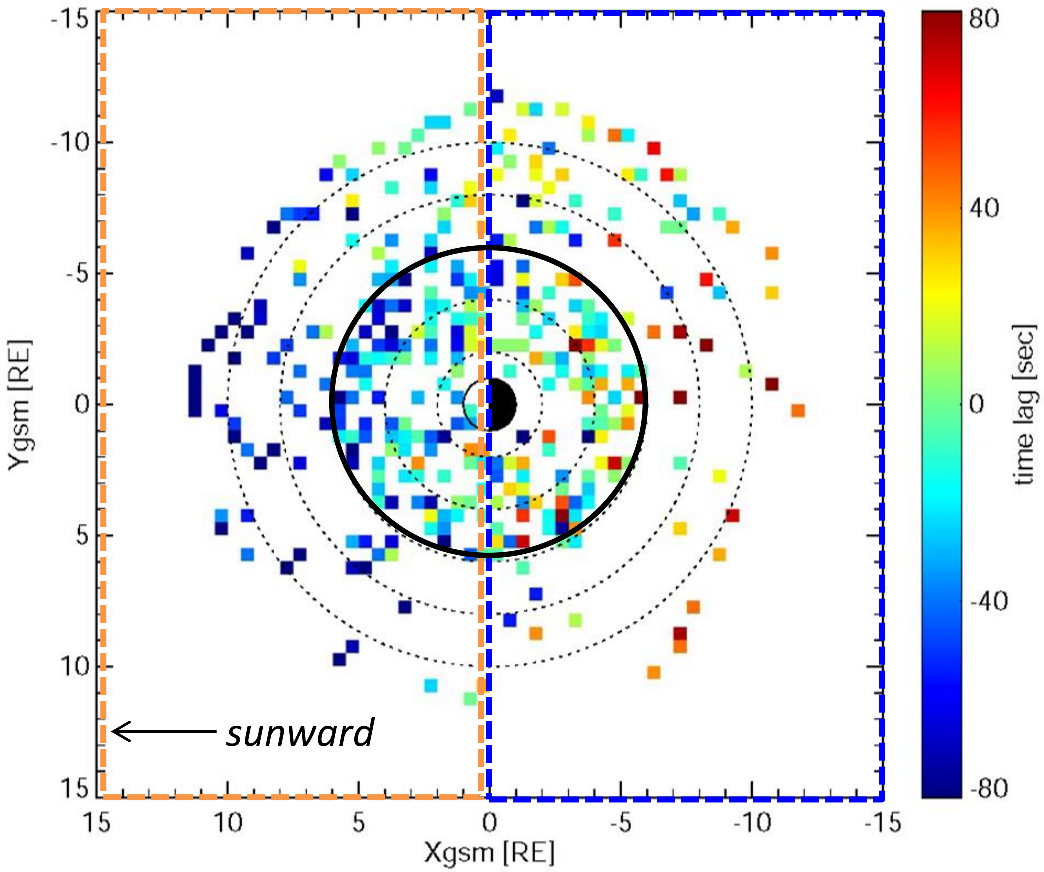
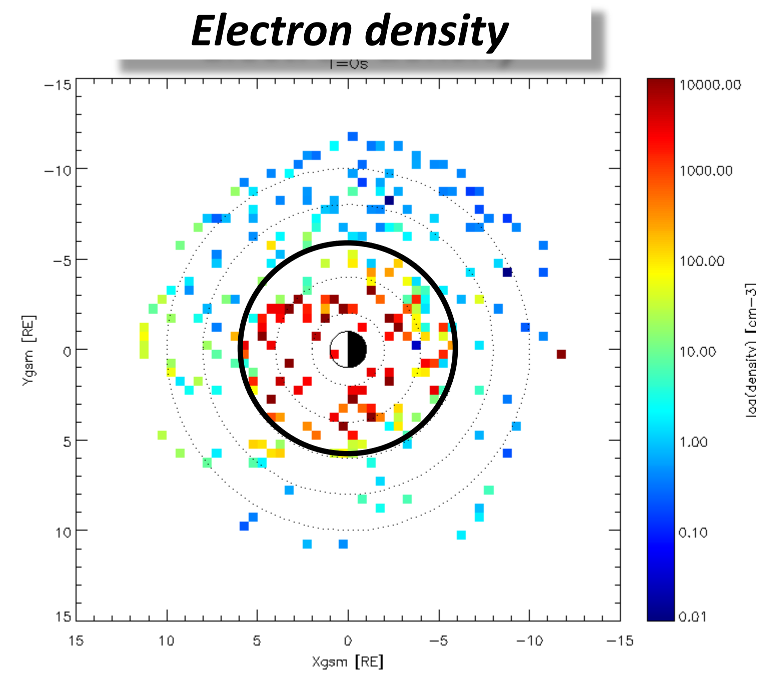
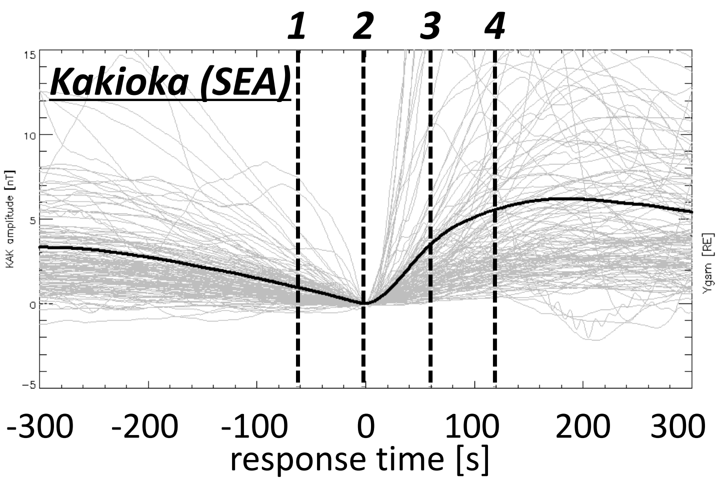
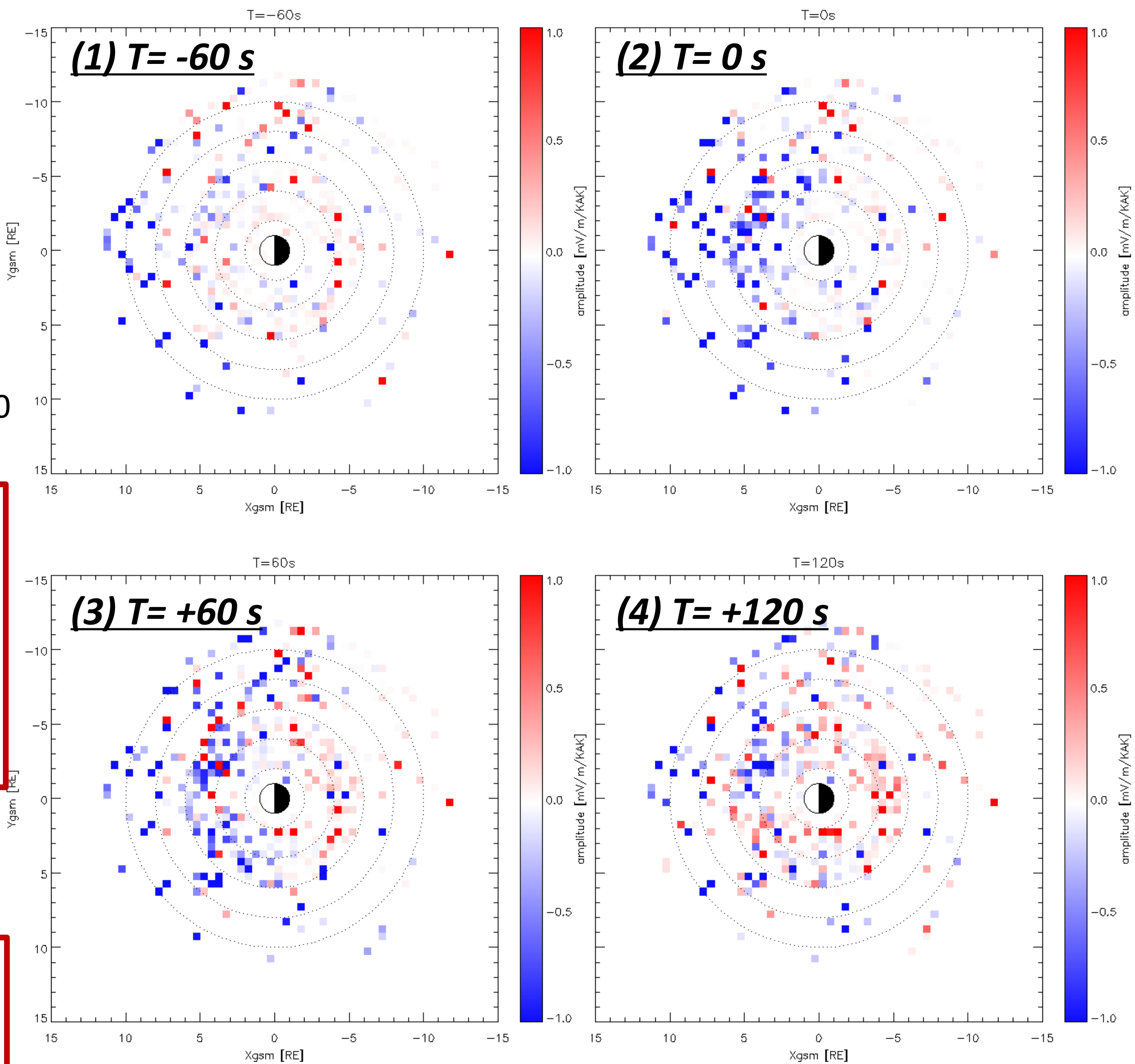




** Black circle: L = 6*

Statistical study: Ey (dawn-dusk direction)





Westward electric field associated with the compression

(1) -> (2): duskward (day)
(3): dawnward (night)

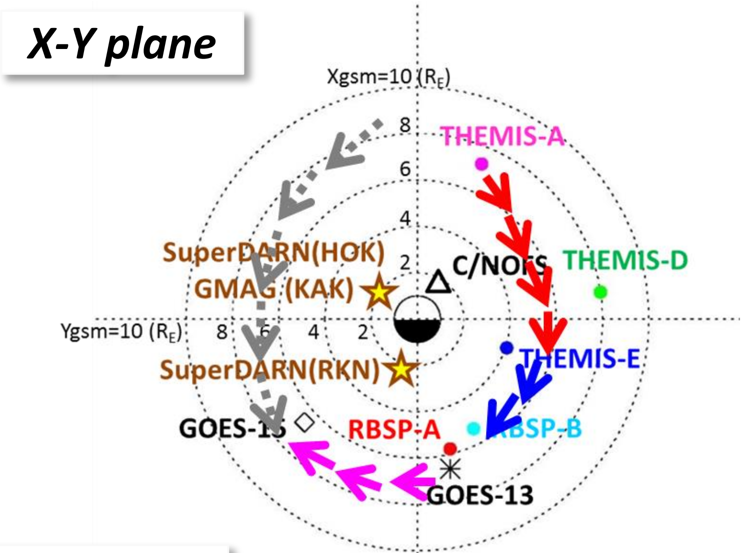
~60 s after…

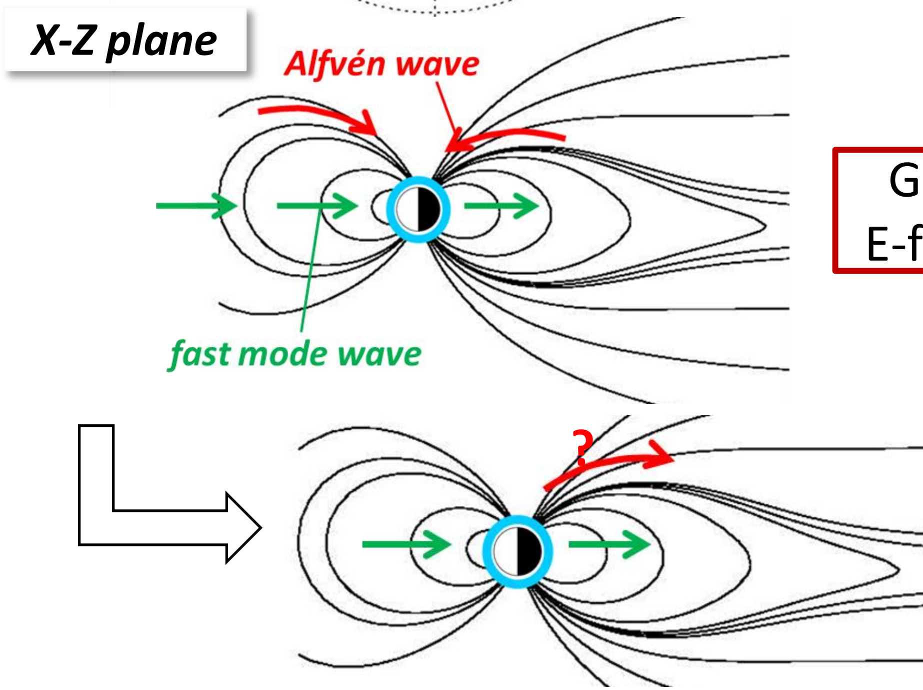
Convection electric field

(4): dawnward (all MLT)

** positive: dawnward*

Summary: Possible propagation path





Compression of the dayside magnetopause

↓

Fast mode wave propagation in the inner magnetosphere

↓ *Alfven wave propagation along field lines*

Global transmission of E-field in the ionosphere

↓ *equatorial plane*

? *Energy transfer toward the nightside magnetosphere by Poynting flux [Nishimura et al., 2010]*

Magnetospheric convection

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