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グローバル地磁気観測によるサブストーム 電流系の研究

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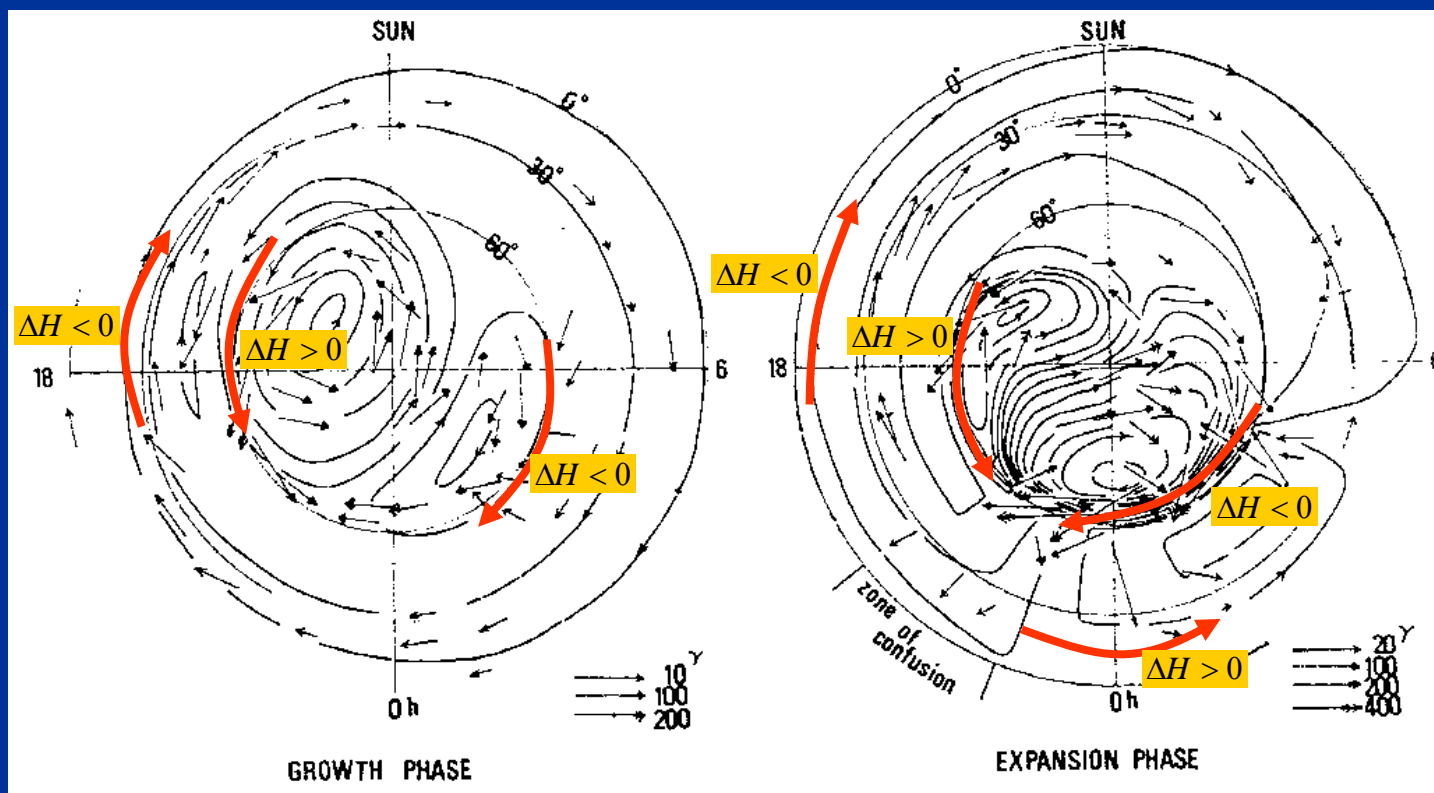
2 Kibi International University

サブストーム電離圏等価電流系 成長相(DP2)と爆発相(DP1)

[Iijima and Nagata, 1972]

Growth phase (DP2)

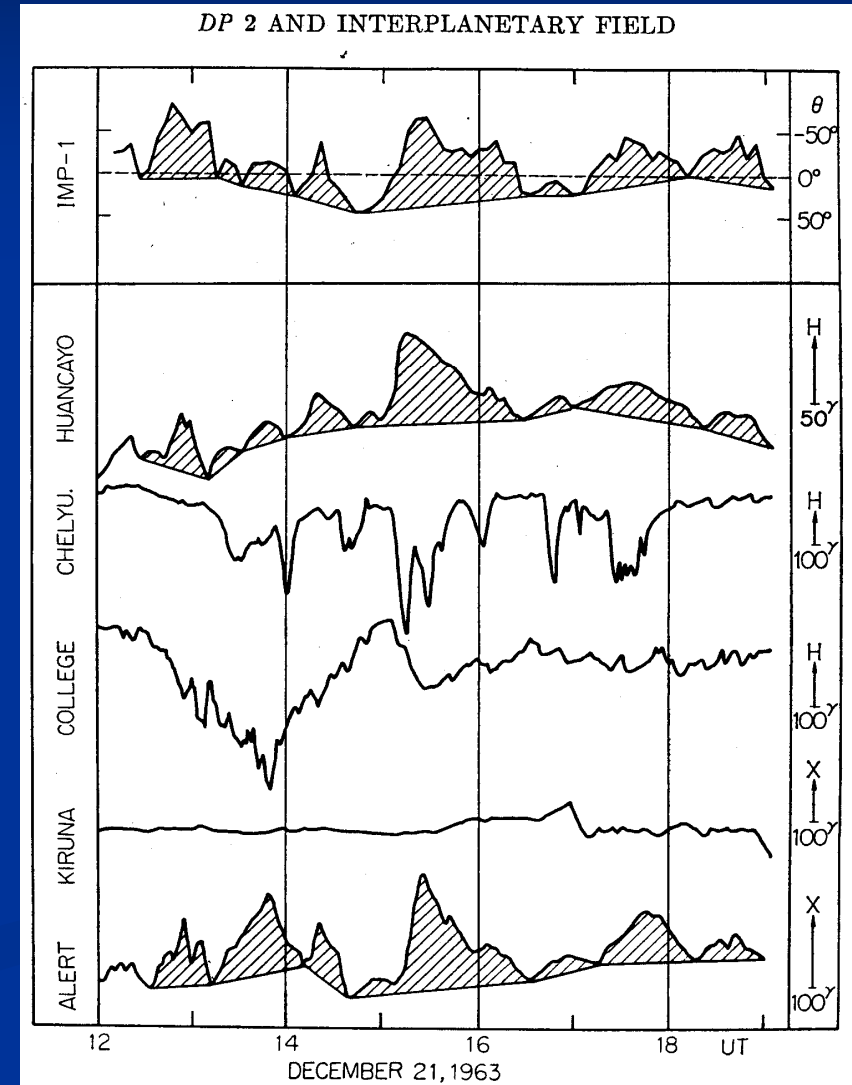
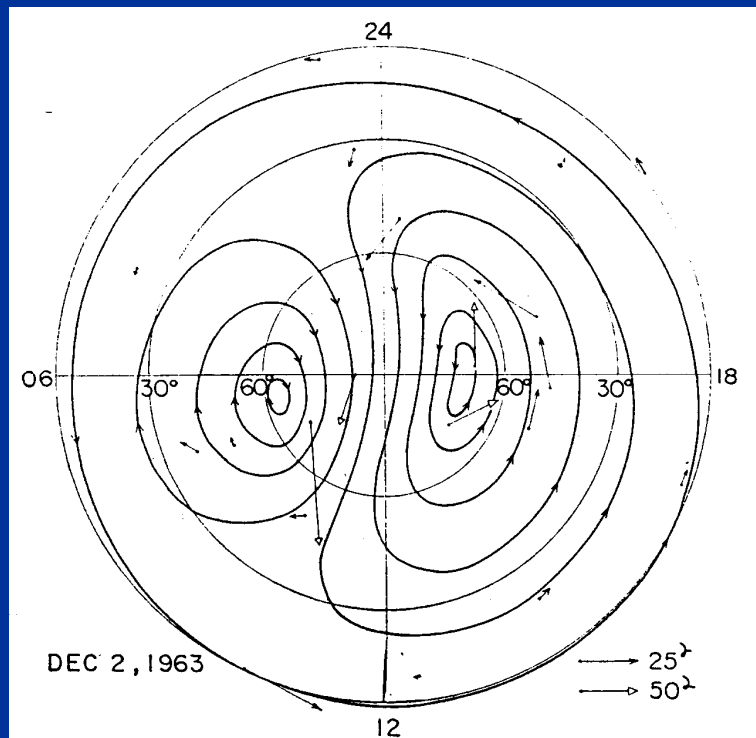
Expansion phase (DP1)



IMFによるDP2 磁場変動と等価電流 (IMF-極域磁場-赤道磁場)

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

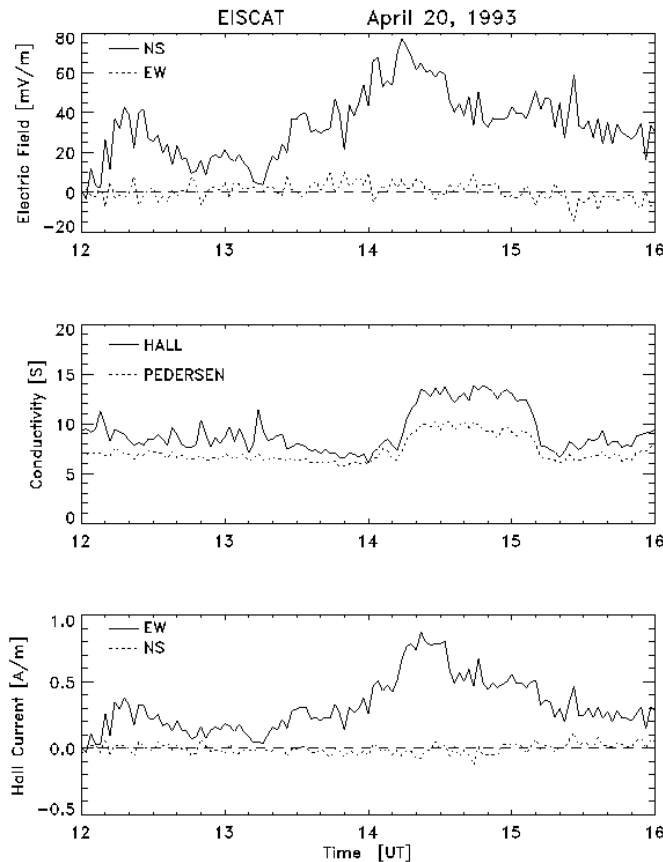
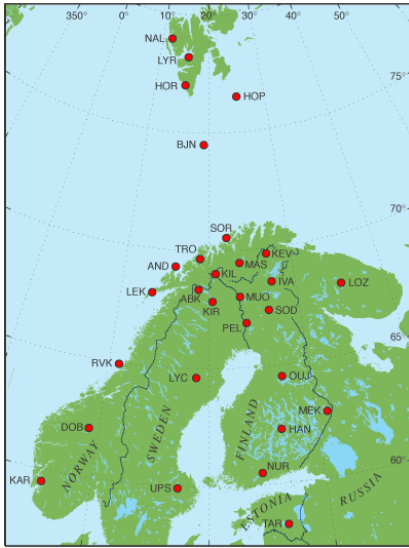
(Nishida, JGR 1968)



サブストーム成長相のDP2と爆発相の過遮蔽電場・磁場 (EISCAT電場とIMAGEチェーン磁場)

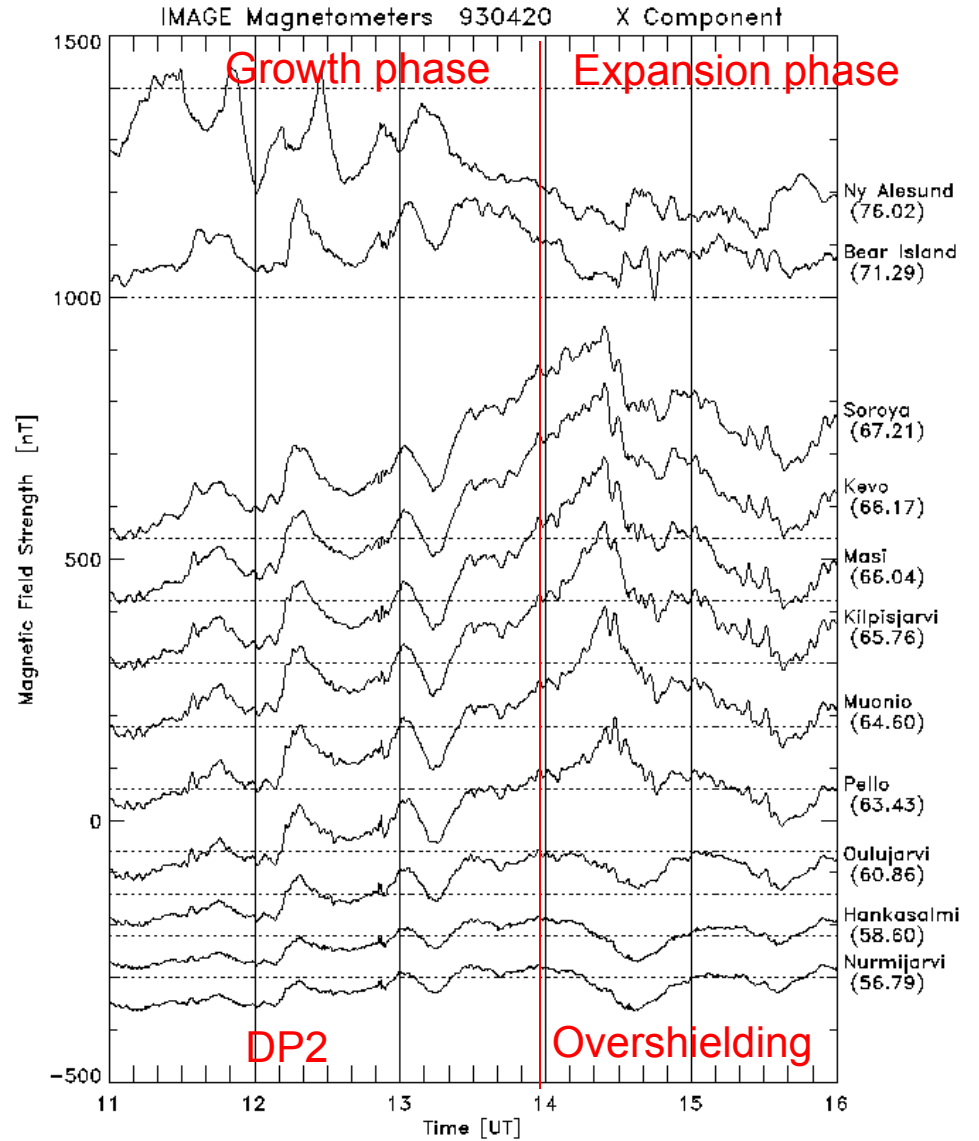
The magnetic perturbations are caused by the ionospheric Hall currents.

EISCAT



(Kikuchi et al., JGR 1996)

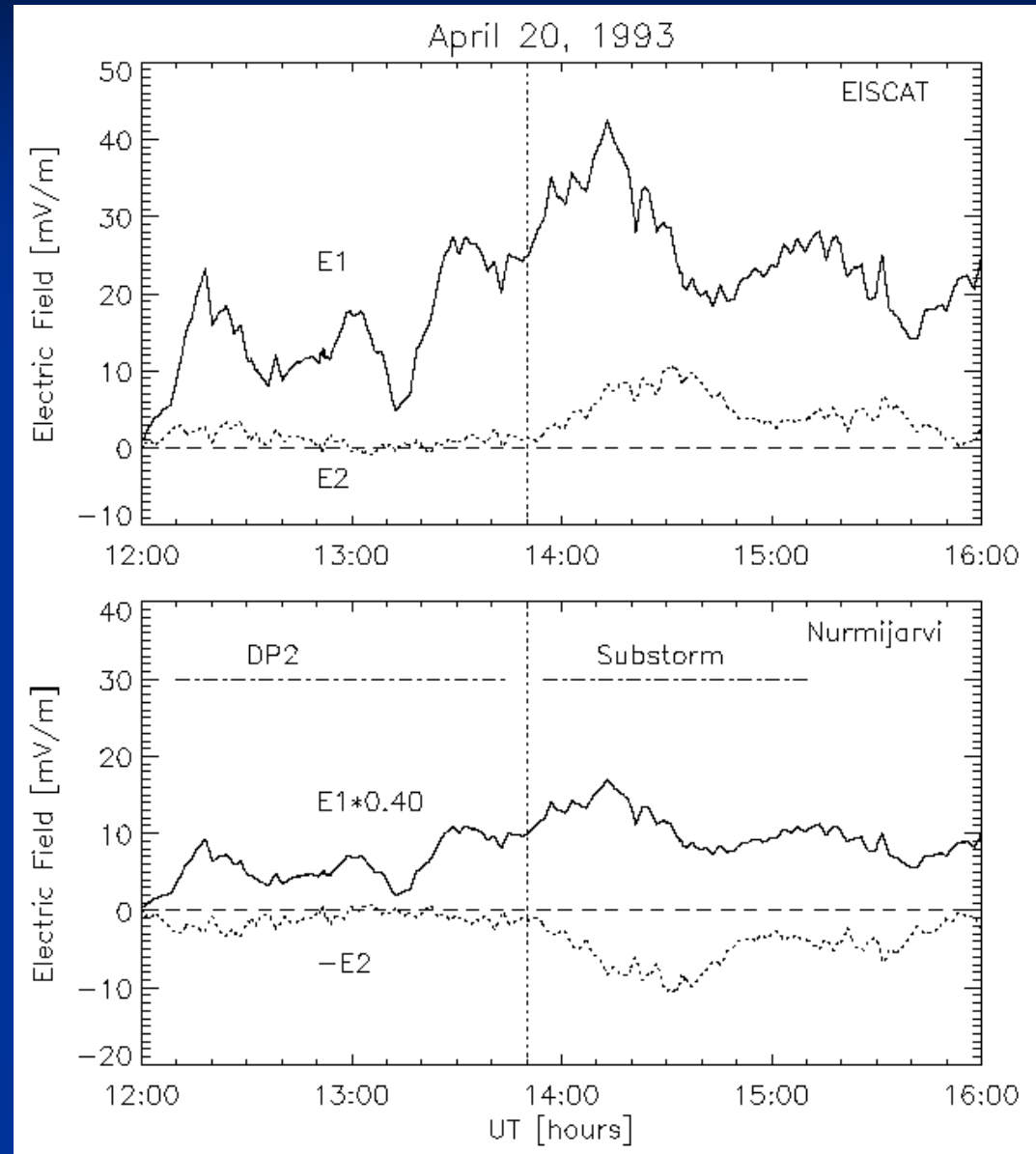
IMAGE Magnetometer chain



オーロラ帯(EISCAT)と中緯度(Nurmijarvi)におけるサブストーム時の 対流電場(E1)と過遮蔽電場(E2)

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)

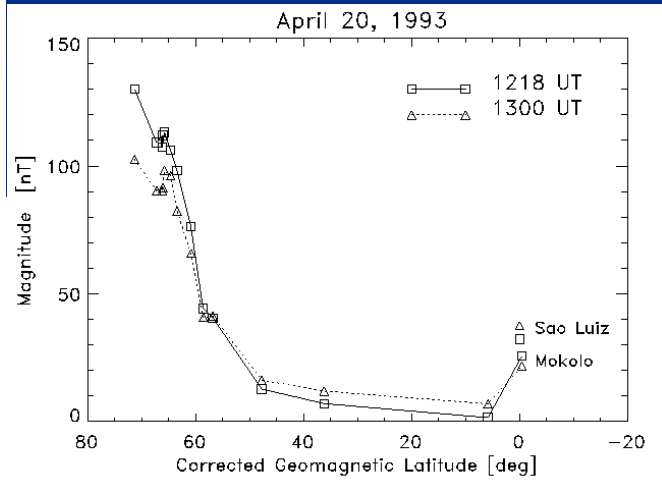


成長相(DP2)と爆発相(過遮蔽) の赤道磁場(EEJ, CEJ)

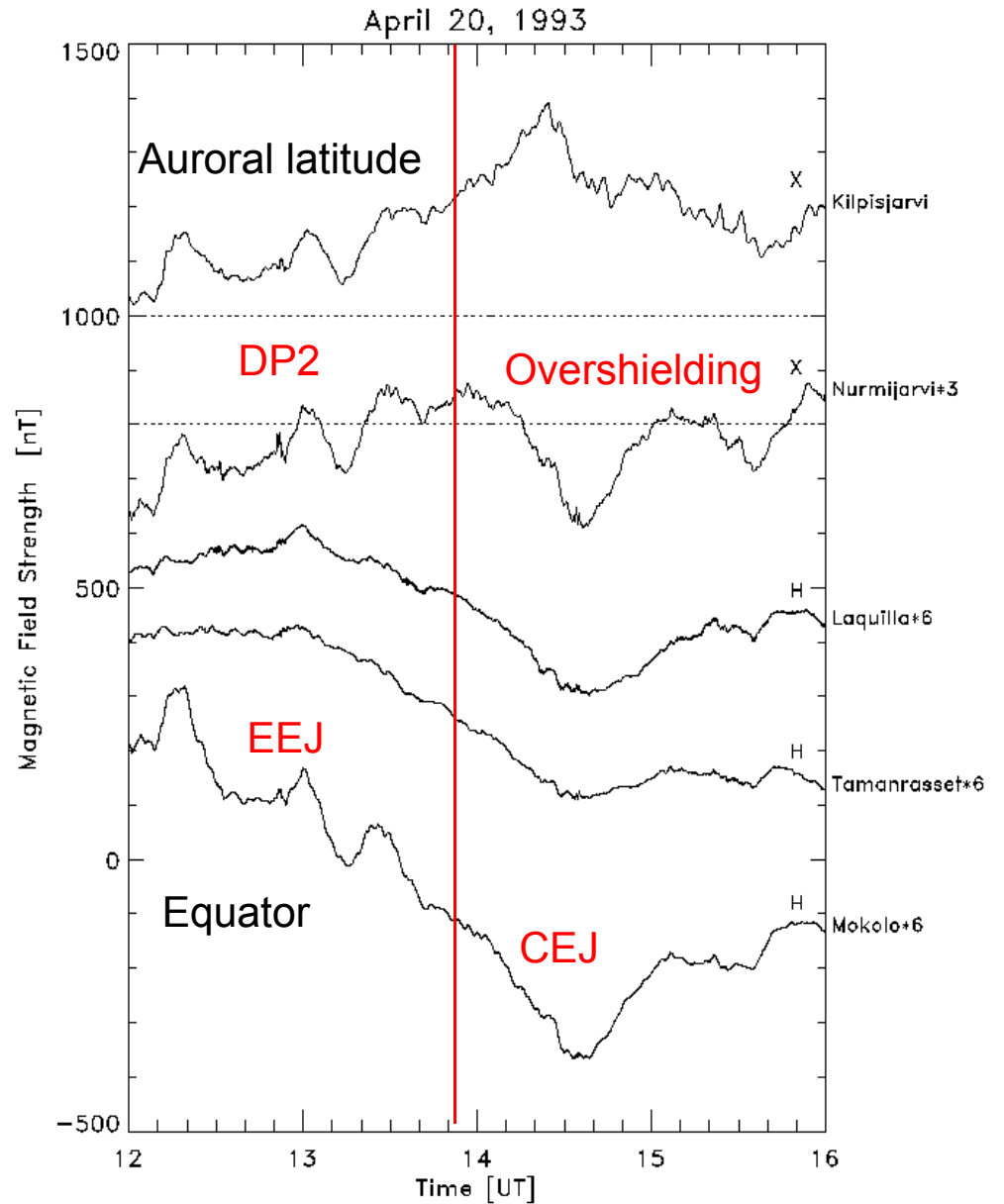
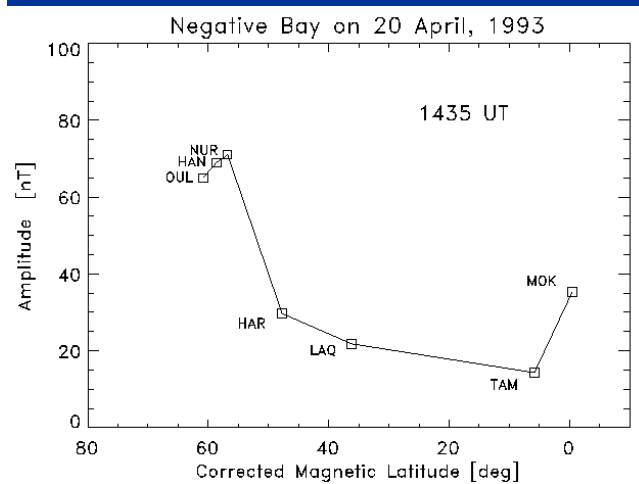
Kikuchi et al. (JGR 1996, 2000)

Magnetometer chain in the afternoon sector

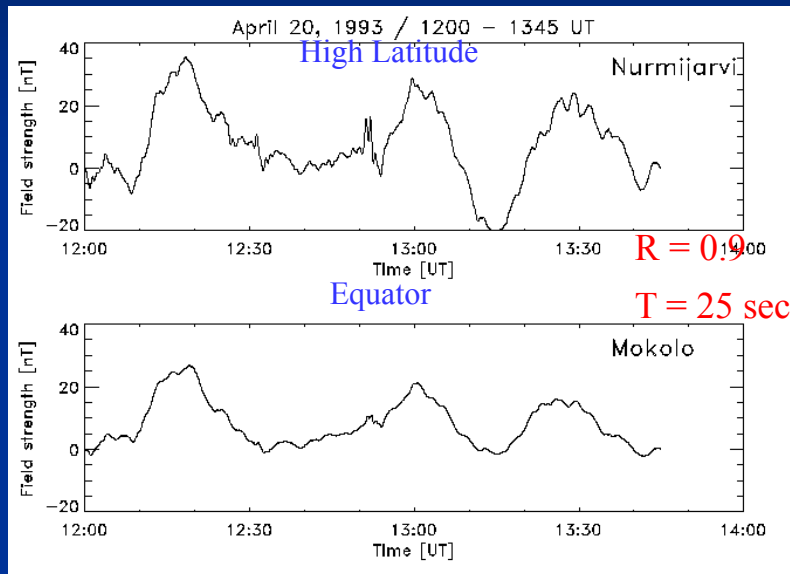
Latitudinal profile of the DP2



Latitudinal profile of the negative bay

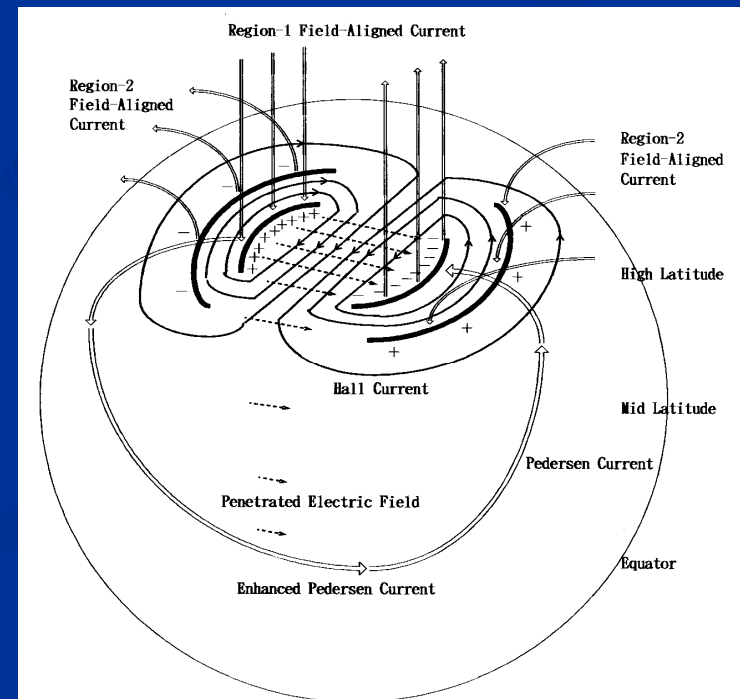


準周期DP2変動の極・赤道磁場変動の同時発達(25秒以内) (領域1型沿磁力線電流 - 赤道ジェット電流回路)

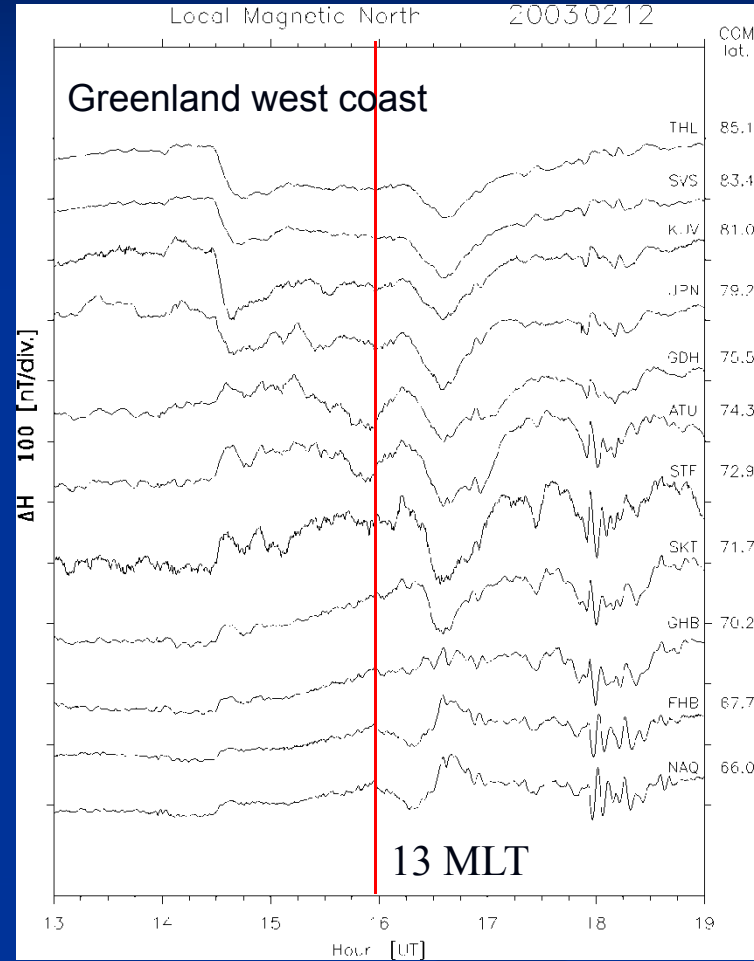
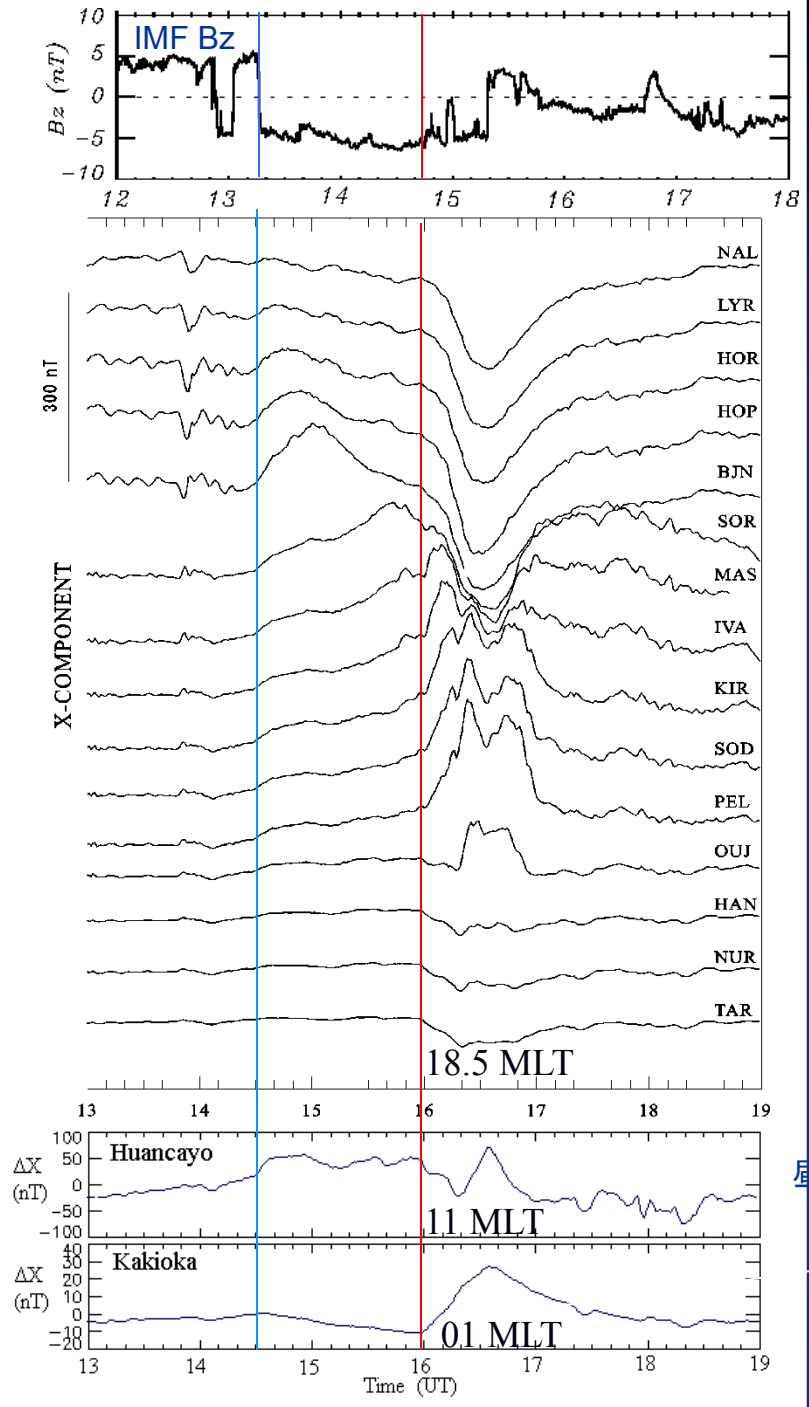


The excellent correlation between the high latitude and equatorial DP2 suggests near-instantaneous transmission of the electric field and current to the equator.

A current circuit is completed between the R1 FACs and the equatorial currents.



サブストーム時に対流電場と過遮蔽電場が同時に発達



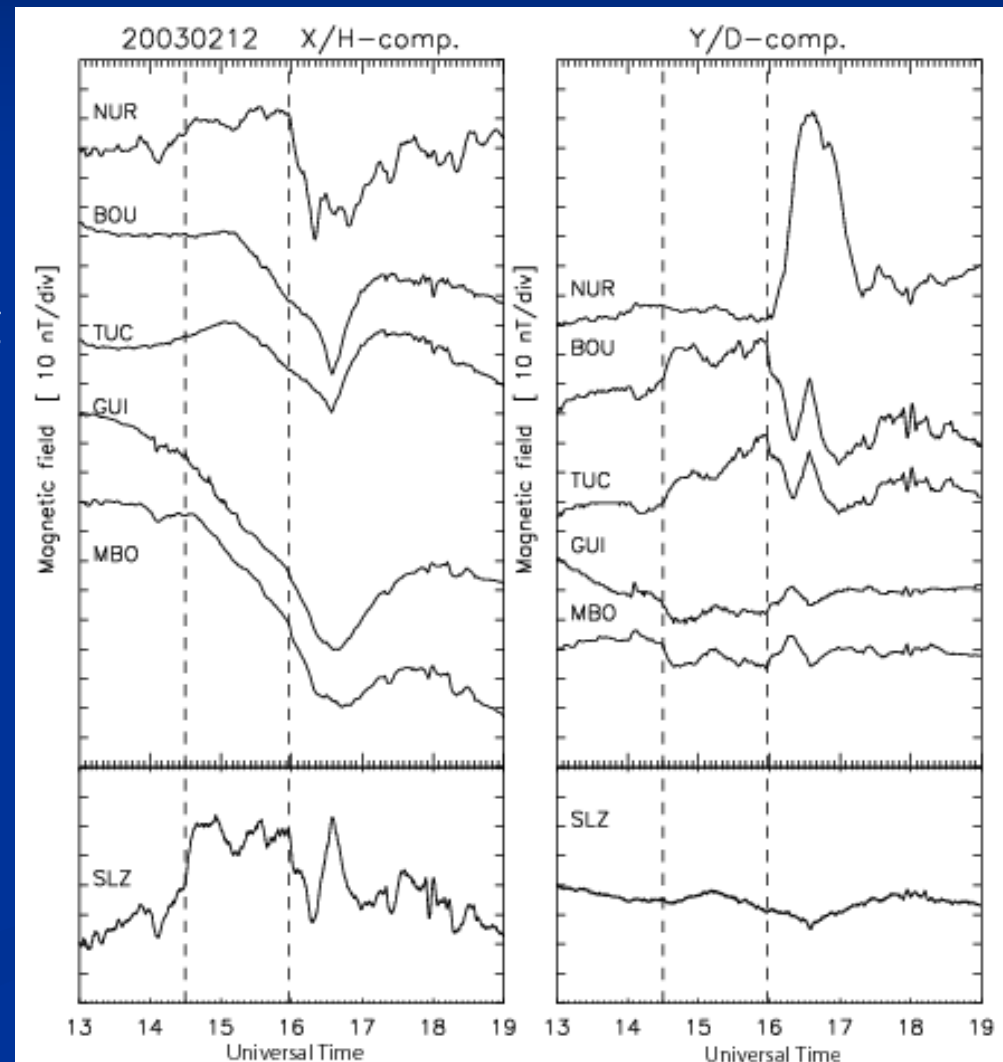
(Hashimoto et al., JGR2011)

サブストーム時の過遮蔽電流 (Pedersen電流) による中緯度Y/D-成分 (赤道CEJ—中緯度Pedersen電流回路)

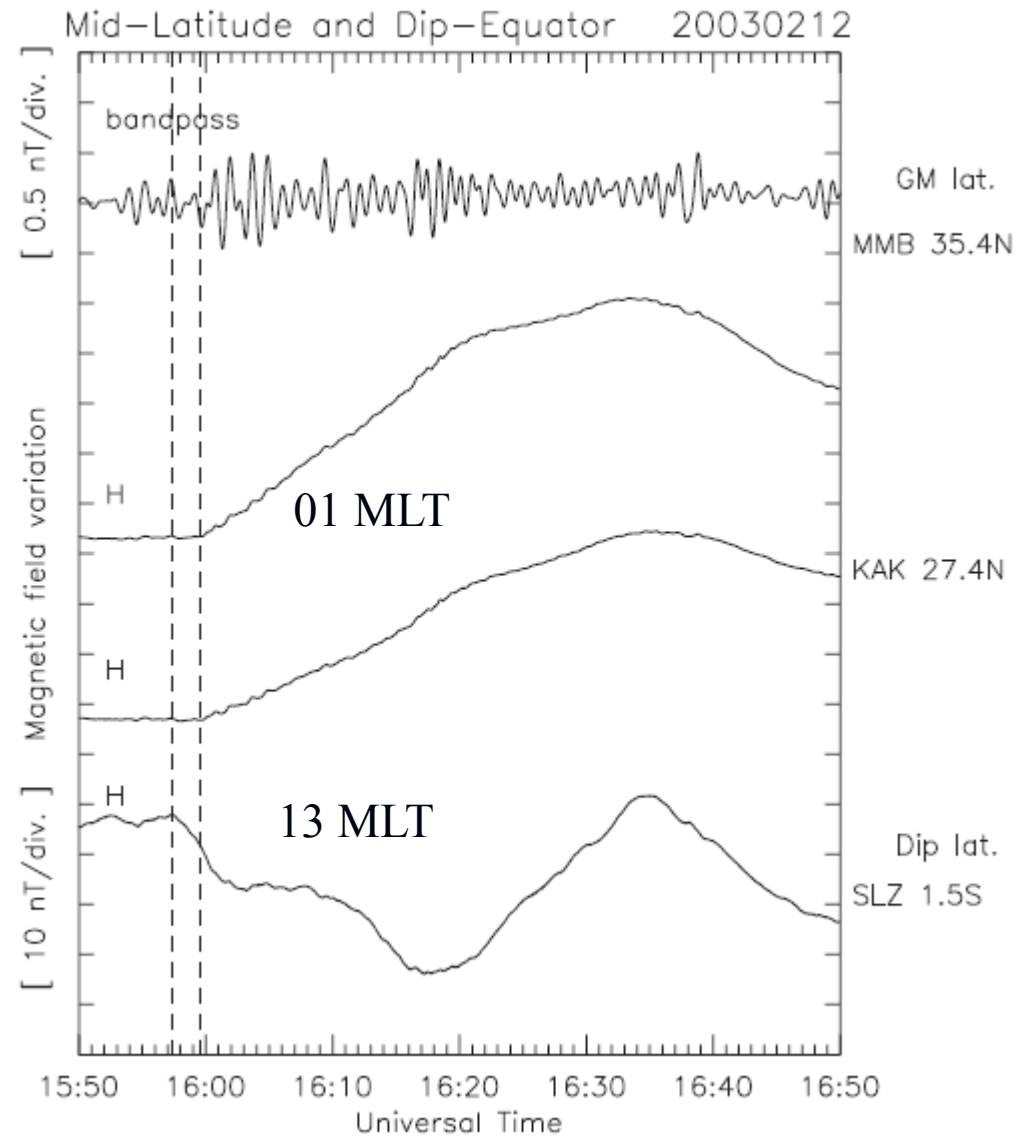
(Hashimoto et al., JGR2011)

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.

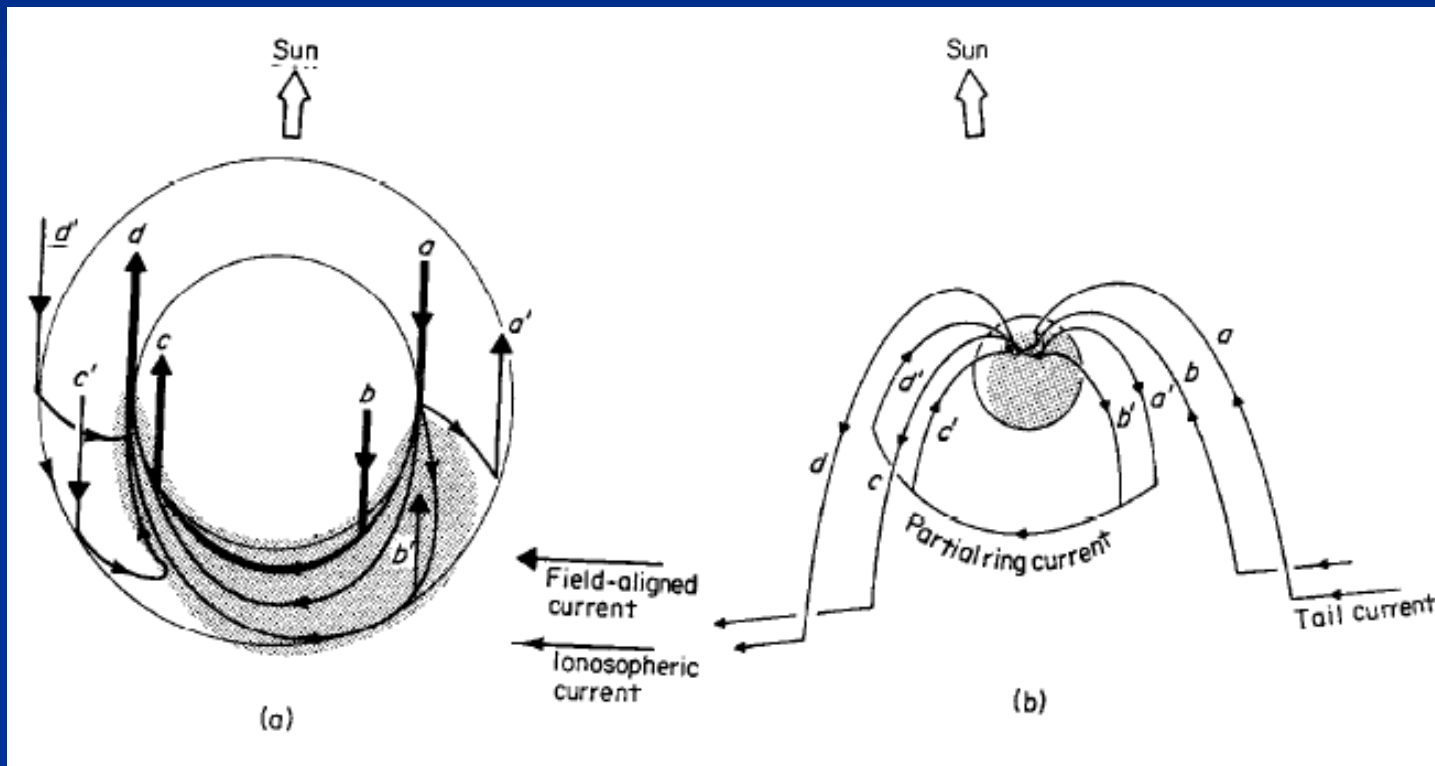


昼間赤道の過遮蔽電流(CEJ)が夜間positive bayより2分早く開始



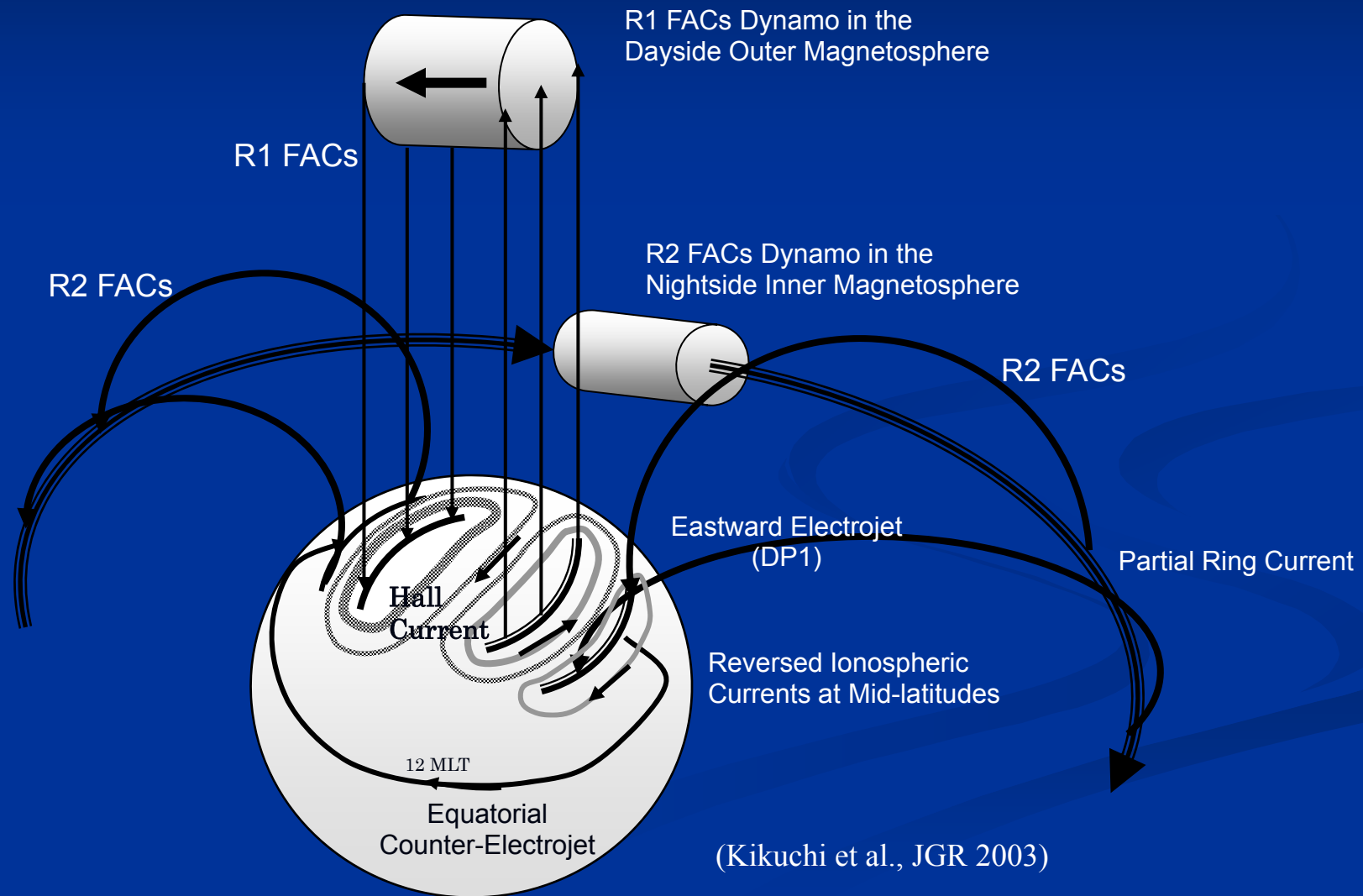
(Hashimoto et al., JGR2011)

サブストームの三次元電流系 (Current wedgeの内側に部分環電流PRCが発達)



(Kamide et al. 1976)

赤道電離圏に延びるサブストーム過遮蔽電流 (PRC-R2FAC-CEJ回路)

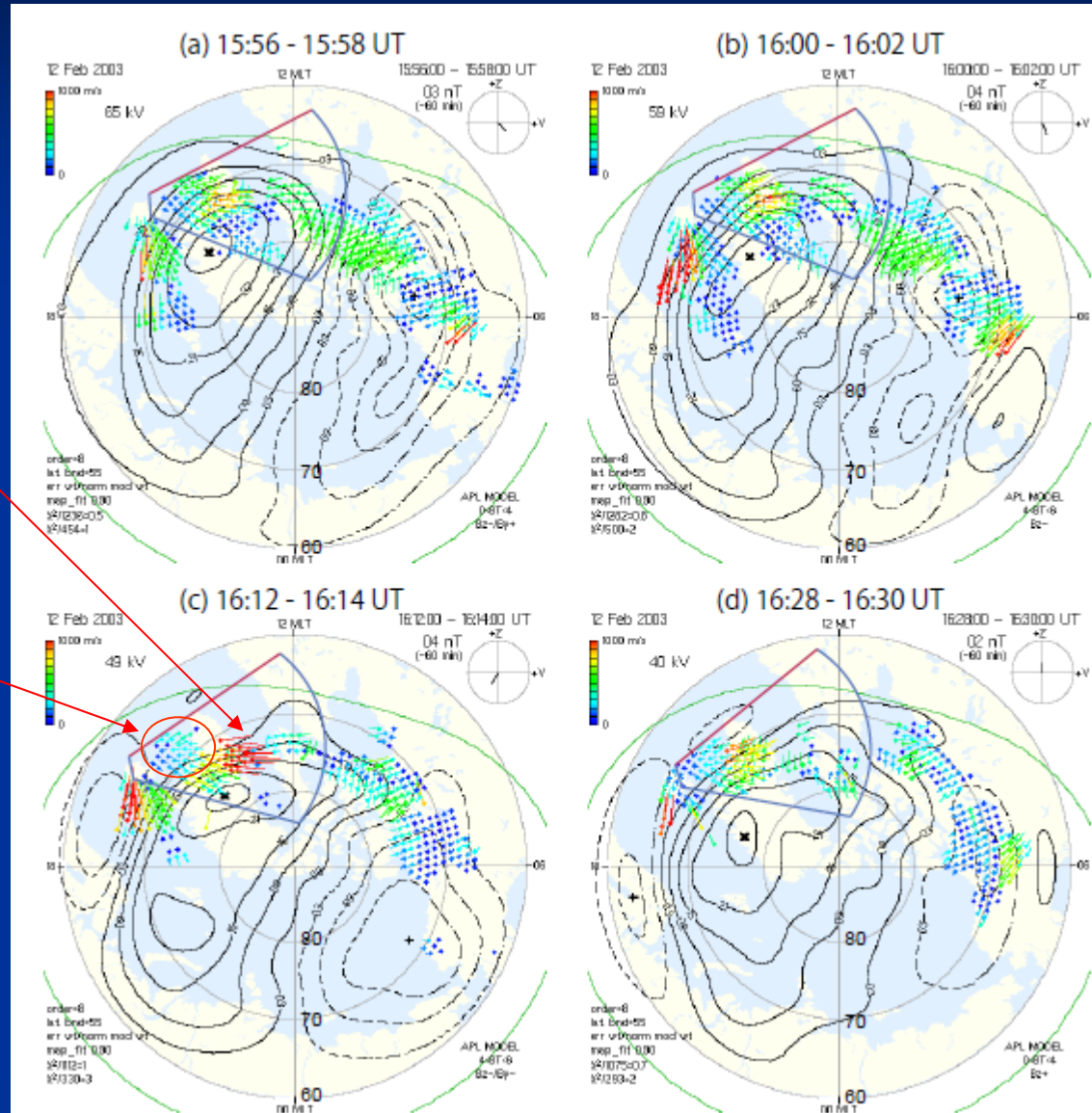


サブストーム時の対流電場と過遮蔽電場による電離圏対流のSuperDARN観測

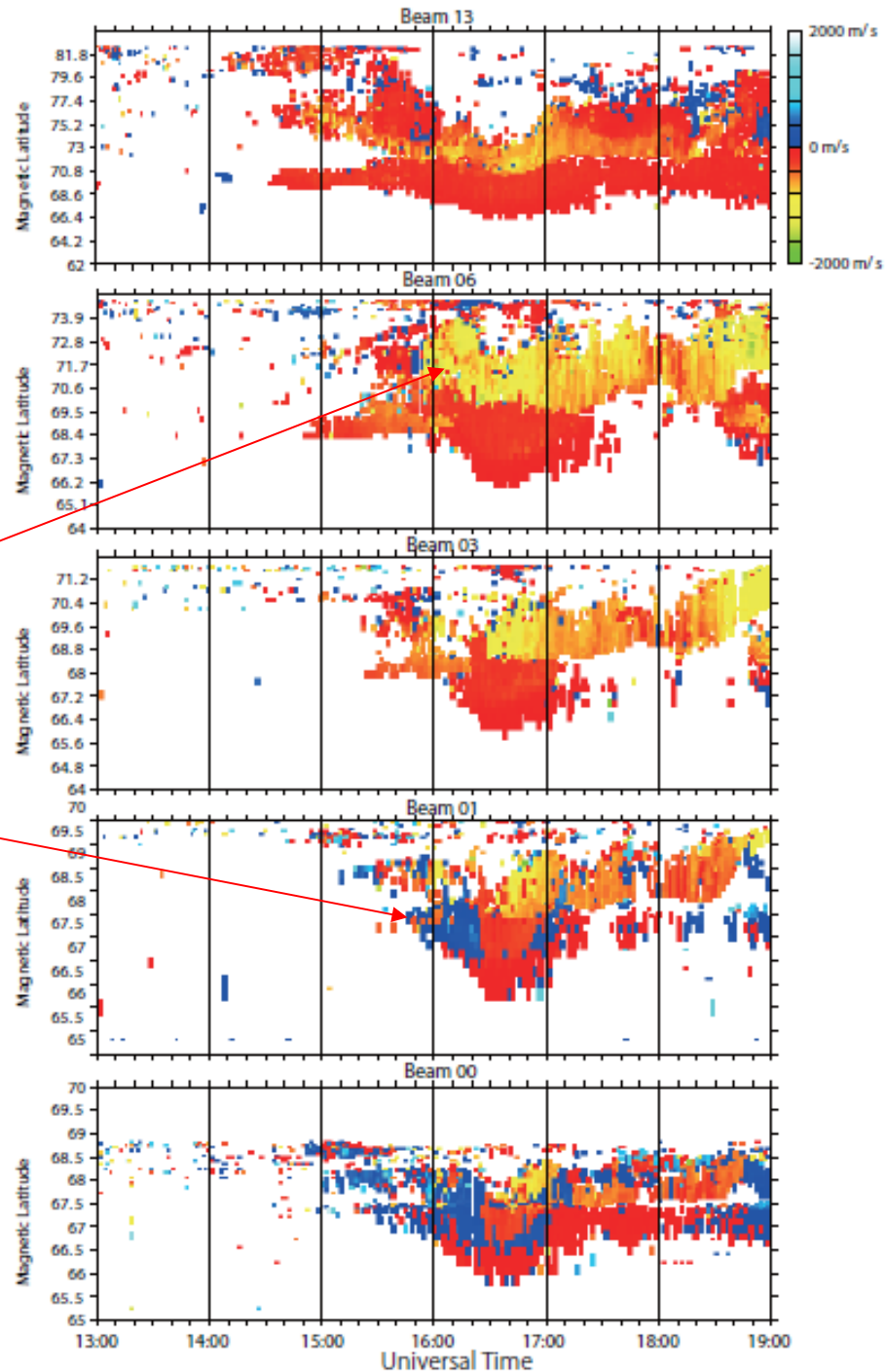
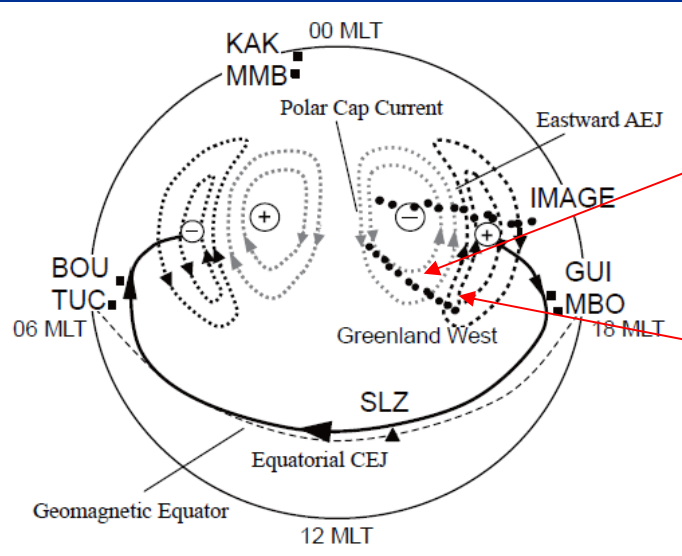
The sunward convection in the afternoon sector is intensified at the onset of substorm.

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

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

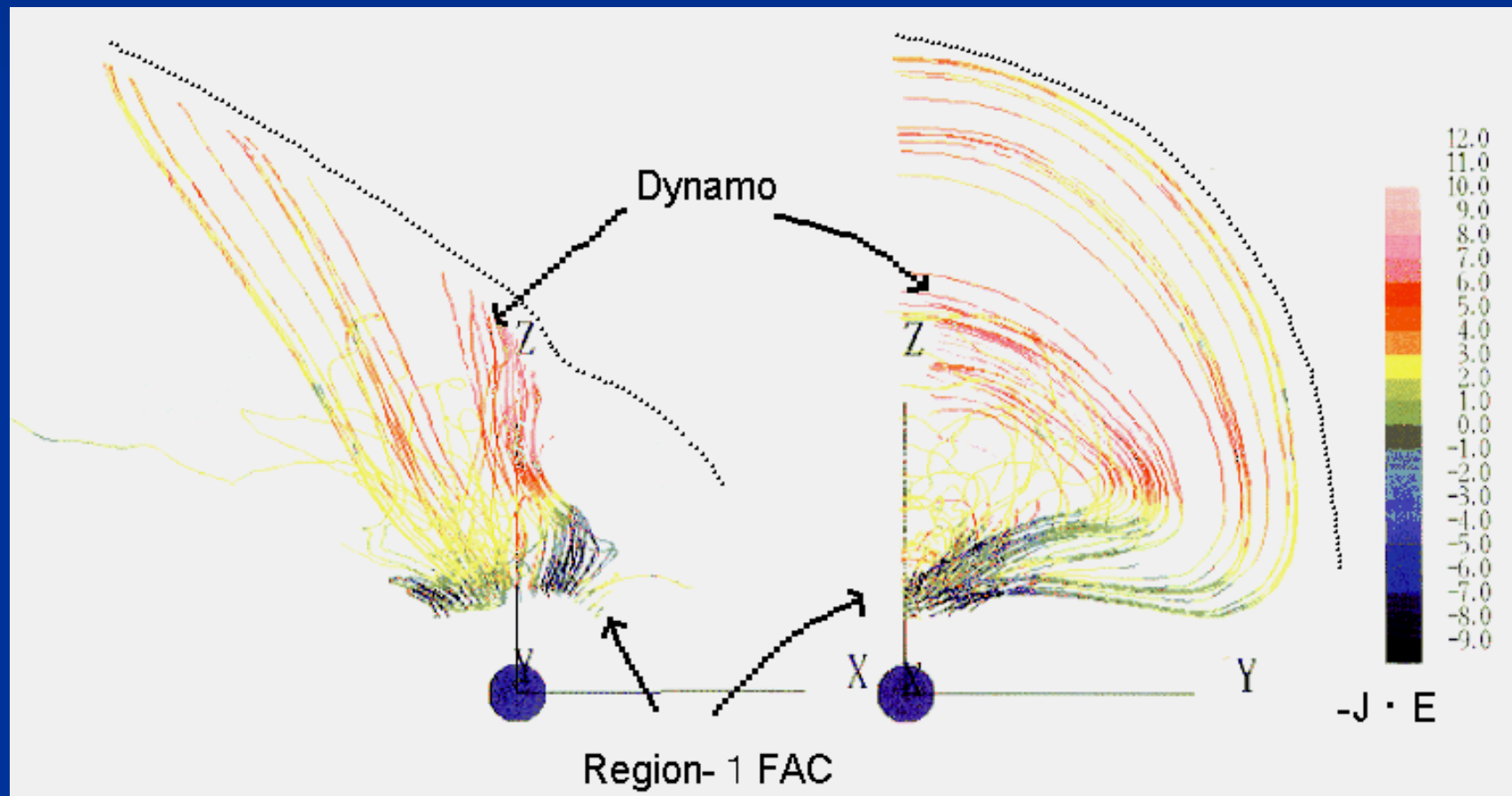


サブストームの過遮蔽電場によるプラズマ流の反転



(Hashimoto et al., JGR 2011)

グローバルMHDシミュレーションにより再現されたR1FACダイナモ(dynamo currents (red) and the R1 FACs (black))



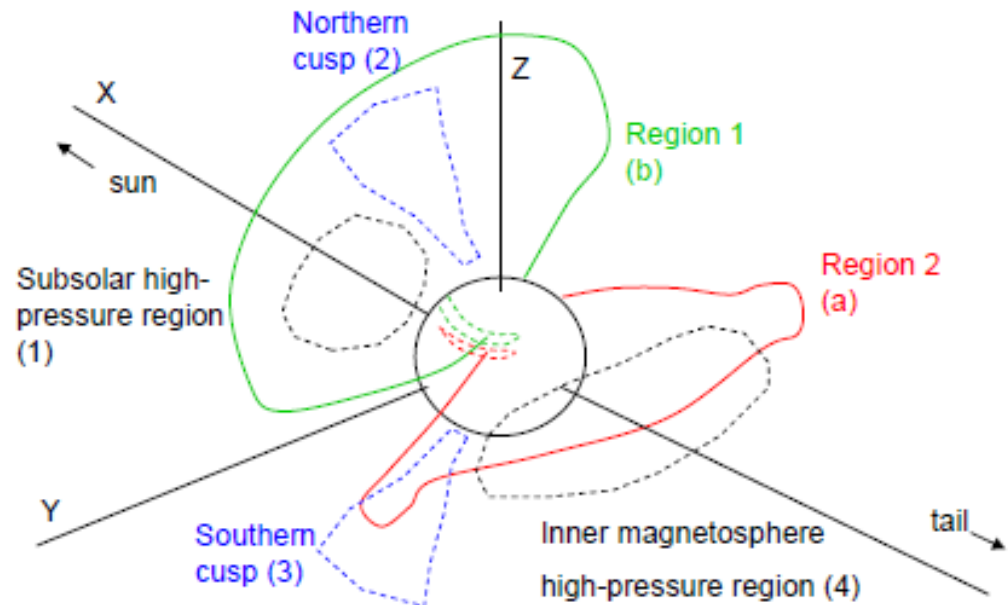
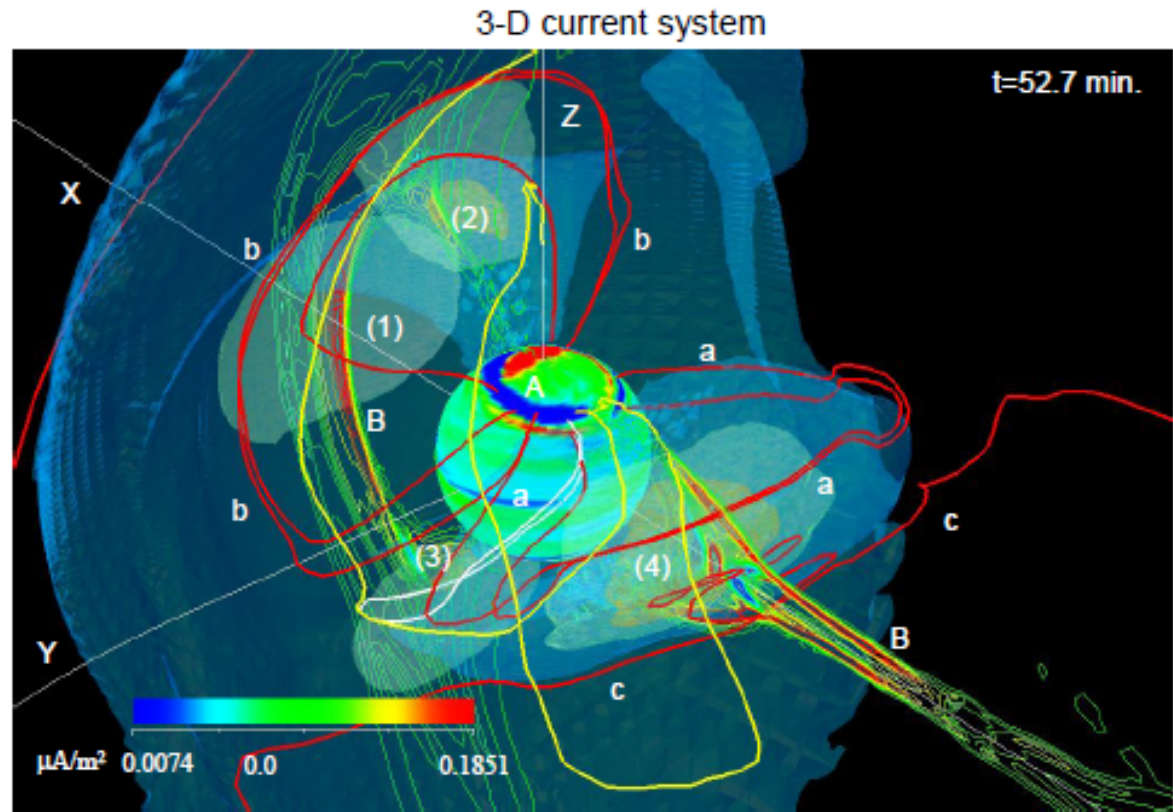
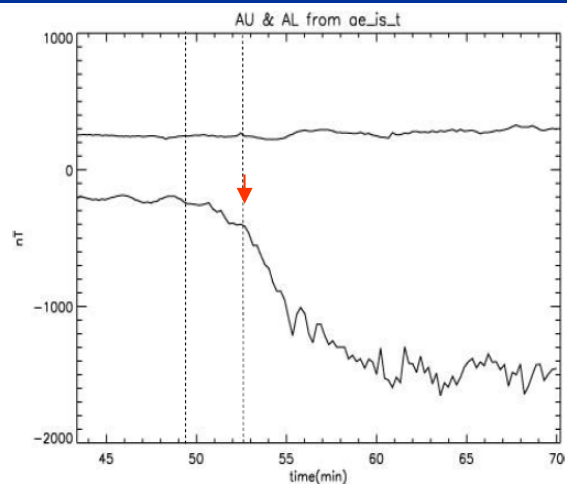
[Tanaka, JGR 1995]

グローバルMHDシミュレーションで再現されたサブストーム電流系

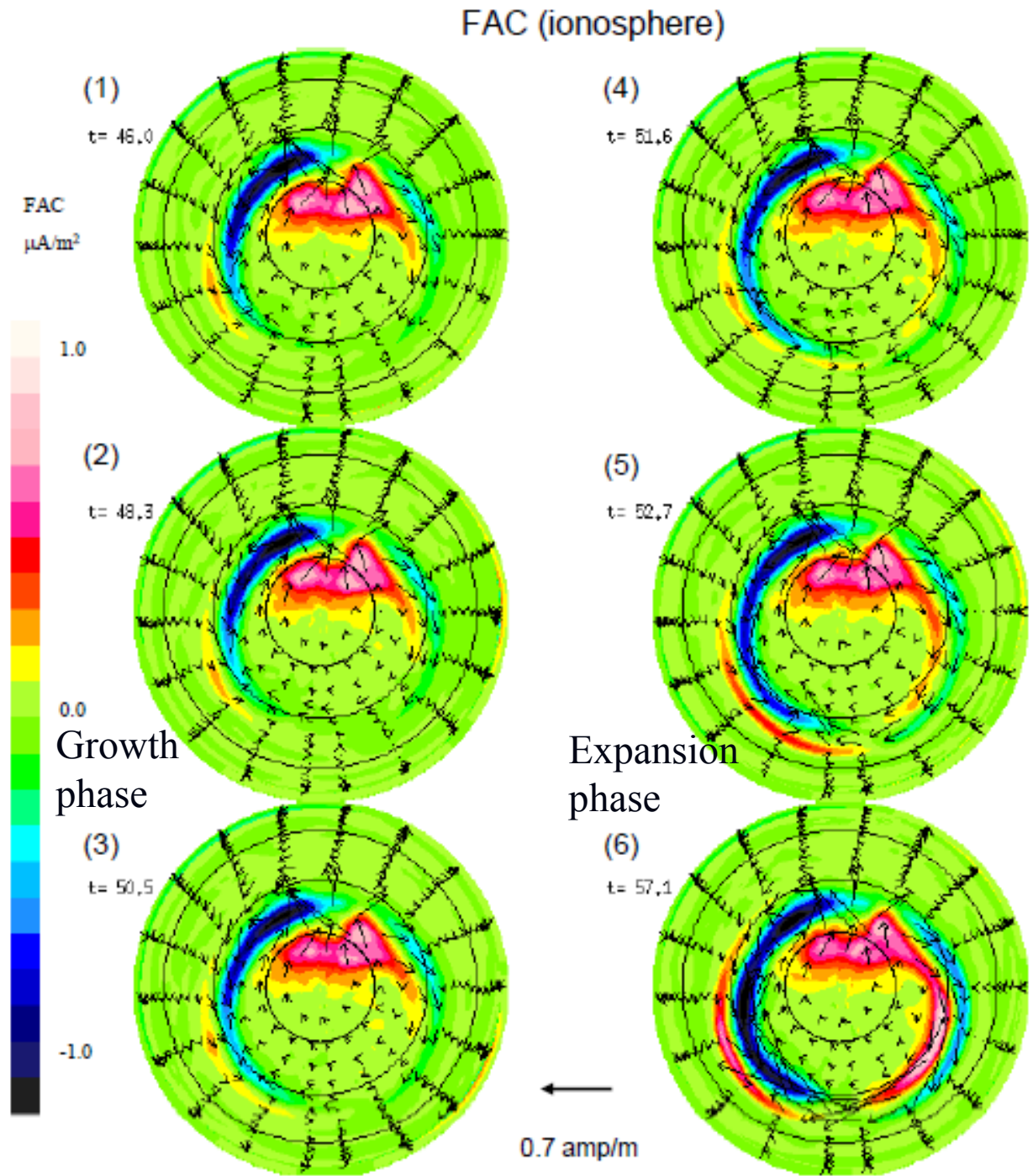
A ring current-R2 FAC current circuit is completed between the inner magnetosphere and auroral ionosphere at the onset of the substorm.

Substorm R1 FACs are generated by the dayside cusp dynamo

(Tanaka et al., JGR 2010)



グローバルMHDシ
ミュレーションで再現
されたサブストーム
のR1FAC, R2FAC
(Tanaka et al., JGR 2010)

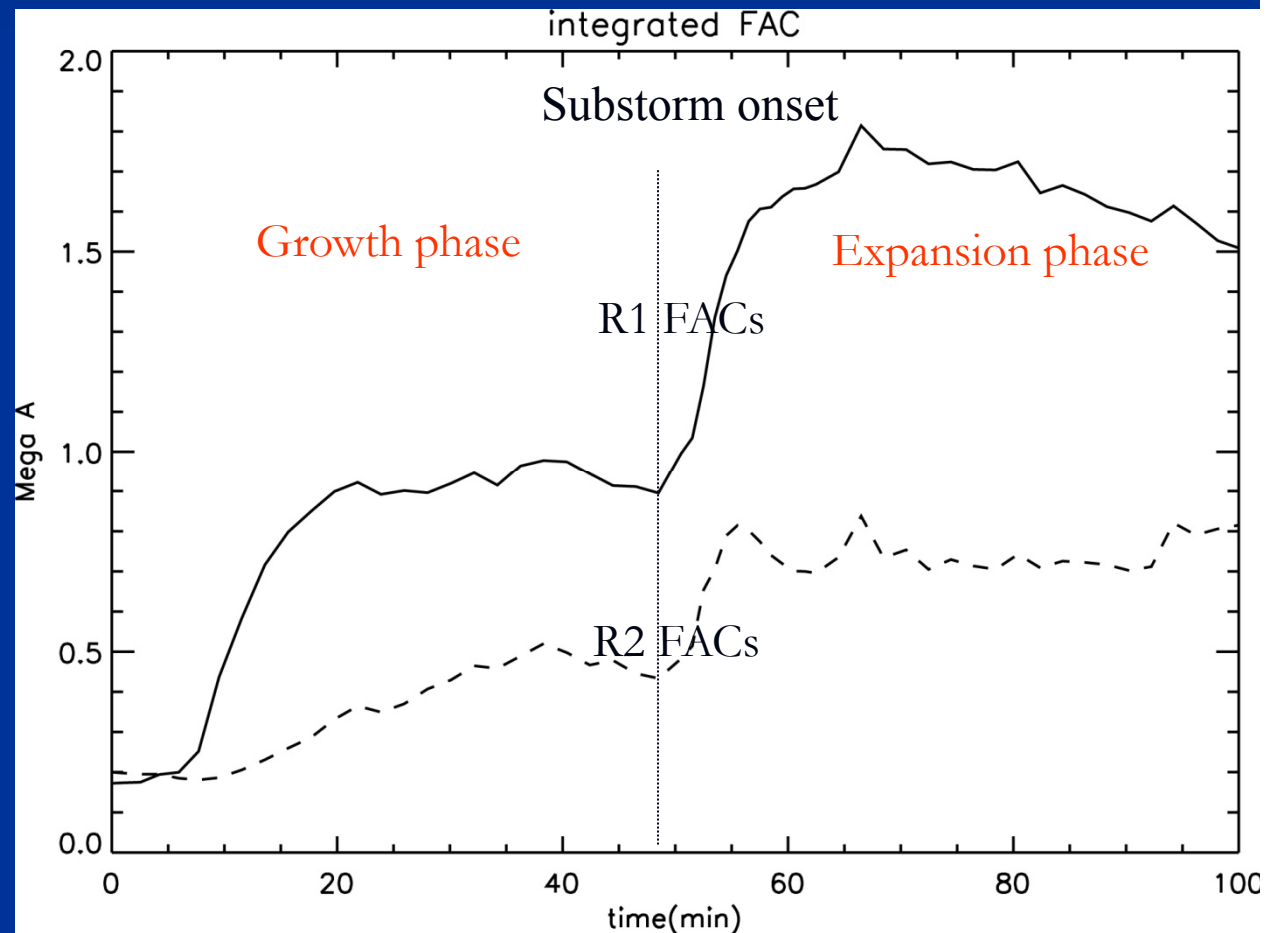


グローバルMHDシミュレーションで再現されたサブストームのR1FAC, R2FACの時間変化

(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.



Advantages of the current description

[Alfvén, H., Cosmic Plasma, 1981]

- it is advantageous to translate the traditional field description of plasma phenomena in space into a **current description**. This gives a deeper understanding of those phenomena in the following respects:
 - (1) The circuit representation demonstrates the **importance of boundary conditions** which have often been forgotten.
 - (2) By studying the electromotive forces driving the current and the regions of dissipation, the **energy transfer from one region to another** is more easily understood.
 - (3) Certain types of important current-produced phenomena, including the formation of double layers, are difficult to understand without accounting for the current explicitly.

Magnetosphere-ionosphere-ground (MIG)伝送線 によるエネルギー伝送

一対の磁力線を伝送線で置換し、地球電離圏導波管を伝送線を置換すると、2種の伝送線が結合した伝送線系ができる。

電離圏はエネルギーの消費地であると同時に伝送路でもある。

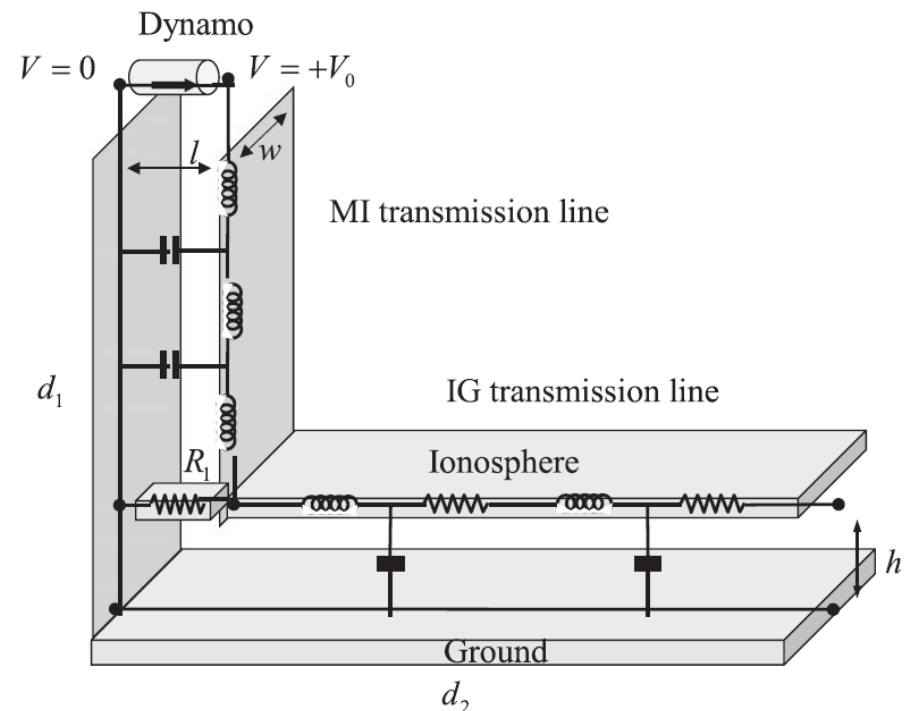
(Kikuchi, JGR 2014)

Transmission line equation

$$\frac{\partial^2 V}{\partial x^2} = \frac{1}{V_{ph}^2} \left[\frac{\partial^2 V}{\partial t^2} + \alpha \frac{\partial V}{\partial t} \right],$$

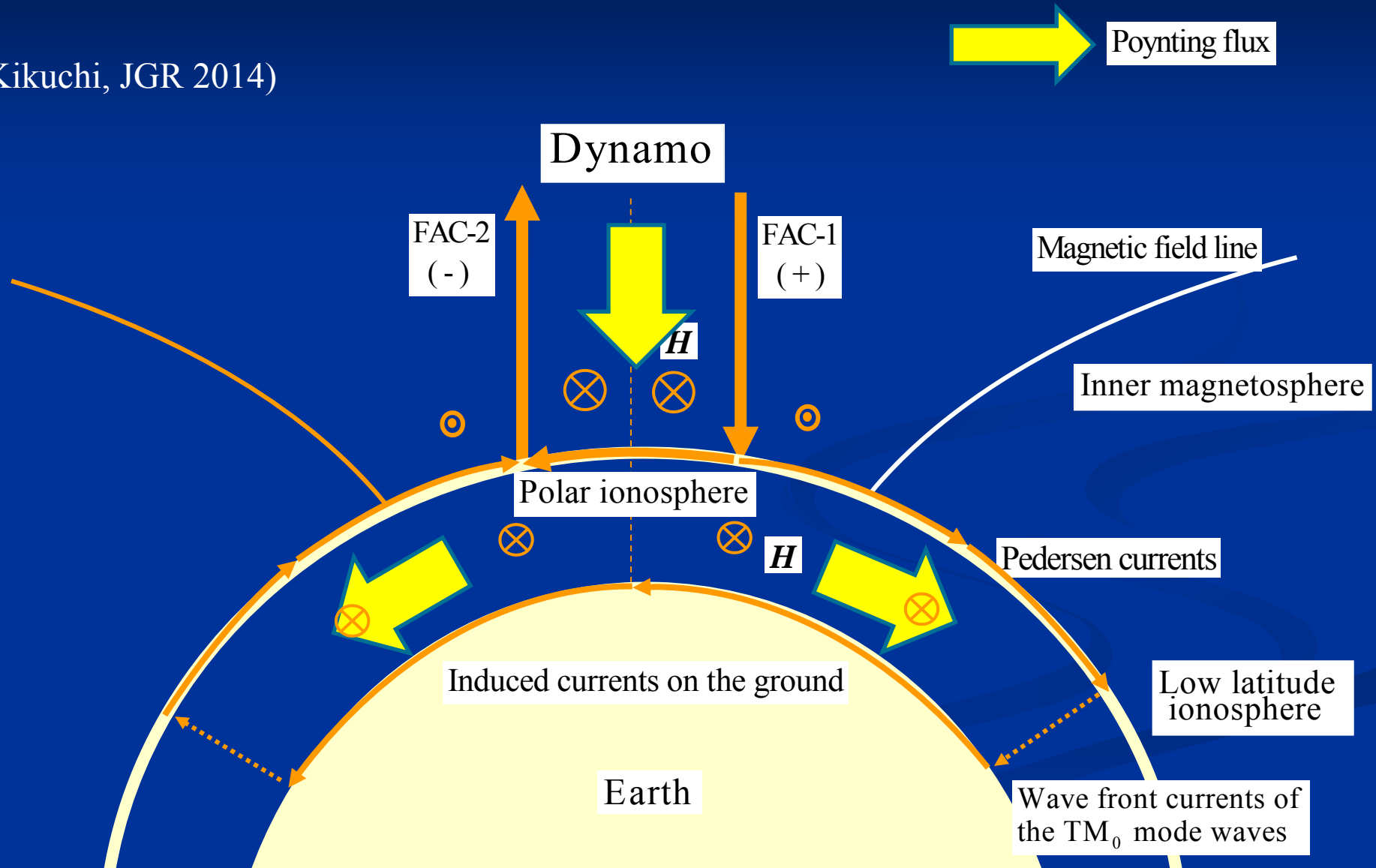
$$\frac{\partial^2 I}{\partial x^2} = \frac{1}{V_{ph}^2} \left[\frac{\partial^2 I}{\partial t^2} + \alpha \frac{\partial I}{\partial t} \right],$$

where $V_{ph}^2 = \frac{1}{LC}$ (phase velocity), $\alpha = \frac{R}{L}$ (attenuation rate).



Magnetosphere-ionosphere-ground (MIG) 伝送線によるエネルギー伝送

(Kikuchi, JGR 2014)



まとめ

- 南向きIMFにより対流電場とR1 FACsのダイナモが形成され(MHDシミュレーション)、電場・電流が極域電離圏を經由して中低緯度電離圏へ伝送される(MIG伝送線)。
- 対流電場が内部磁気圏へ伝送され、過遮蔽電場とR2 FACsを生成する。IMF変動によるDP2変動時にはR1 FACs とR2 FACsの両方が寄与する。
- サブストーム/ストーム時にR1 FACsとR2 FACs が強められ、中低緯度電離圏に伝送される。特に、過遮蔽電場が低緯度電離圏で強くなり、CEJや電離圏変動の原因となる。
- 電場・電流は、磁気圏で磁力線を伝送線とし、地面電離圏導波管を伝送線として中低緯度電離圏へ伝送される。Poynting fluxはAlfven波とTM0 (TEM)モード波により伝送される。
- MIG電流系は磁気圏から電離圏と地面へのエネルギー伝送路であり、グローバルデータの相関関係を解析することにより、全体像が理解できる。