Mid latitude radar workshop (Nagoya, 2011. 10. 24)

# Electric field and currents in the global ionosphere during substorms

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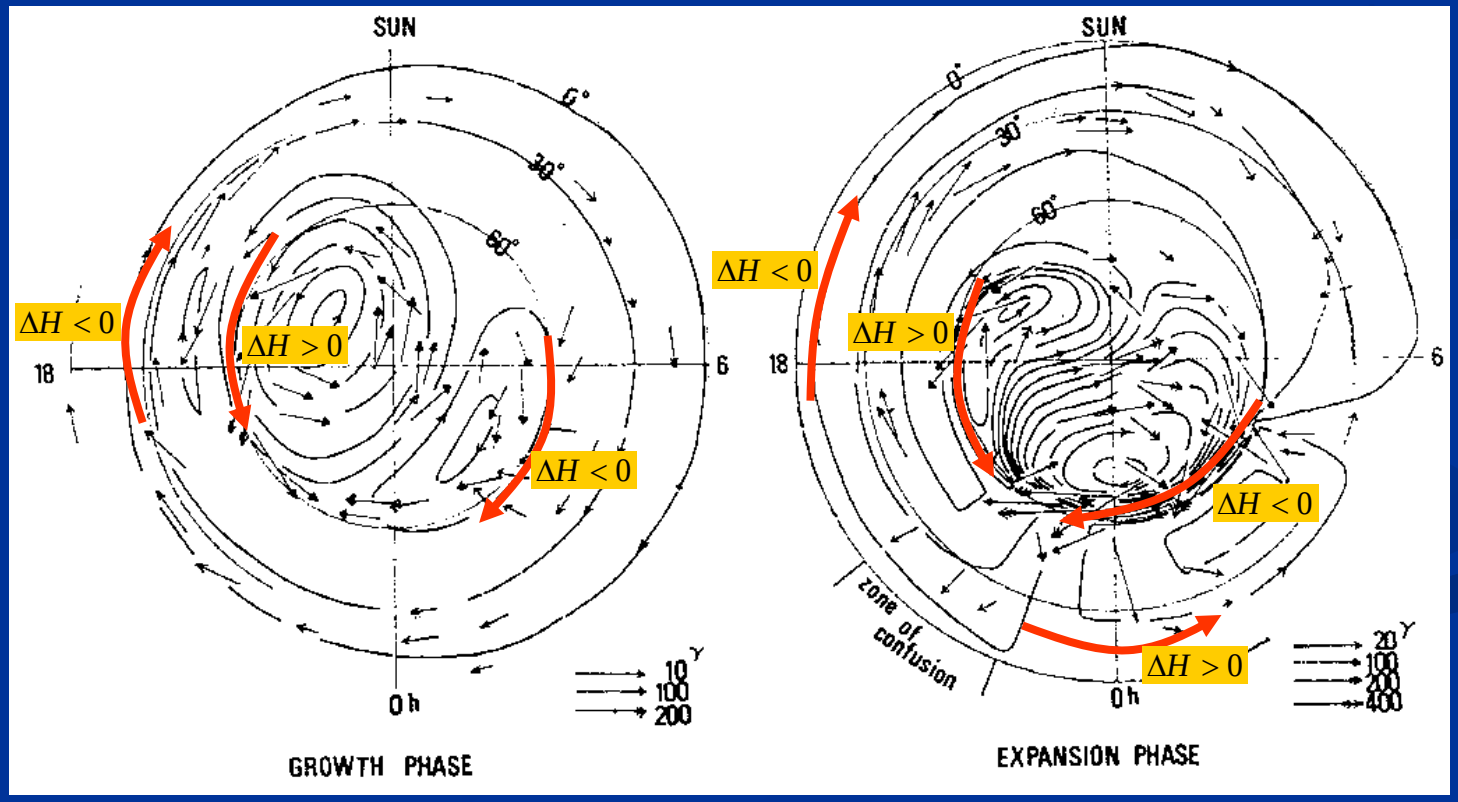
# Equivalent currents for ground magnetic disturbances during the growth and expansion phases of substorms

[Iijima and Nagata, 1972]

Growth phase (DP2)

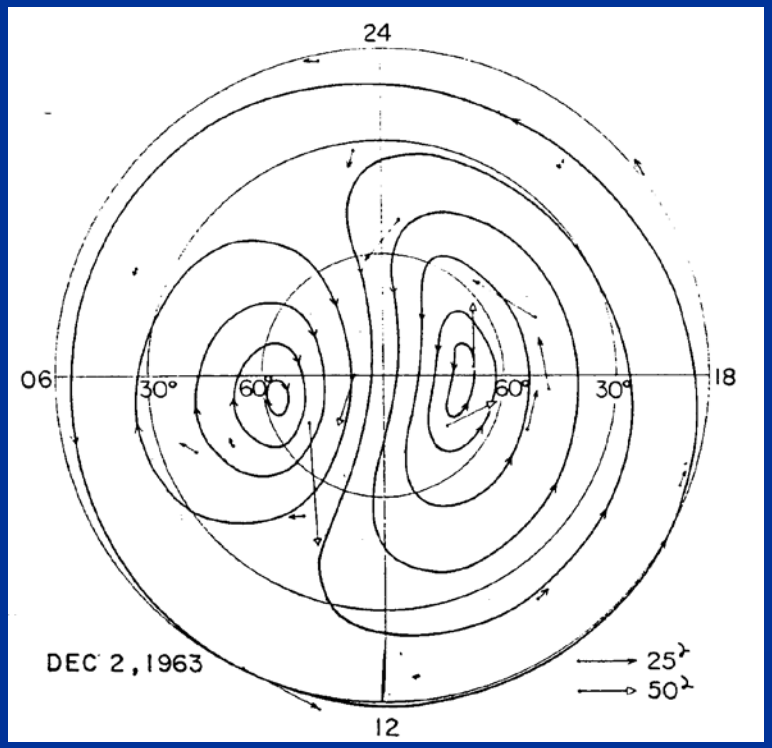
Expansion phase (DP1)

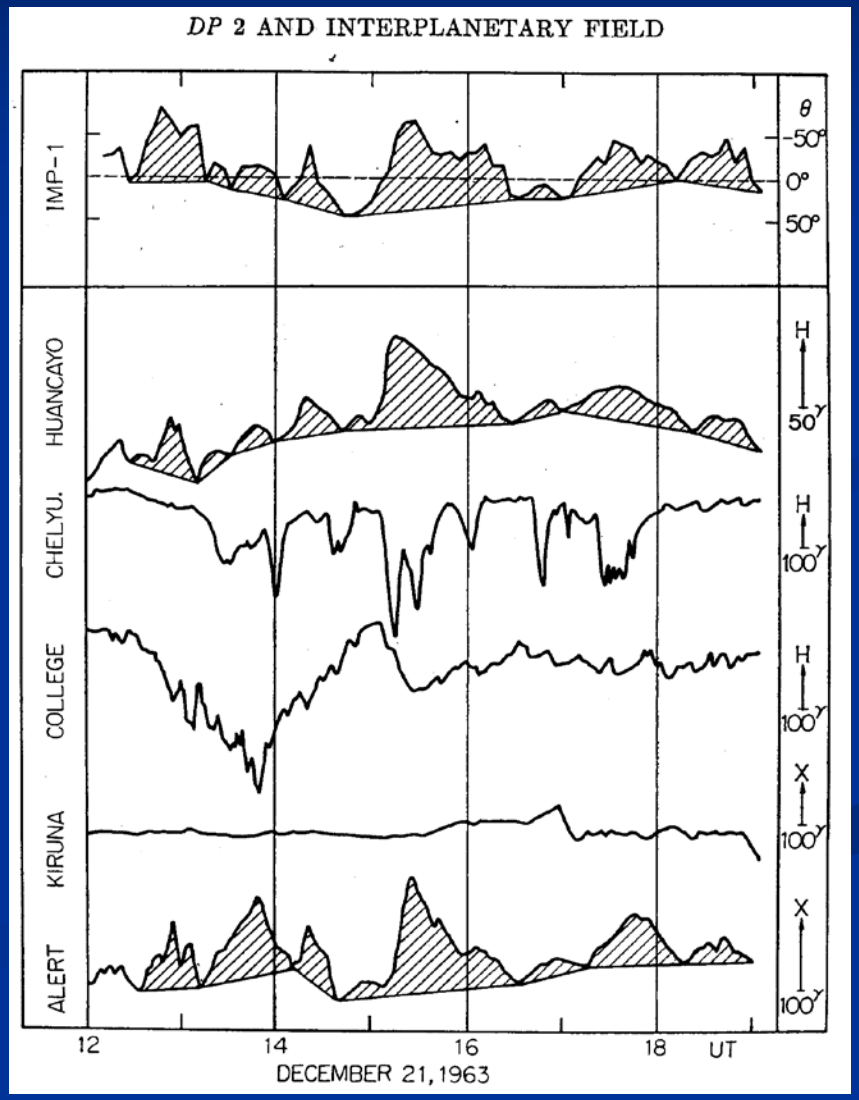


# DP2 magnetic fluctuations caused by the fluctuating southward IMF

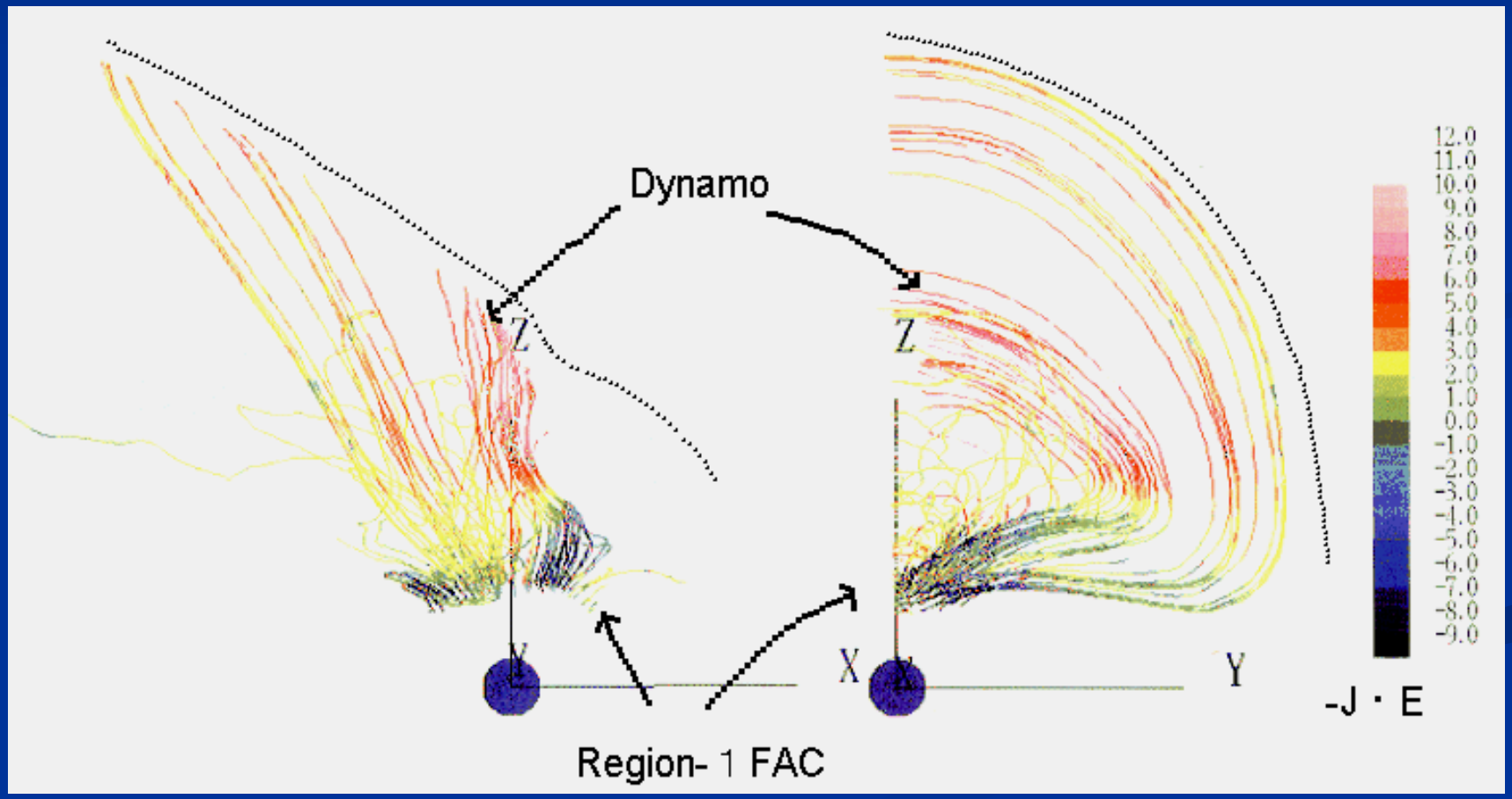
Quasi-periodic DP2 magnetic fluctuations are caused by convection electric fields controlled by the southward IMF.

(Nishida, JGR 1968)



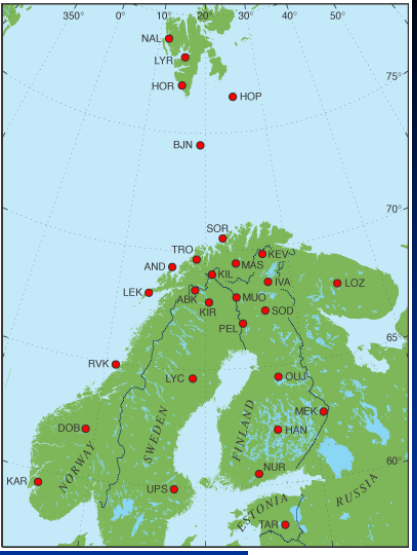



# Global MHD simulation of dynamo currents (red) and the R1 FACs (black)



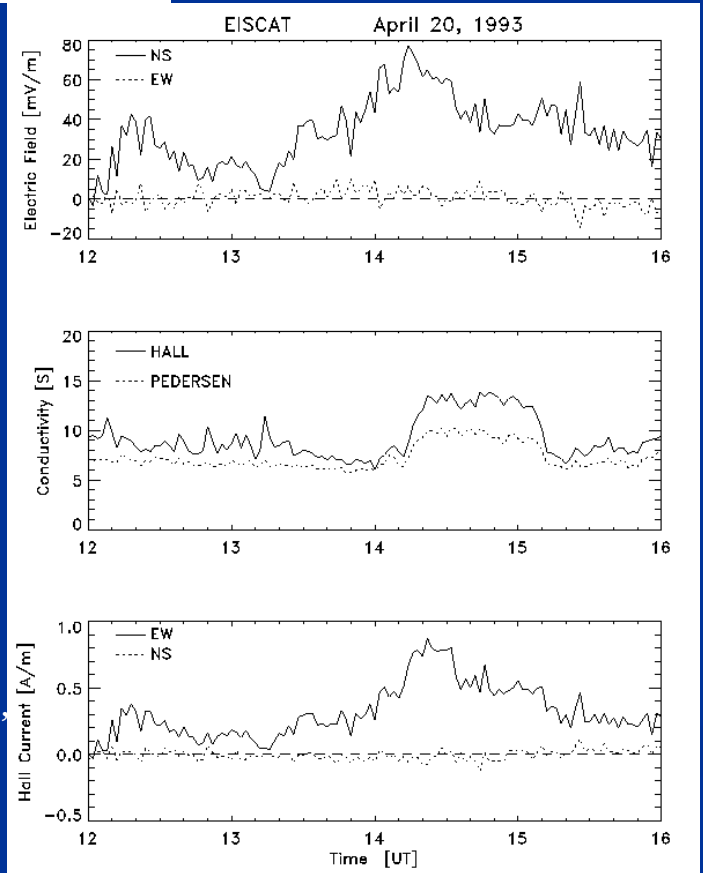

[Tanaka, JGR 1995]

# DP2/overshielding during the substorm growth/expansion phase



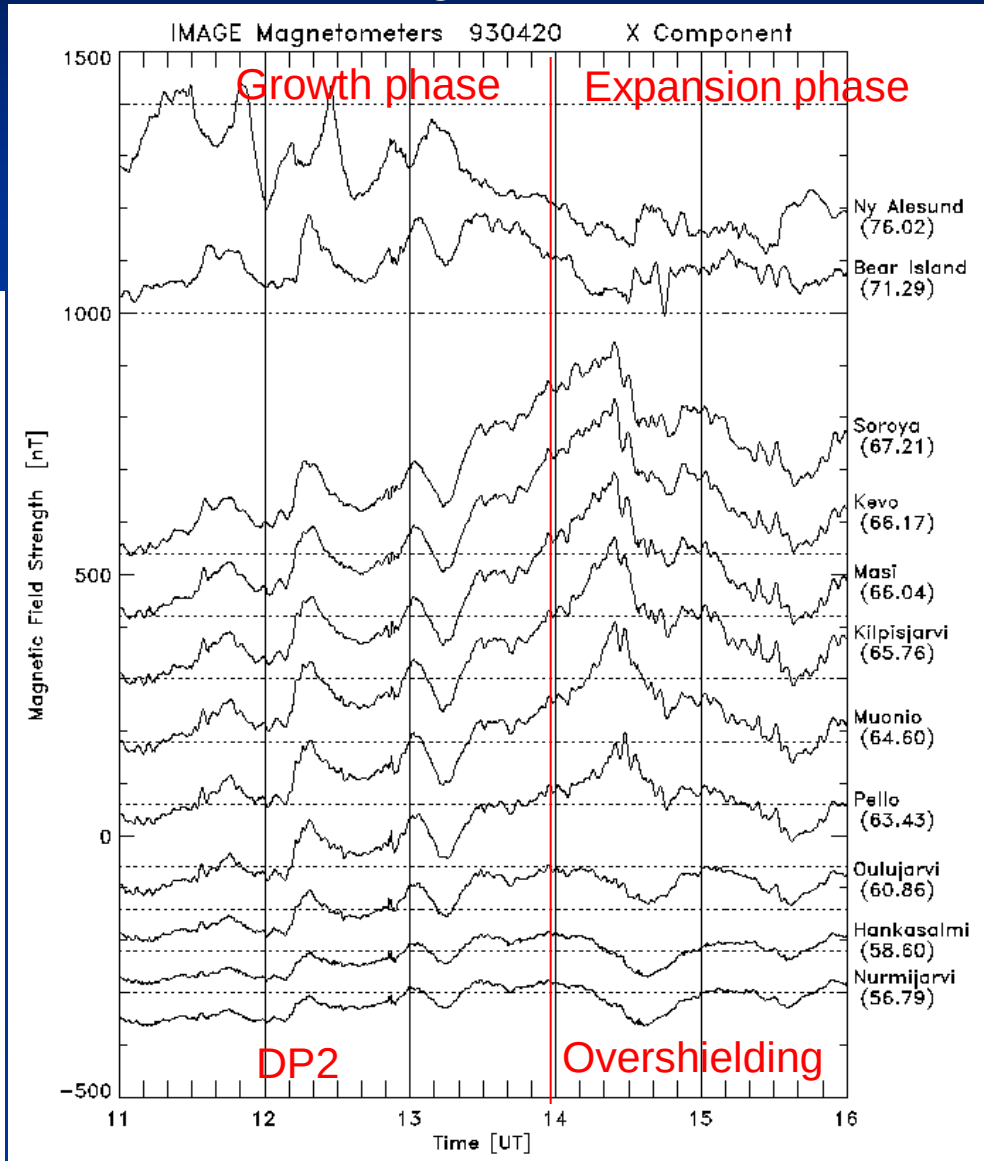

The magnetic perturbations are caused by the ionospheric Hall currents.

EISCAT

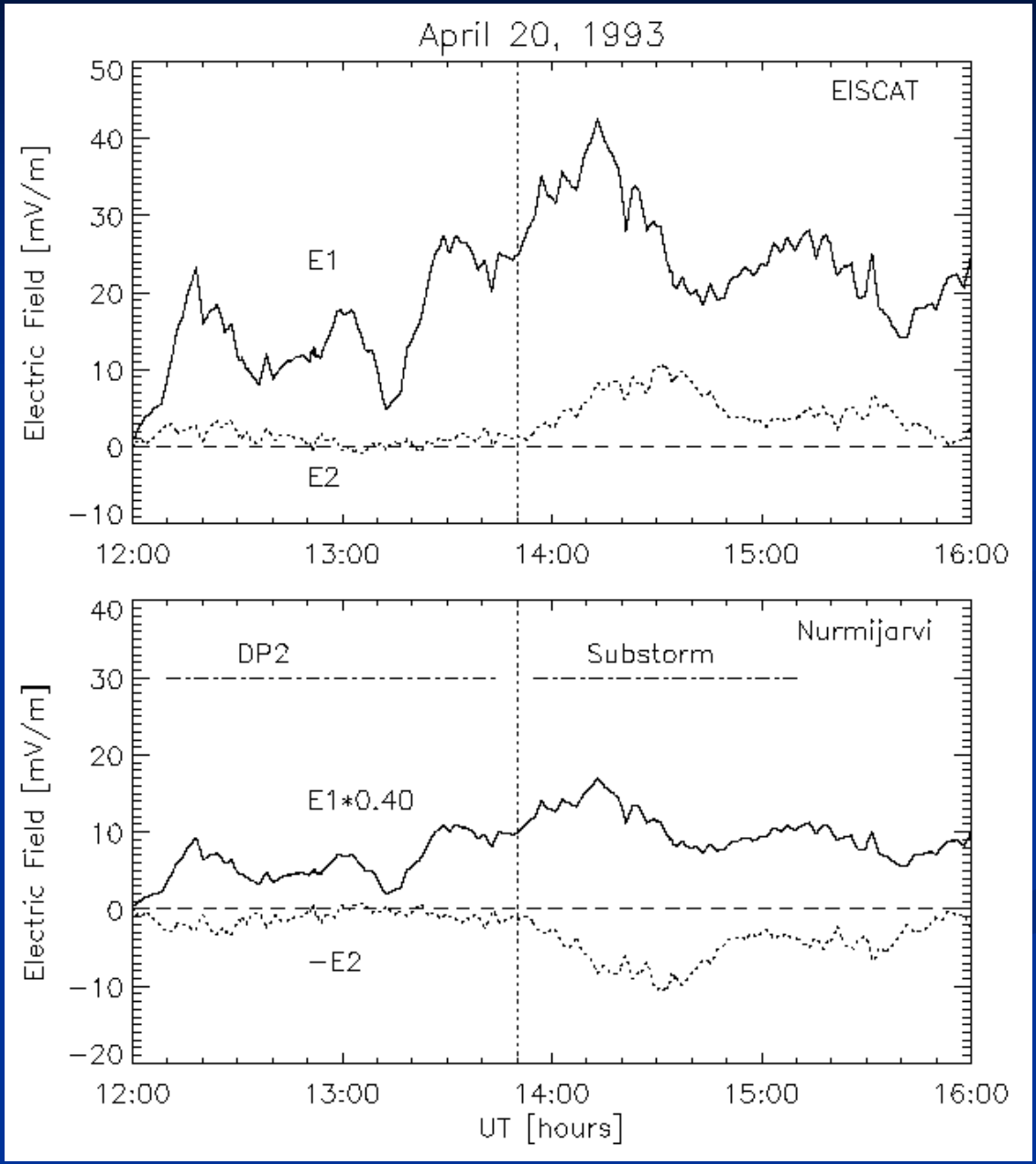



(Kikuchi et al., JGR 1996)

IMAGE Magnetometer chain



# Convection electric field (E1) and shielding/overshielding electric field (E2) at auroral (EISCAT) and mid latitudes (Nurmijarvi) during the substorm



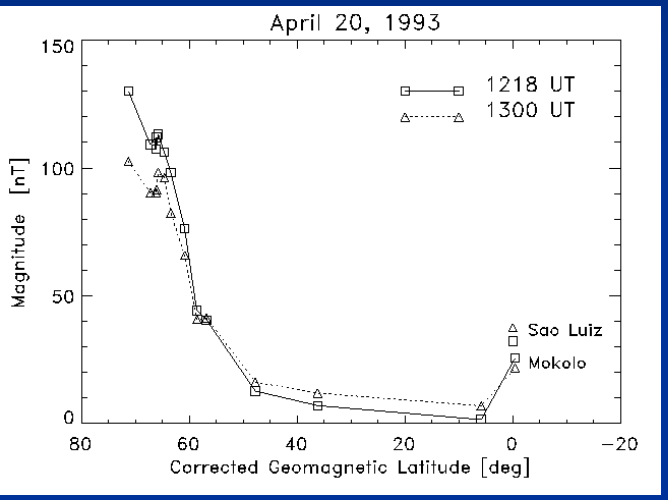

Overshielding occurs when the R2 FAC electric field overcomes the R1 FAC electric field when the R1 FACs decrease rapidly.

(Kikuchi et al., JGR 2000)

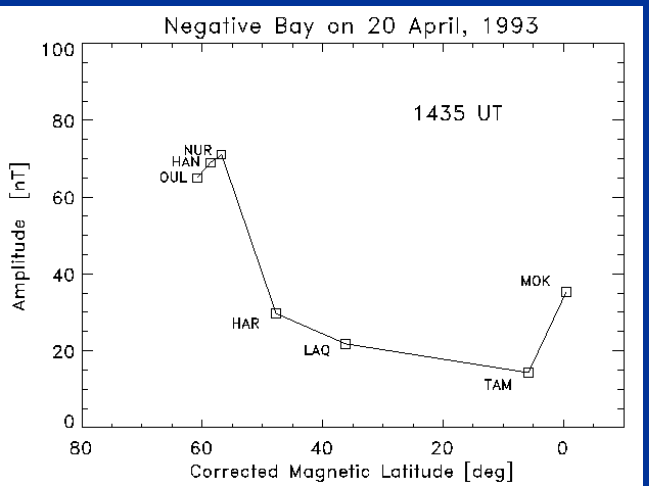
# Equatorial DP2/overshielding during the substorm growth/expansion phase

Kikuchi et al. ( JGR 1996, 2000)

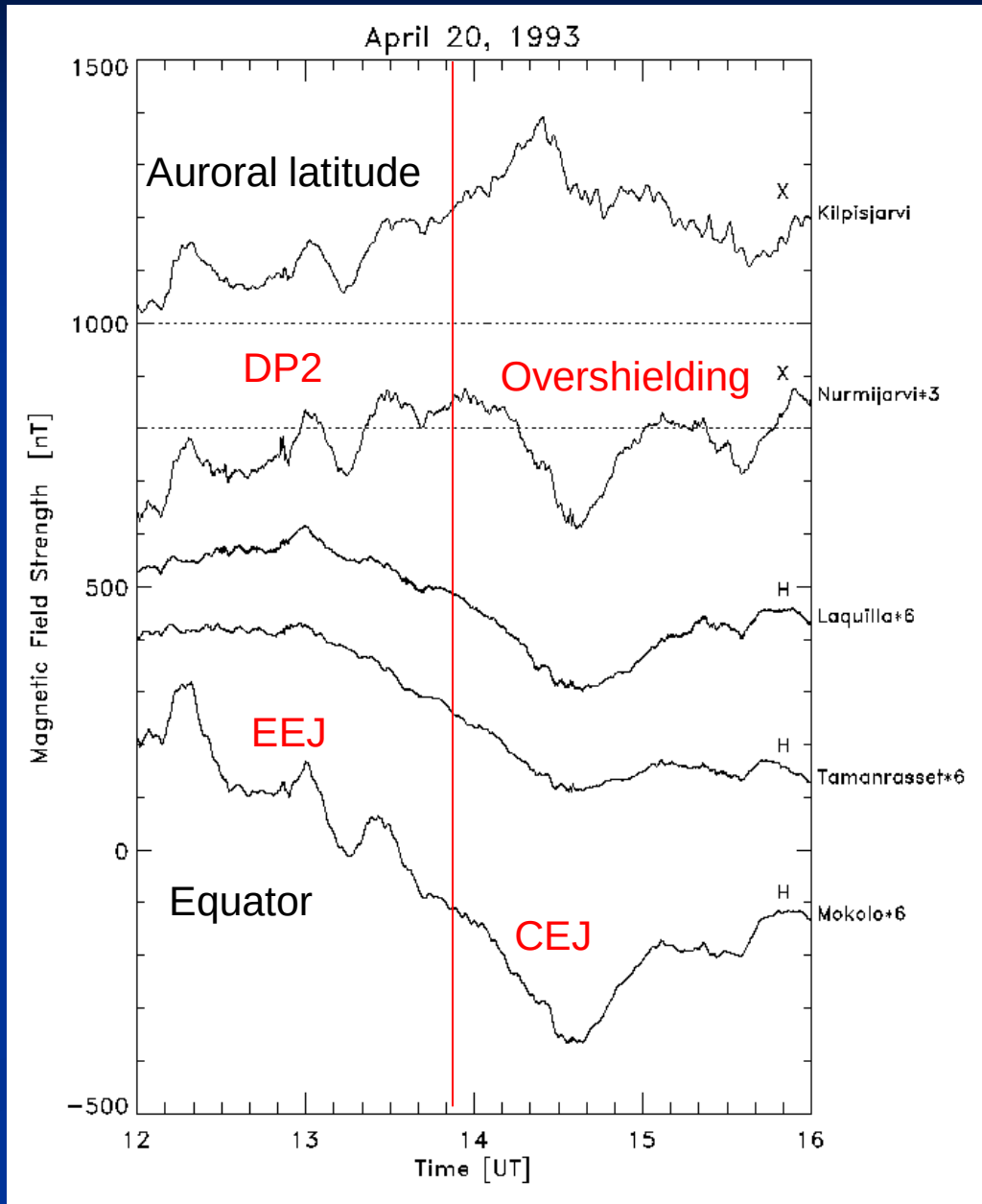
Latitudinal profile of the DP2




Latitudinal profile of the negative bay

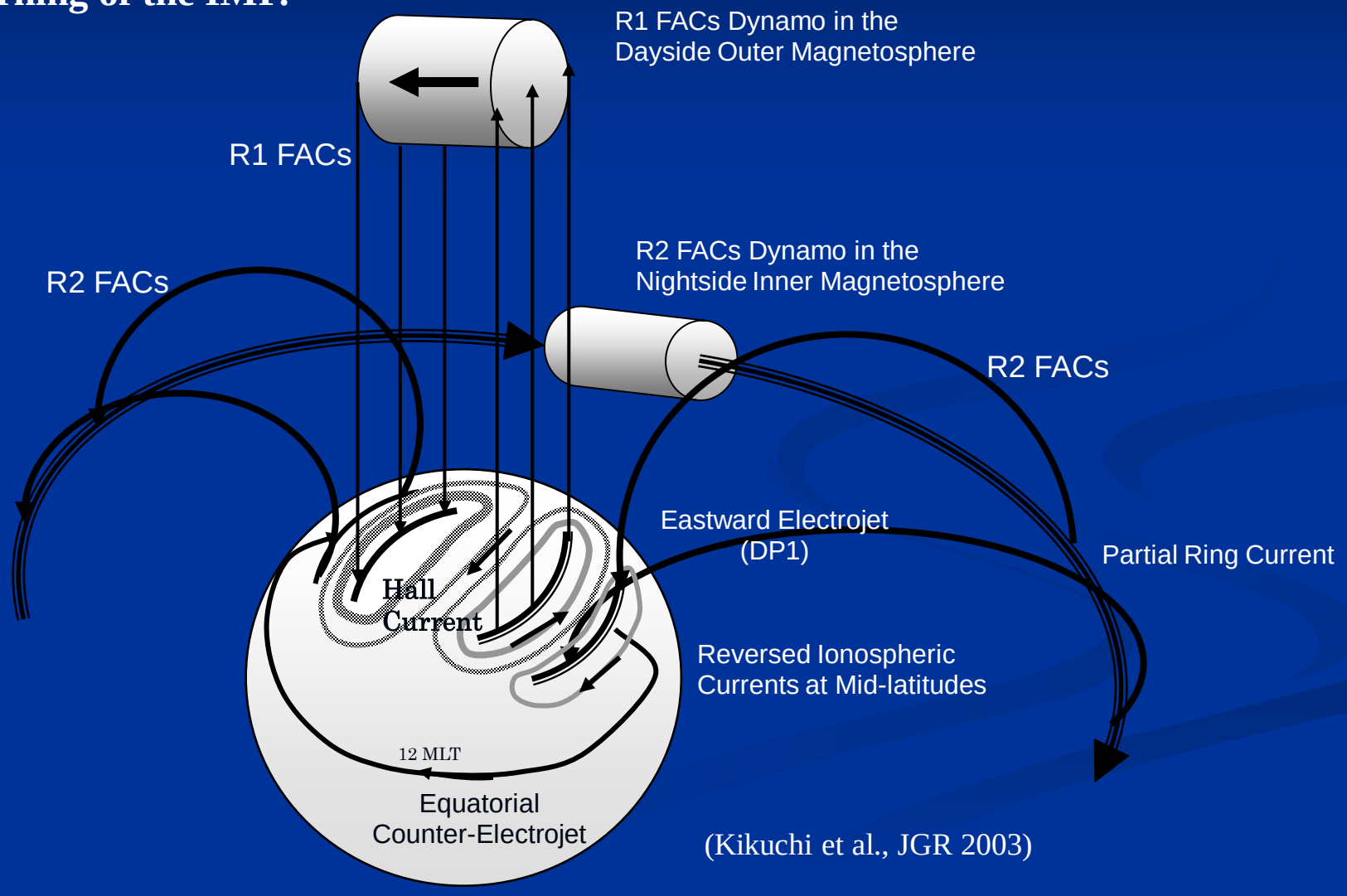



Magnetometer chain in the afternoon sector



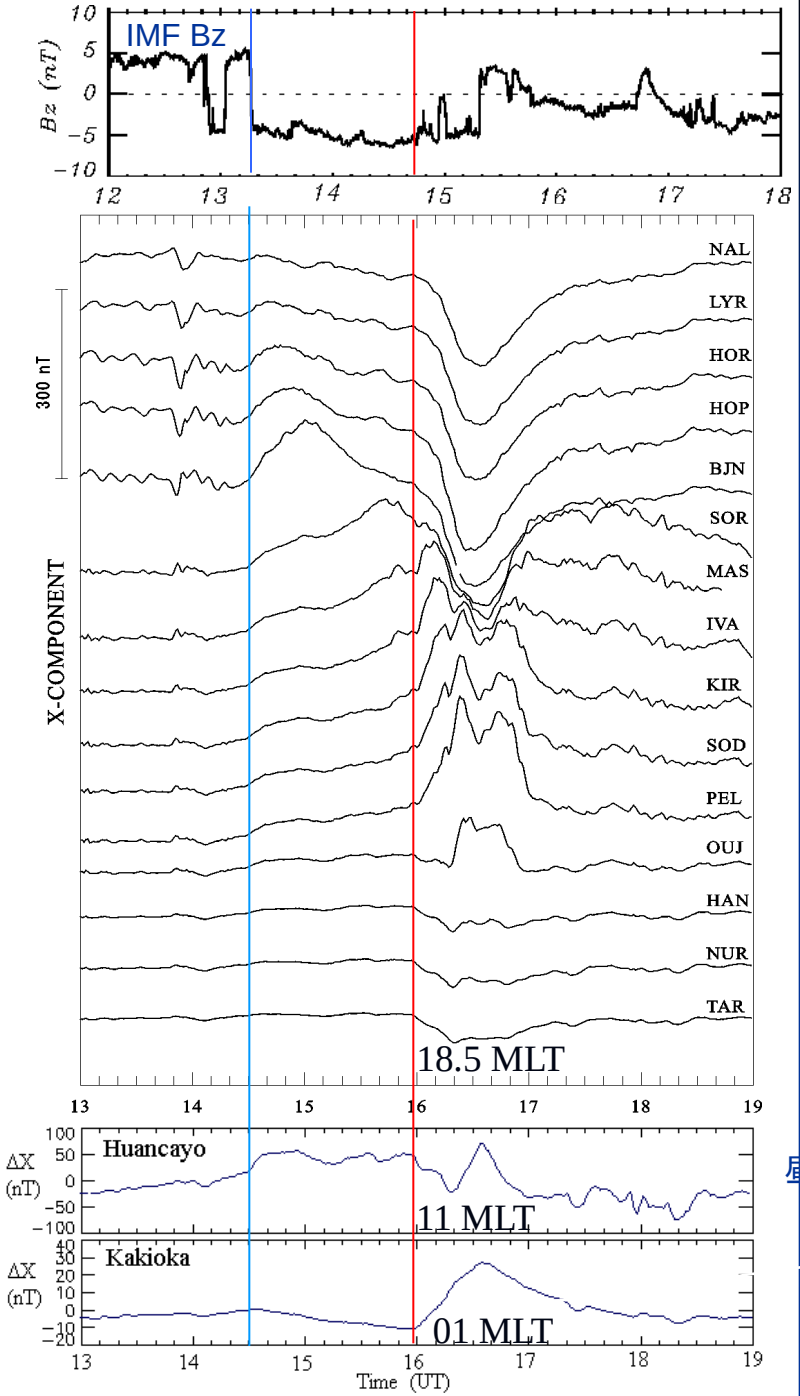
# R2FAC-CEJ Current Circuit

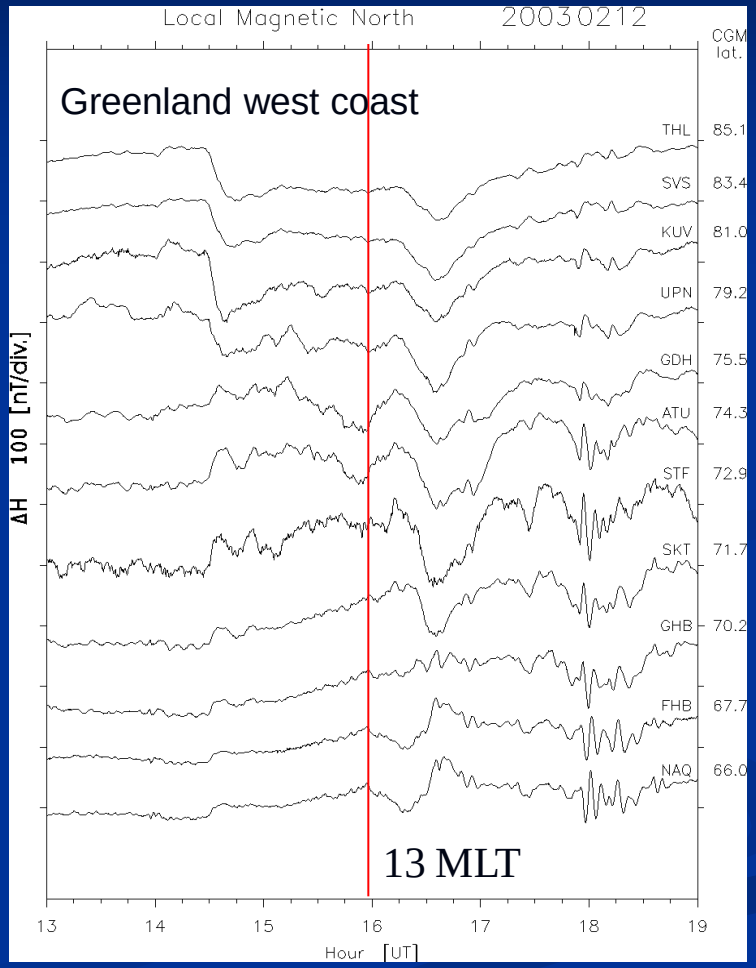
**Magnetosphere-ionosphere current system is composed of the R1 and R2 FACs and ionospheric currents. The equatorial CEJ connects with the R2 FACs, which become dominant when the R1 FACs decay rapidly because of the northward turning of the IMF.**




(Kikuchi et al., JGR 2003)

# Overshielding with an increase in the convection electric field at the onset of substorms



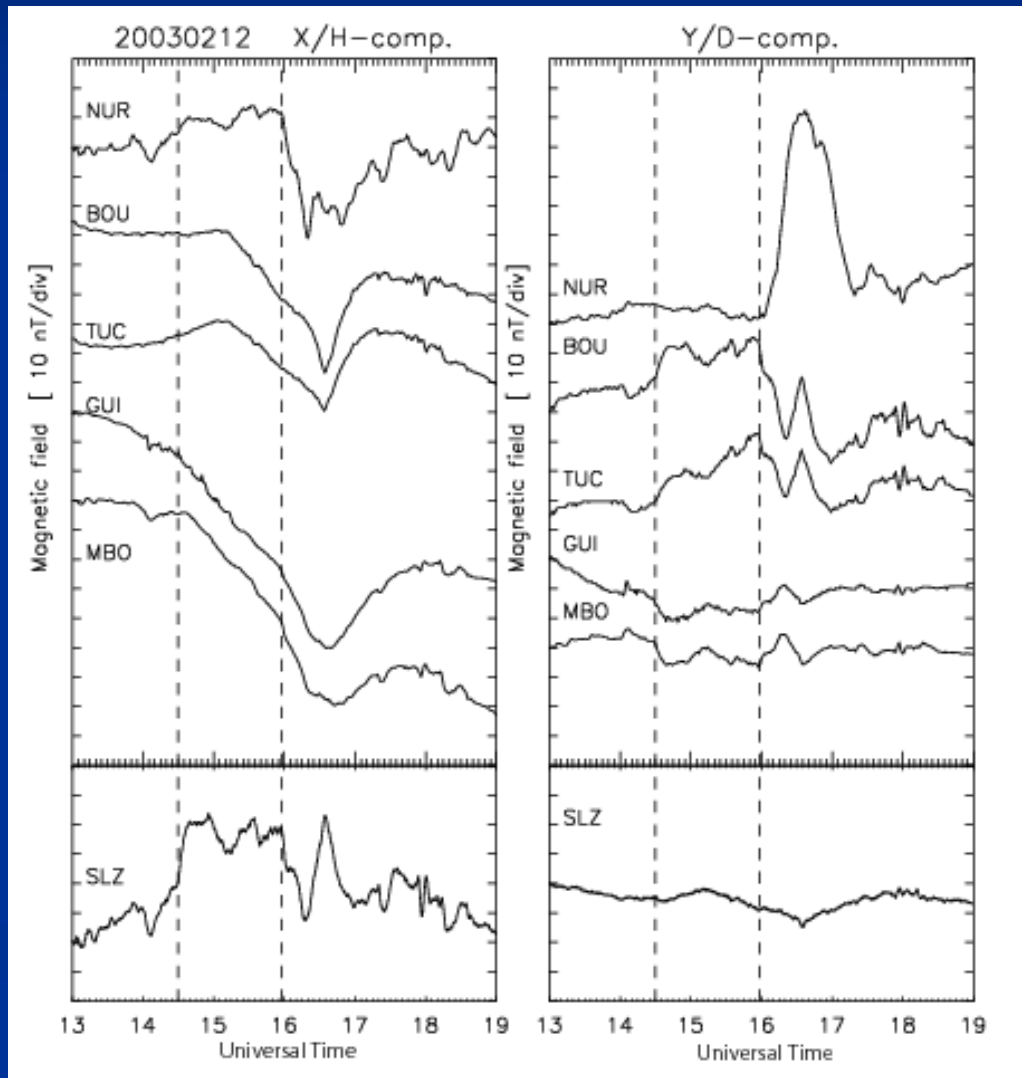




(Hashimoto et al., JGR2011)

# The H/D-component deflections at mid latitudes (BOU, TUC, GUI, MBO)

The H-component decreases gradually at all mid latitude stations, caused by the partial ring current.

The D-component deflections are negative in the morning (BOU, TUC) and positive in the afternoon sector (GUI, MBO), which should be caused by ionospheric currents closing with the equatorial CEJ.

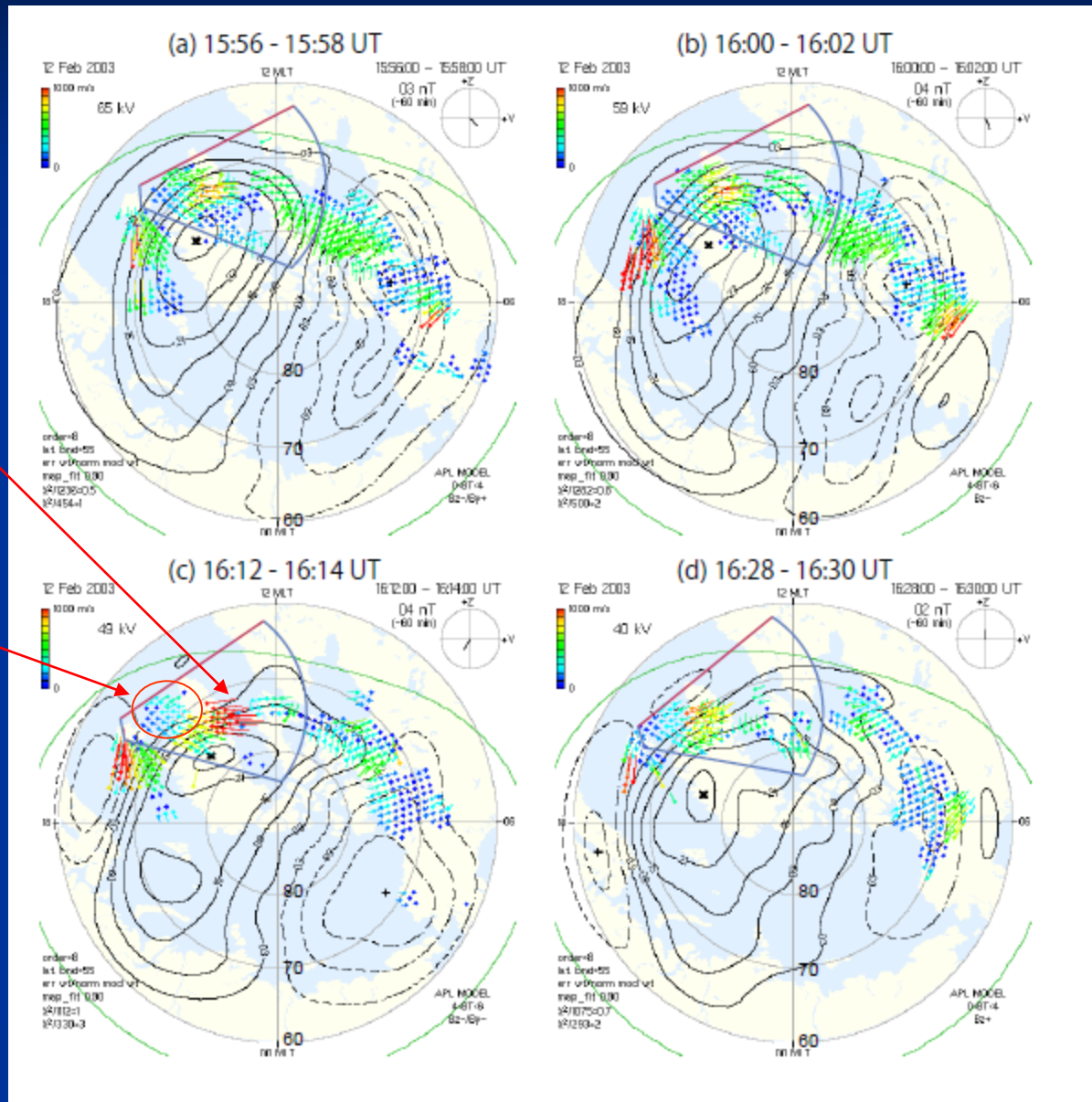


# SuperDARN observation of the overshielding electric field during the substorm

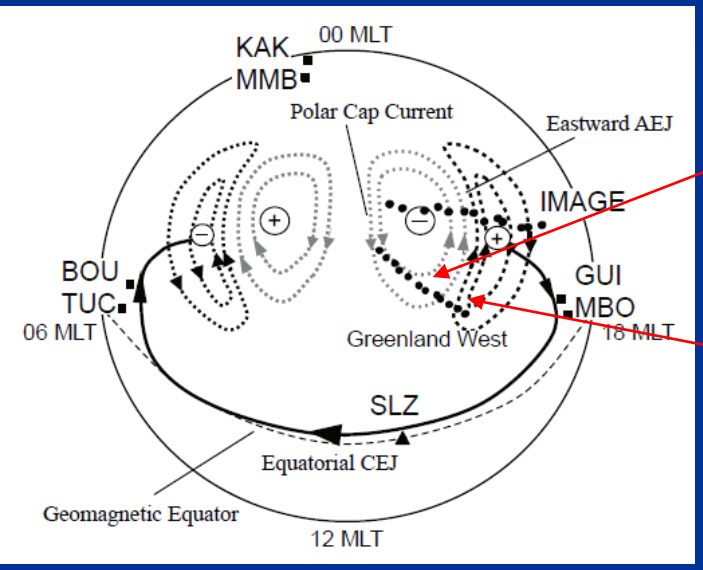
The sunward convection in the afternoon sector is intensified at the onset of substorm.

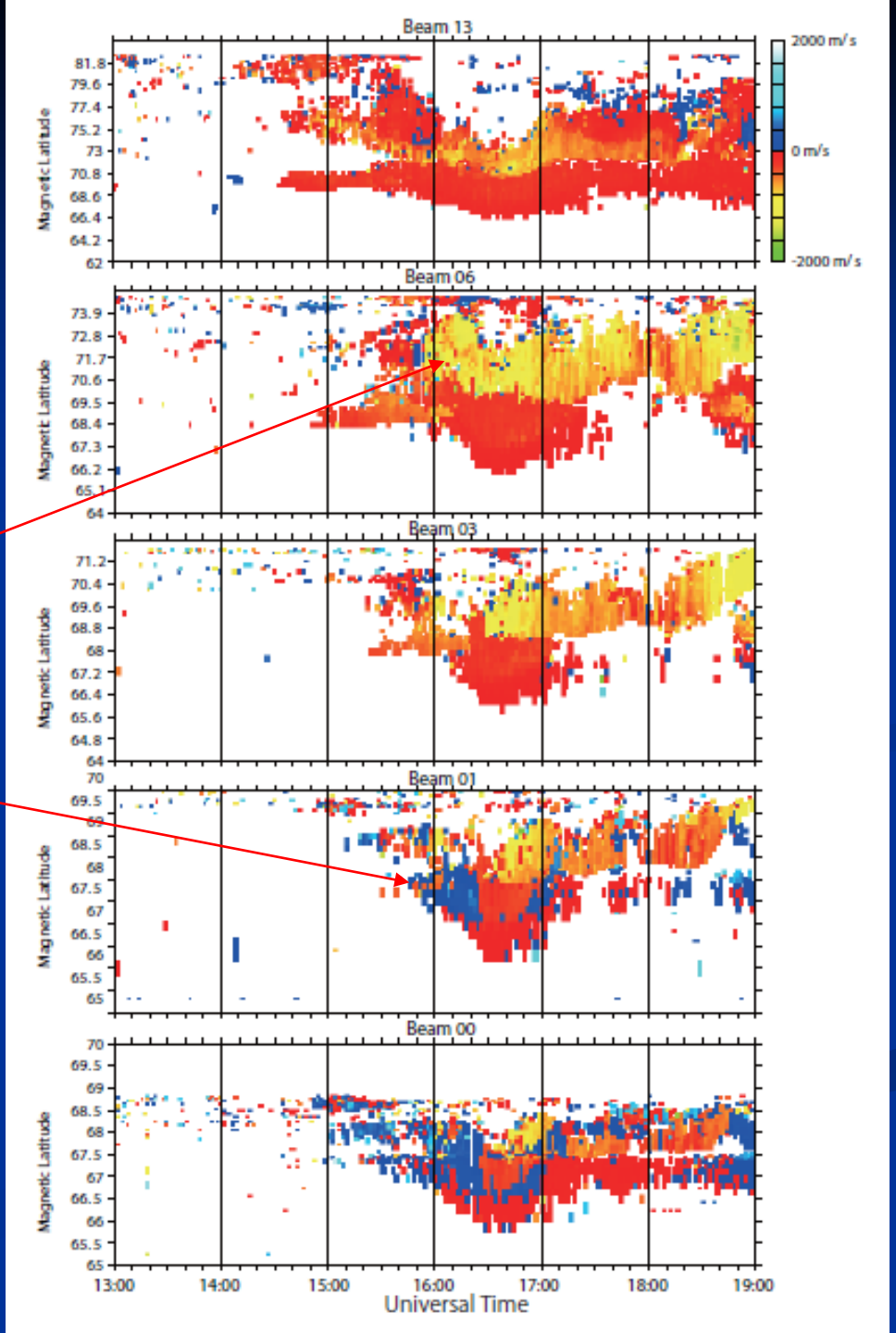
The anti-sunward convection appears equatorward of the sunward convection.

The latitudinal features of the convection flow implies development of the R2 FACs.



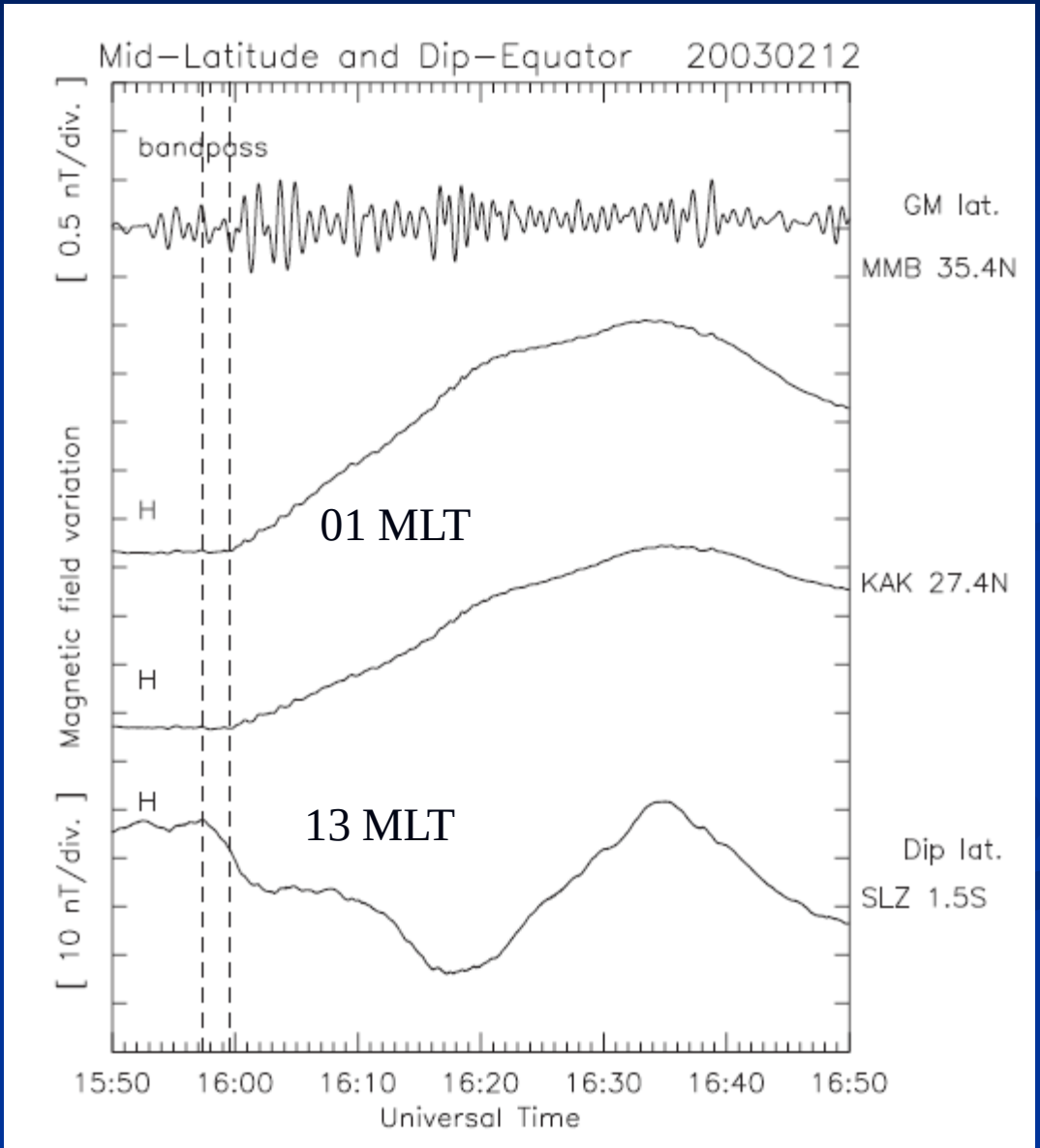
The sunward convection intensifies at auroral latitude, while the anti-sunward convection appears at subauroral latitude after the onset of the substorm



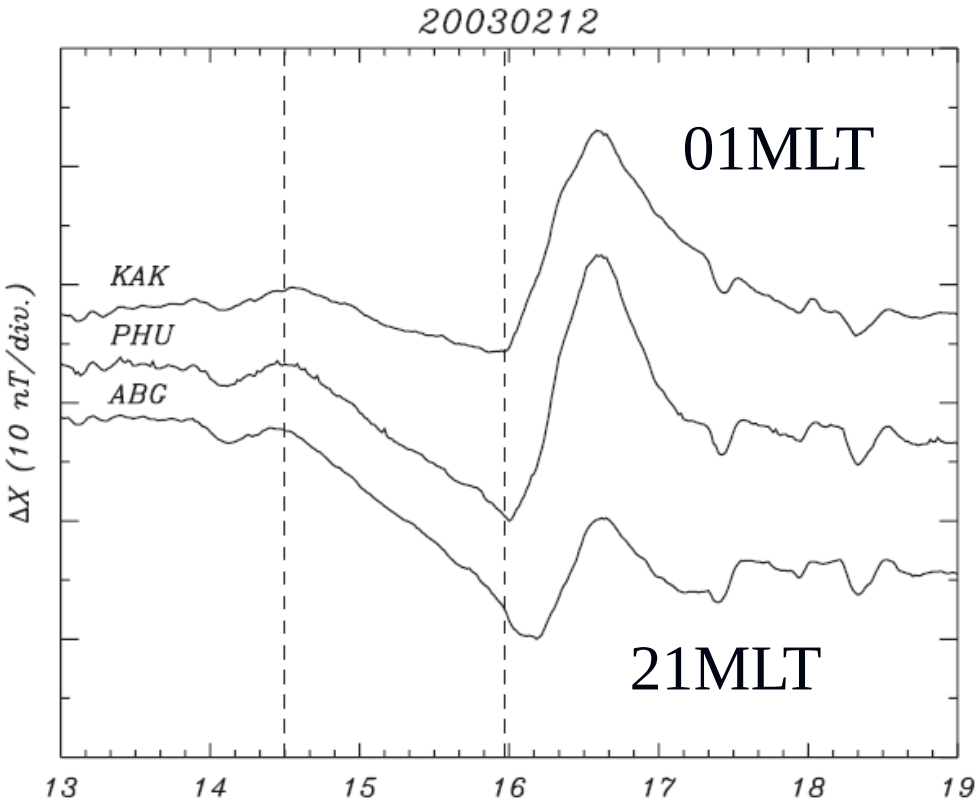



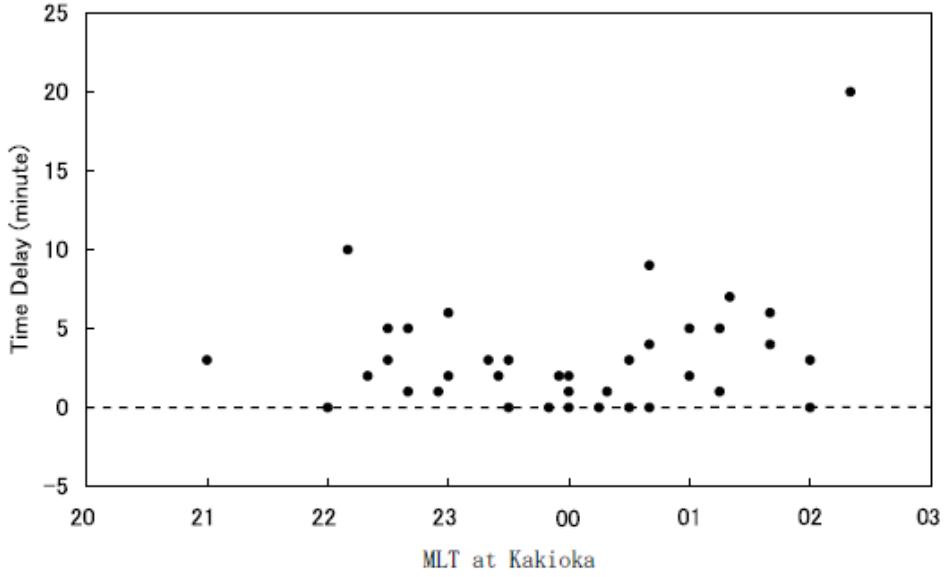

(Hashimoto et al., JGR 2011)

# The overshielding (CEJ) begins 2 min earlier than the midnight positive bay



The overshielding at the dayside equator (CEJ) begins simultaneously or a few min earlier than the positive bay on the nightside.



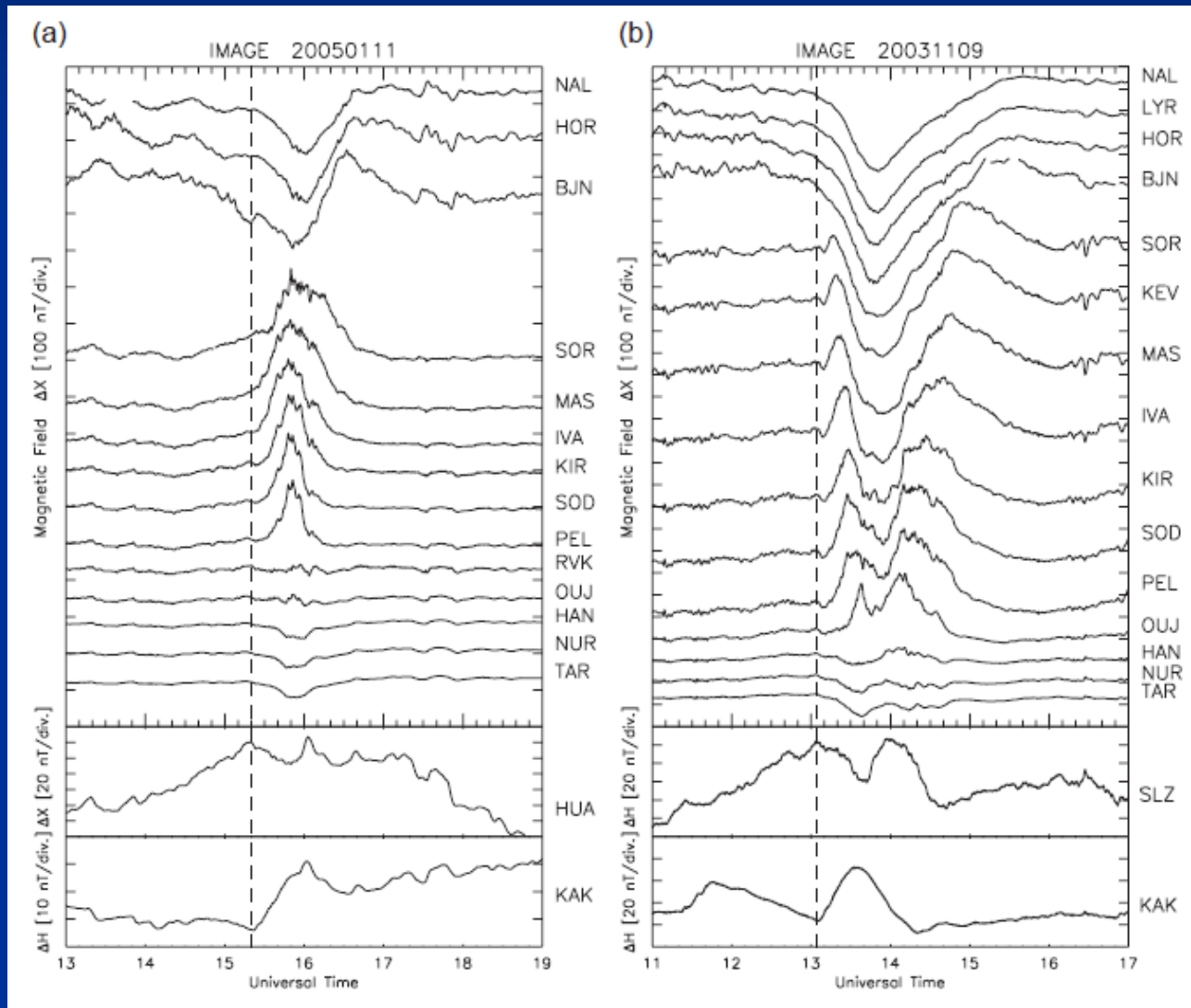
# Substorm-associated overshielding events characterized by the convection enhancement

(Upper panel): X-component of the IMAGE magnetometer array for the overshielding events.

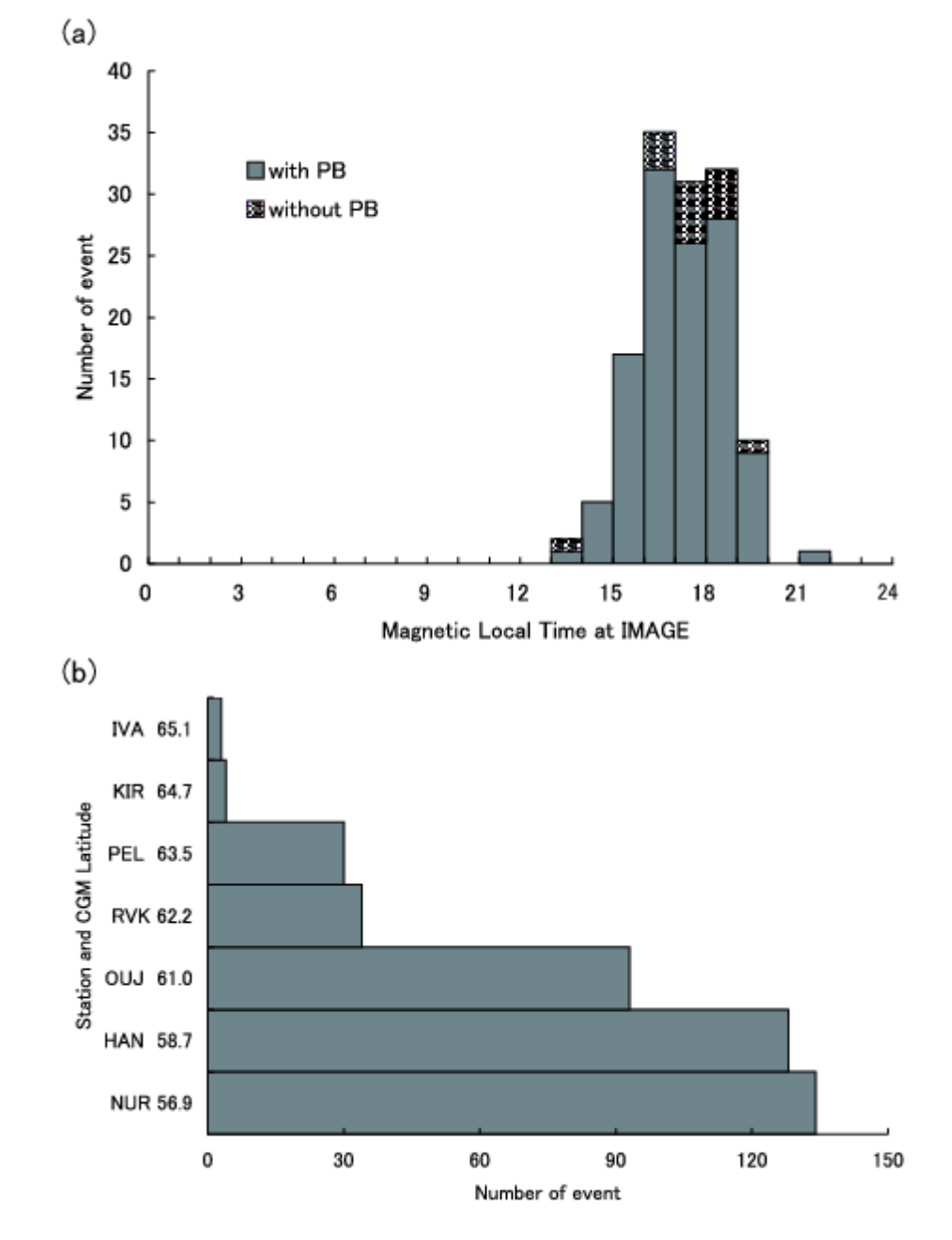
(Middle panel): X/H-component at the dayside geomagnetic equator, Huancayo (HUA) and Sao Luis (SLZ).

(Bottom panel): H-component at the nightside low latitude, Kakioka (KAK)

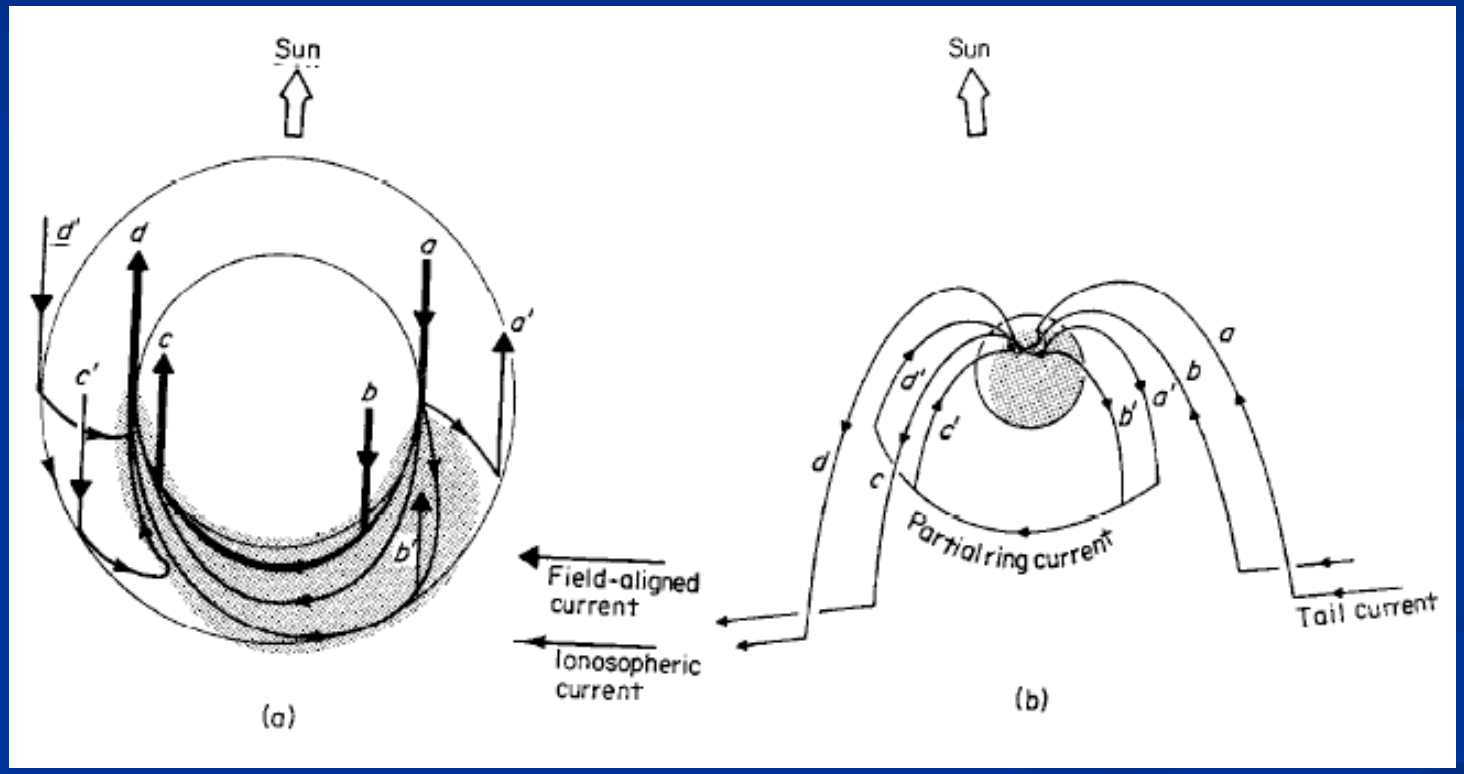
The overshielding begins as negative deflections at subauroral to equatorial latitudes concurrently with the increases in the eastward auroral electrojets and westward polar cap currents (vertical dashed line).



# Local time and latitude distribution of the occurrence of the overshielding

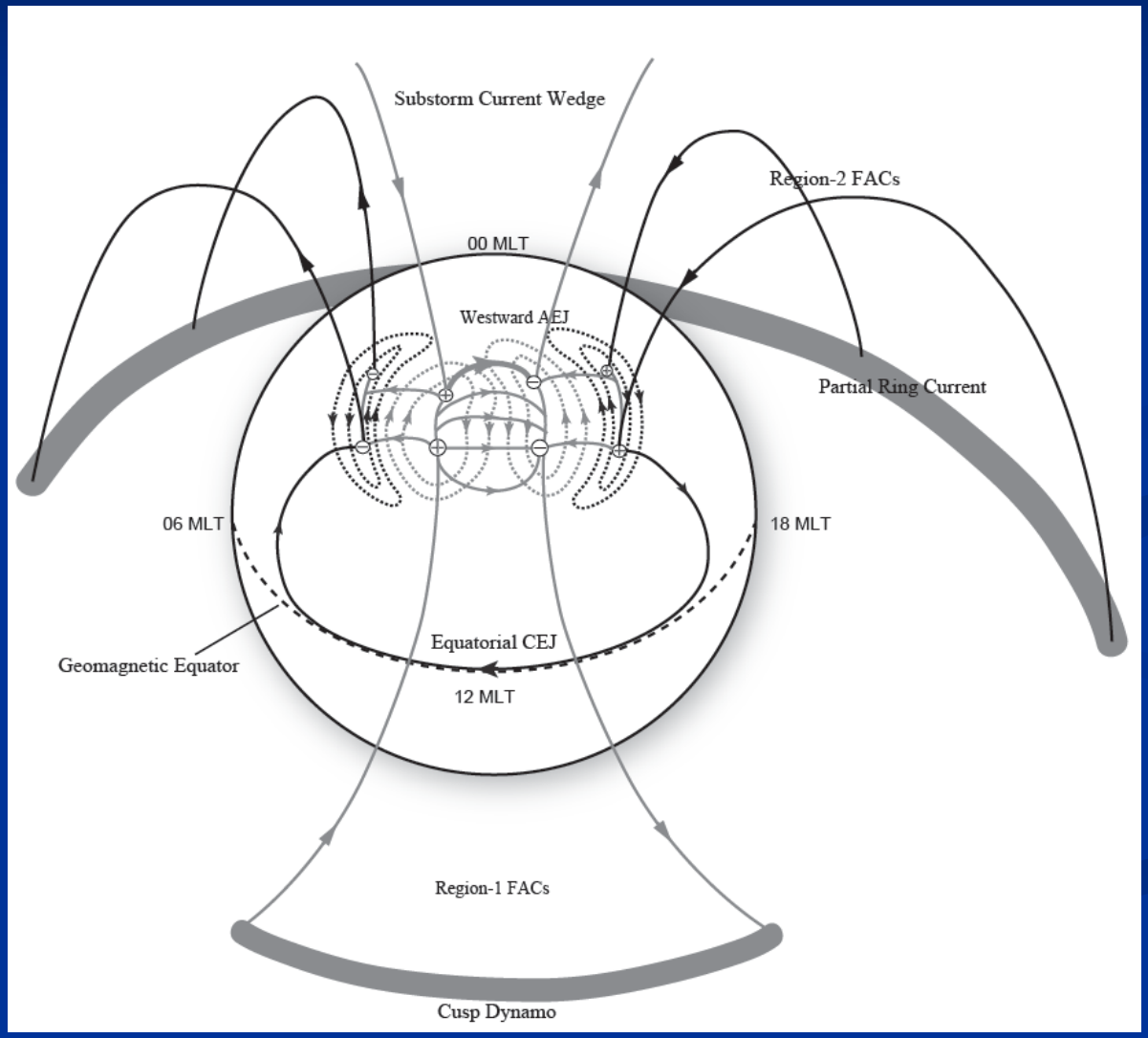


# Conventional magnetosphere-ionosphere current circuits during substorms




(Kamide et al. 1976)

Substorm current system is composed of the ionospheric currents driven by the R2 FACs extending to the equator in addition to the current wedge on the nightside.

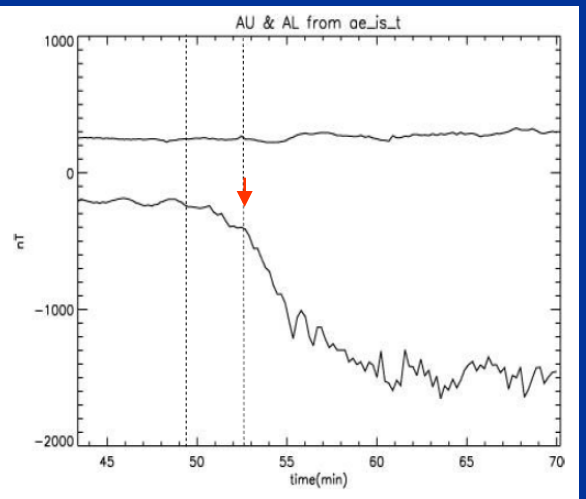


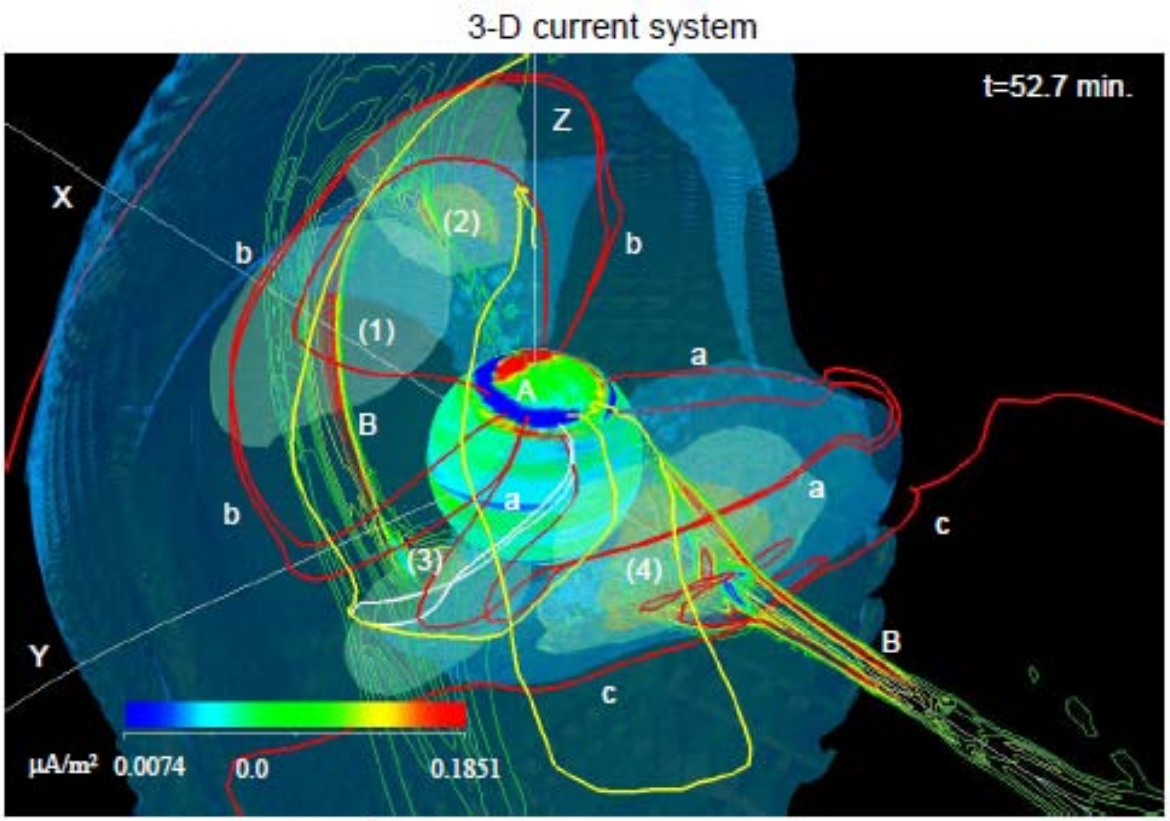
# Global MHD simulation of the substorm current system

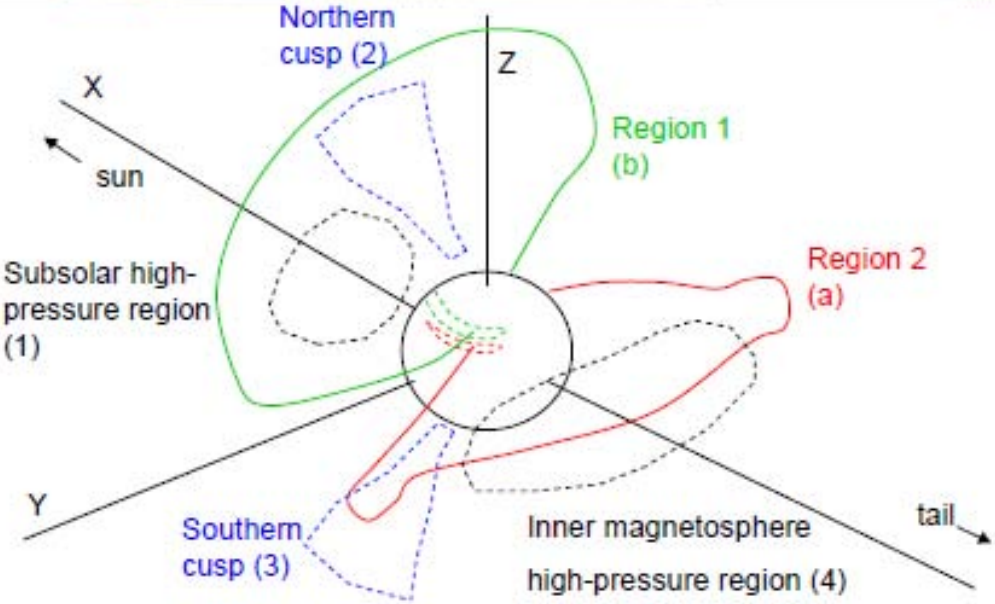
A ring current-R2 FAC current circuit is completed between the inner magnetosphere and auroral ionosphere at the onset of the substorm.

Substorm R1 FACs are generated by the dayside cusp dynamo

(Tanaka et al., JGR 2010)

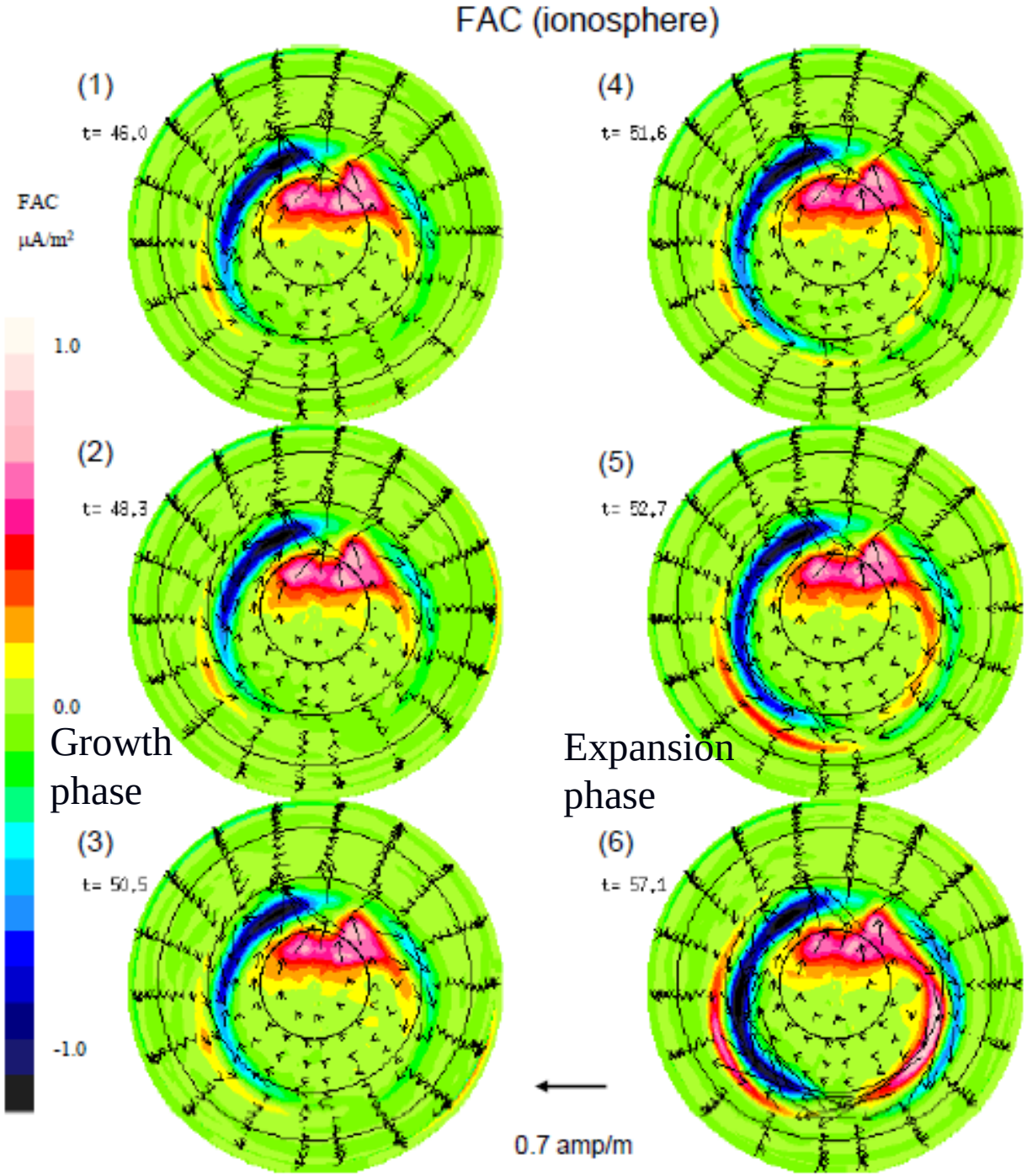


# MHD simulation of the R1 and R2 field-aligned currents during a substorm

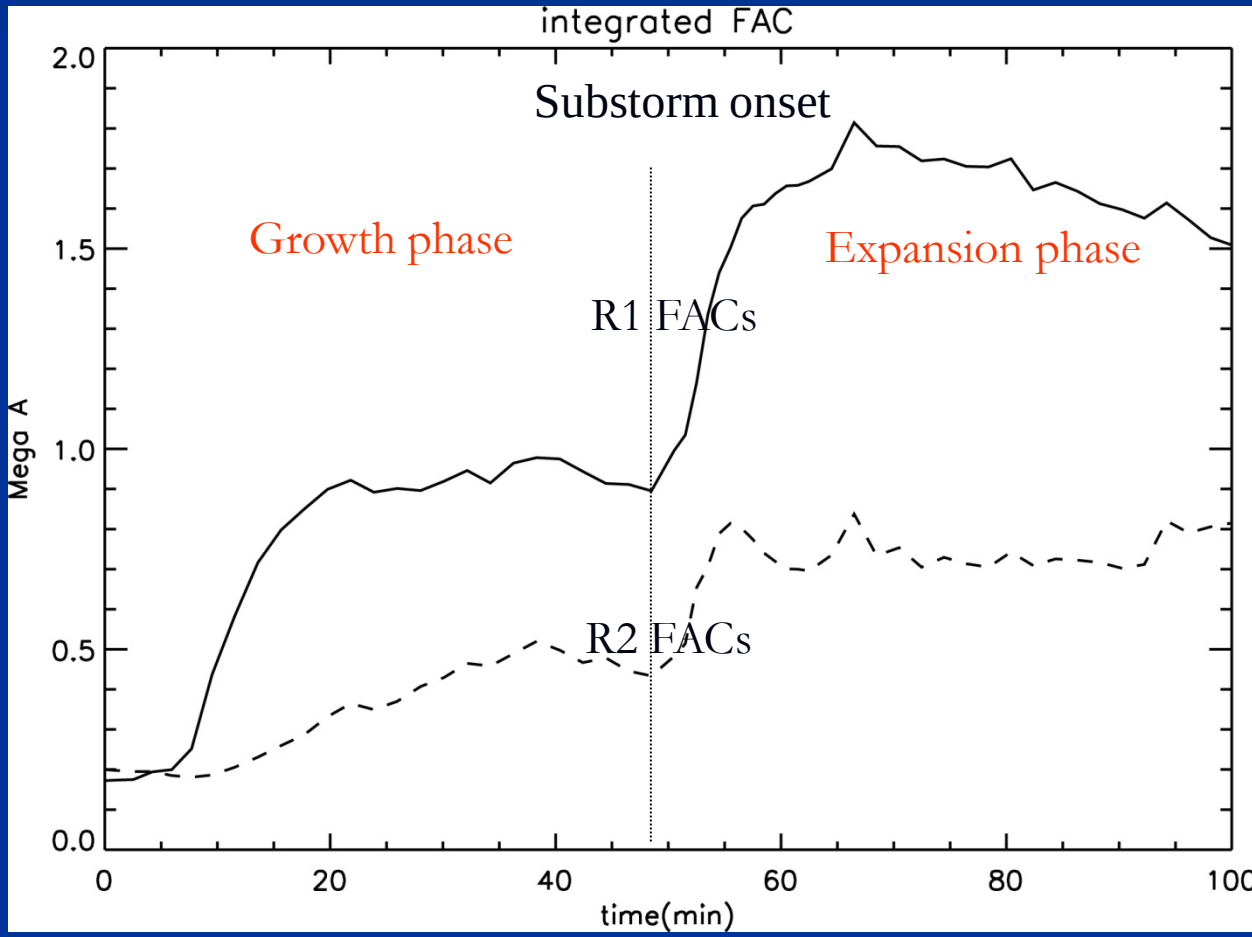
(Tanaka et al., JGR 2010)



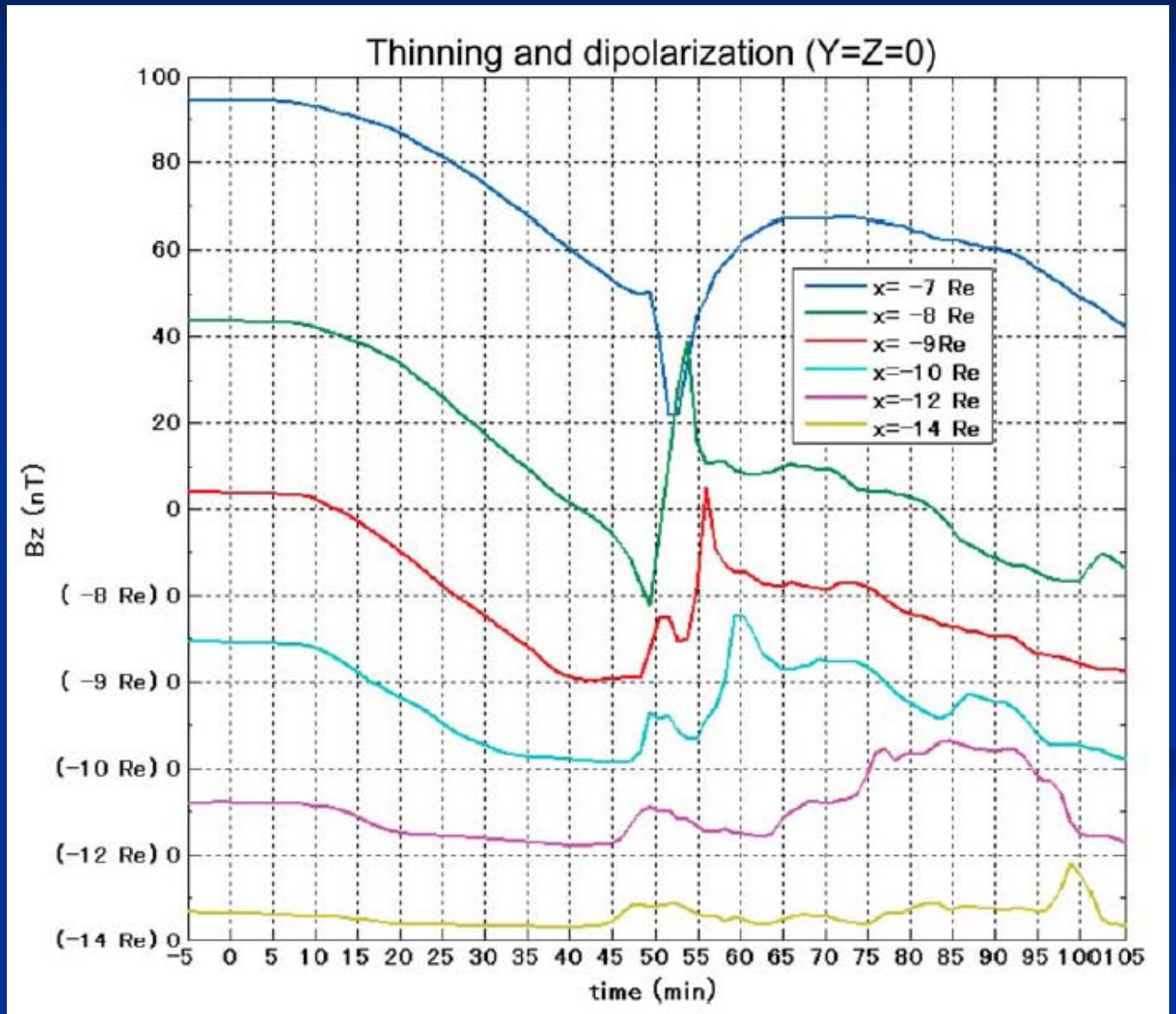
# Integrated R1 and R2 FACs during the substorm (Courtesy of Fujita and Tanaka)

Both the R1 and R2 FACs increase significantly during the expansion phase in agreement with the observations.

The R2 FACs are strong enough to cause the overshielding at low latitude.



# Earthward propagation of the dipolarization front (MHD simulation)




(Tanaka et al., JGR 2010)

# Summary

- During the substorm growth phase, the convection electric field is transmitted near-instantaneously to low latitude, driving the DP2 currents at high-equatorial latitudes. A current circuit is completed between the dynamo in the outer magnetosphere and the equatorial ionosphere (EEJ) via the polar ionosphere.
- The convection electric field would be transmitted to the inner magnetosphere from the ionosphere, causing quick development of the magnetospheric electri1c field and partial ring current.
- The overshielding occurs at the onset of substorms, appearing as the CEJ at the dayside equator. The CEJ begins simultaneously with or a few minutes earlier than the mid latitude positive bay on the nightside.
- The CEJ is accompanied by an increase in the eastward AEJ and westward currents in the polar cap in the afternoon to evening sectors.
- The observations suggest that both the R1 and R2 FACs intensify at the onset of substorms, while the R2 FACs are strong enough to cause the overshielding at the equator.
- We confirmed the overshielding electric field with SuperDARN convection maps showing that the ionospheric convection changes its direction from sunward to anti-sunward at subauroral latitudes in the afternoon sector during the expansion phase.
- It is emphasized that the equatorial CEJ-R2 FACs-partial ring current circuit develops at the onset of substorms simultaneously with or earlier than development of the traditional substorm current circuit around the midnight.