

# 極域中緯度電離圏結合

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# 中緯度電場の役割

## 1. 中低緯度電離圏の正嵐の原因

- TEC増加を引き起こしGPS利用障害の原因となる

## 2. 内部磁気圏電場を決める

- 電離圏が伝送路となり外部磁気圏電場が内部磁気圏へ侵入する
- 内部磁気圏電場は磁気嵐時の環電流、高エネルギー粒子の生成・輸送に寄与する

# 中緯度電場を決めるもの

## 1. Region-1沿磁力線電流の強さと位置

- IMF  $B_z < 0$ により電流は強くなり、位置は低緯度へ移動
- Region-1電流はグローバル電離圏へ流れ、DP2電流系を形成する。DP2電流に伴い対流電場が中低緯度へ侵入する。

## 2. Region-2沿磁力線電流による遮蔽効果

- Region-2はRegion-1発達から時間遅れを伴って発達する
- 平均的にはRegion-1より弱い、Region-1が減少するとRegion-2が卓越しover-shieldingが発生する。
- Region-2の位置はRegion-1発達と共に変化？

# 電場モデルの検討

1. Volland-Sternモデルは過度な遮蔽を仮定している
  - モデルによる電場の緯度分布とKikuchi et al. (1996)のDP2電流の緯度分布を比較すると観測された中緯度電場減衰は小さい。
  - 磁気嵐時にはRegion-1電流の位置が低緯度へ移動するために中緯度電場減衰はさらに小さくなるであろう。しかし、Region-2の発達が減衰を決めるために中緯度での実測が必要。

# 電場の伝わり方

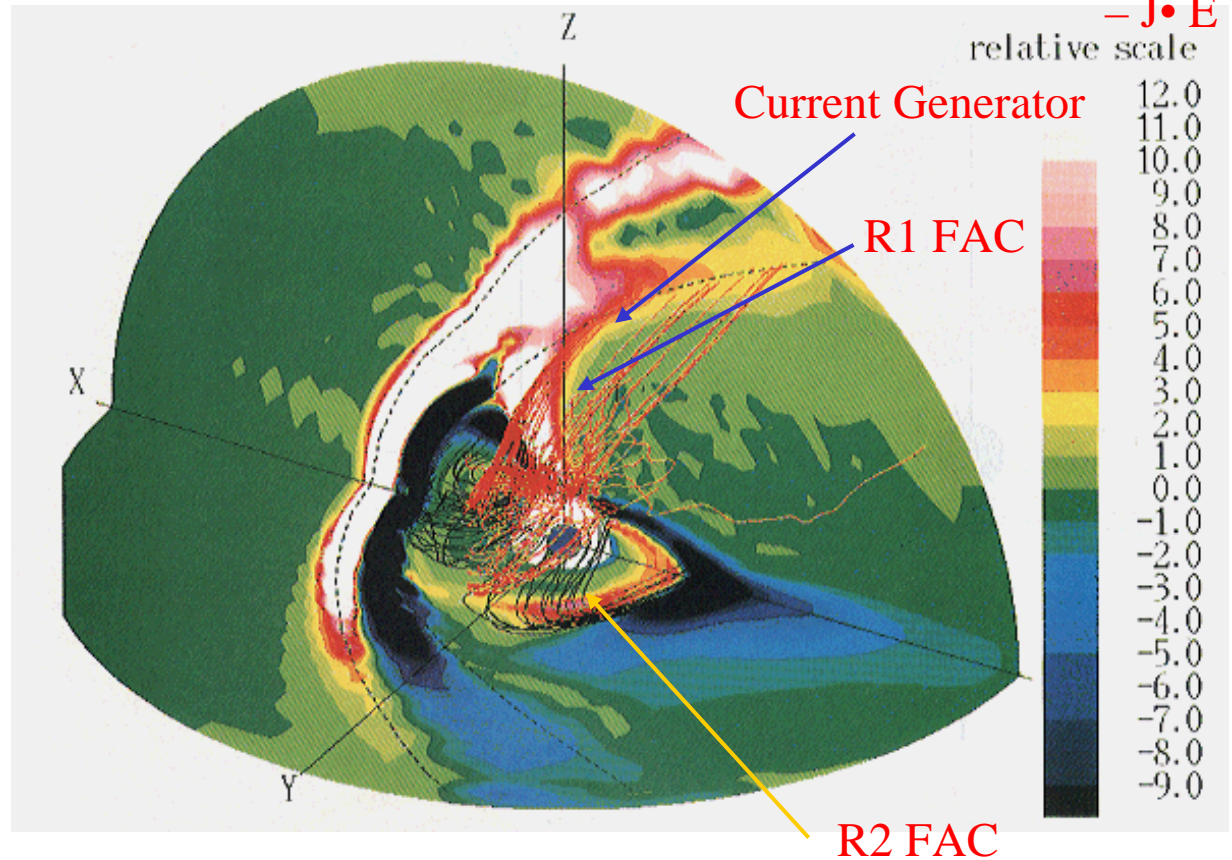
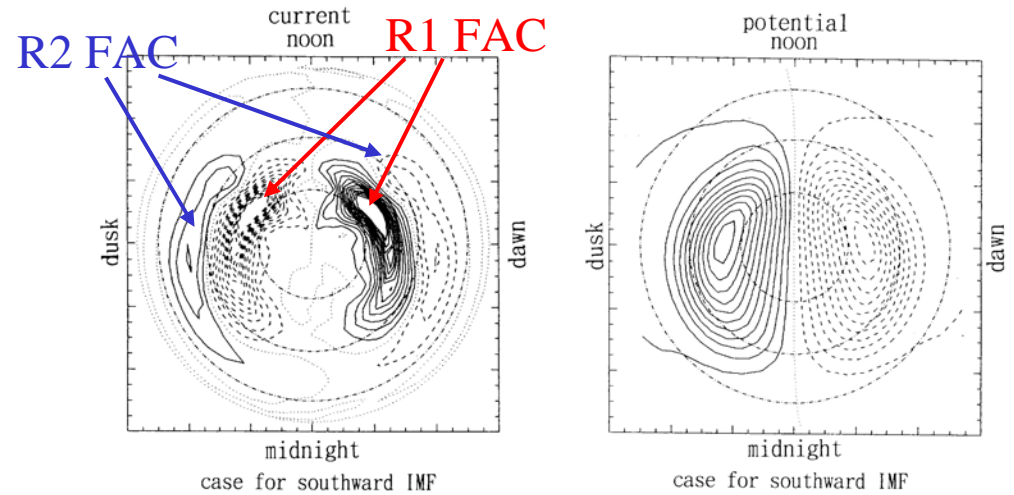
1. 一対の沿磁力線電流は磁力線対が電磁エネルギーの伝送路であることを示している。
  - Region-1沿磁力線電流を流すダイナモがCuspで作られることがMHDシミュレーションで示された。
2. 磁気圏伝送線は地面と電離層で構成される地球電離層伝送線に接合され、電磁エネルギーの一部が中低緯度電離圏へ伝送される。
3. 電磁エネルギーの伝送により電離圏電位と電離層内水平電場が伝送され、さらに磁力線沿いに内部磁気圏へ伝送される。

# Generator of the R1 FACs

(Tanaka, JGR 1995, p.12,057)

$B_z < 0$

Electric currents are generated in the cusp ( $J \cdot E < 0$ ) and flow into the polar ionosphere along the magnetic field lines (R1 FAC).



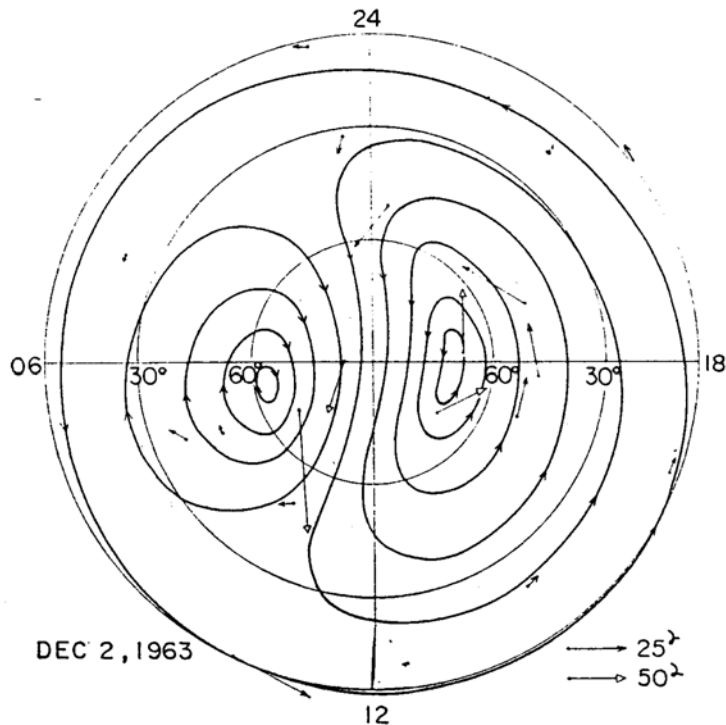
# DP2グローバル電離層電流

## DP2 ionospheric currents

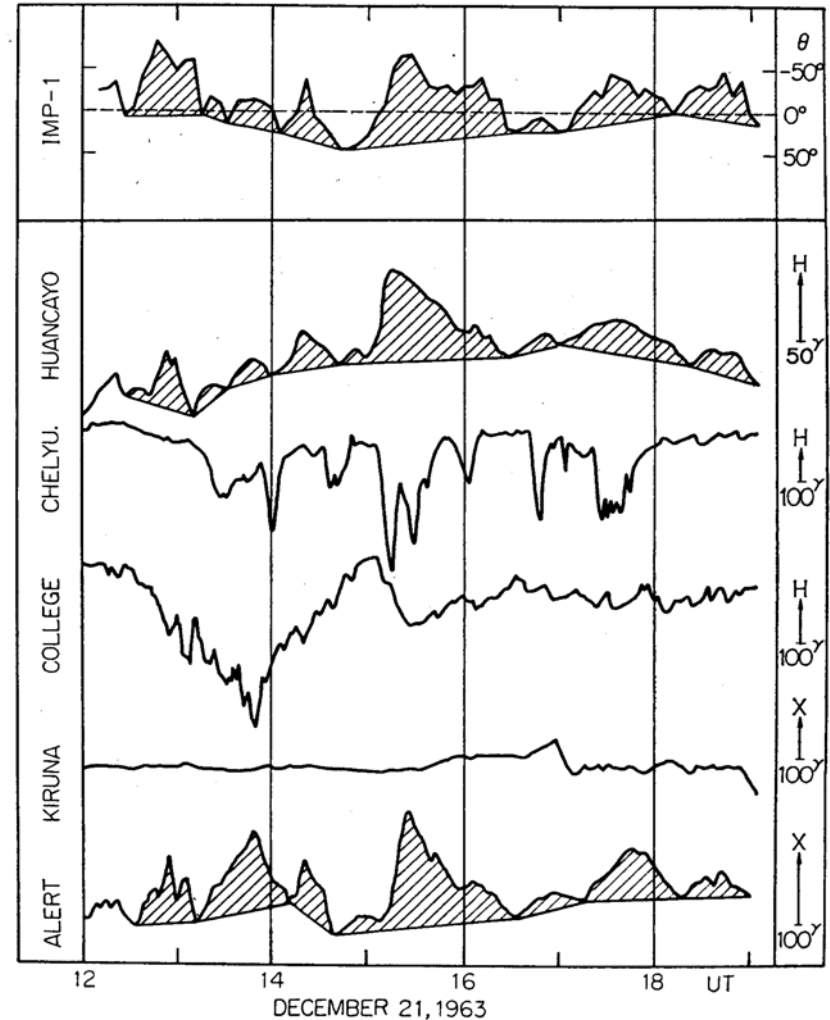
IMFとの相関は磁気圏電離圏3次元電流系を示唆している

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

(Nishida, JGR 1968, p.5549)



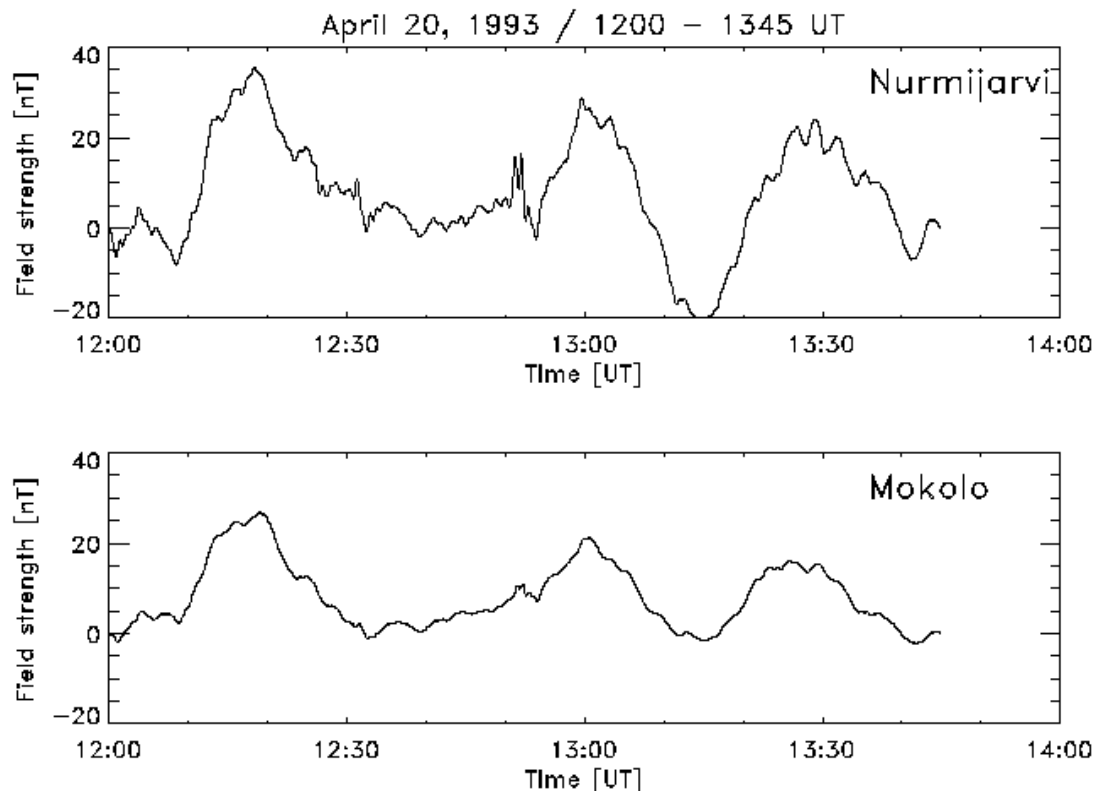
DP 2 AND INTERPLANETARY FIELD



# DP2電離層電流は瞬時に中低緯度へ伝わる

## Instantaneous Propagation of Convection Electric Fields to the Equator

The DP2 fluctuations (period of 40 min) at Mokolo and Nurmijarvi are coherent with a correlation coefficient of 0.9. The time shift between the magnetic fluctuations is 25 sec, suggesting instantaneous propagation of the convection electric fields to the equatorial ionosphere.

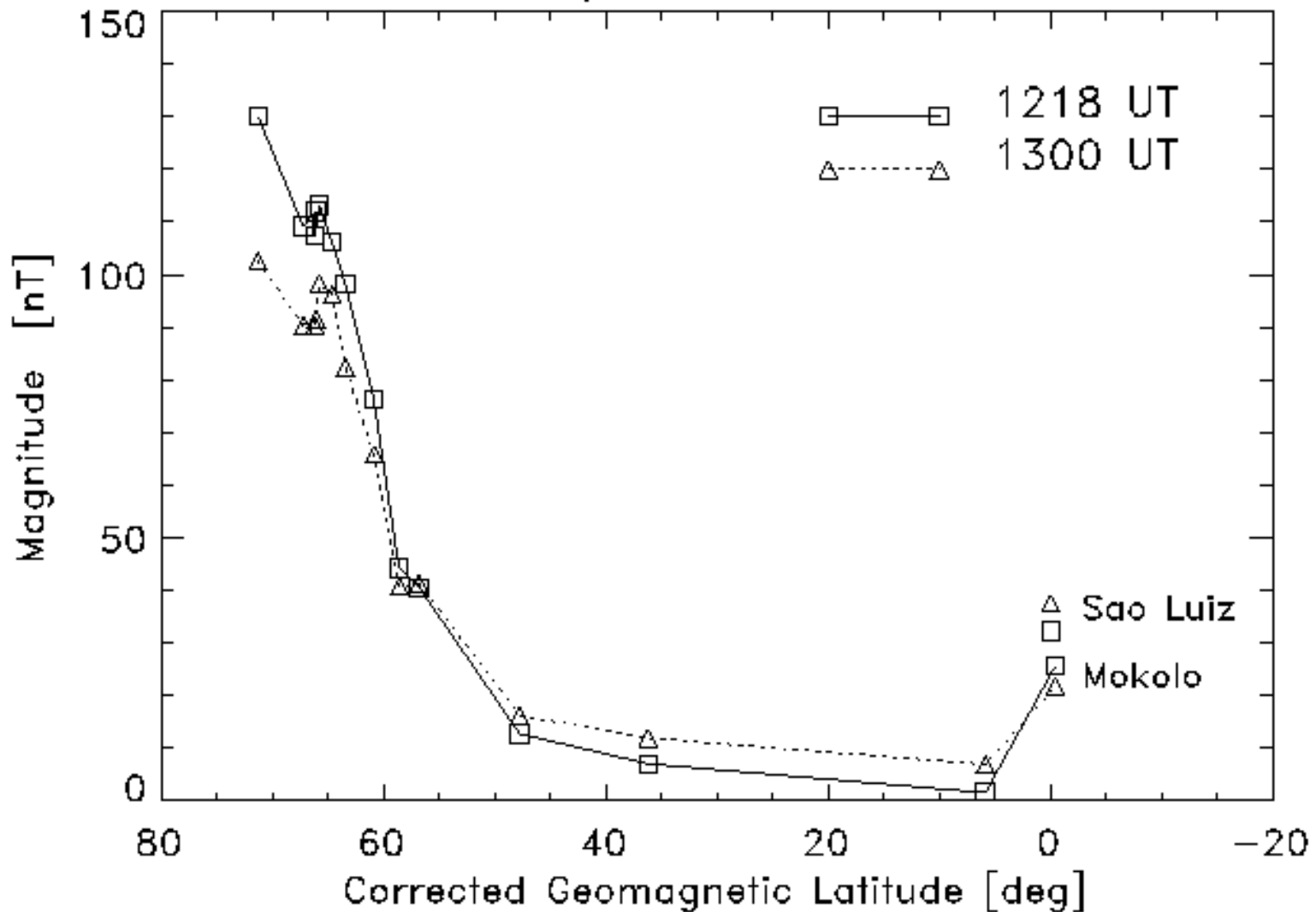


(Kikuchi et al., JGR 1996)



# Latitudinal Profile of the DP2

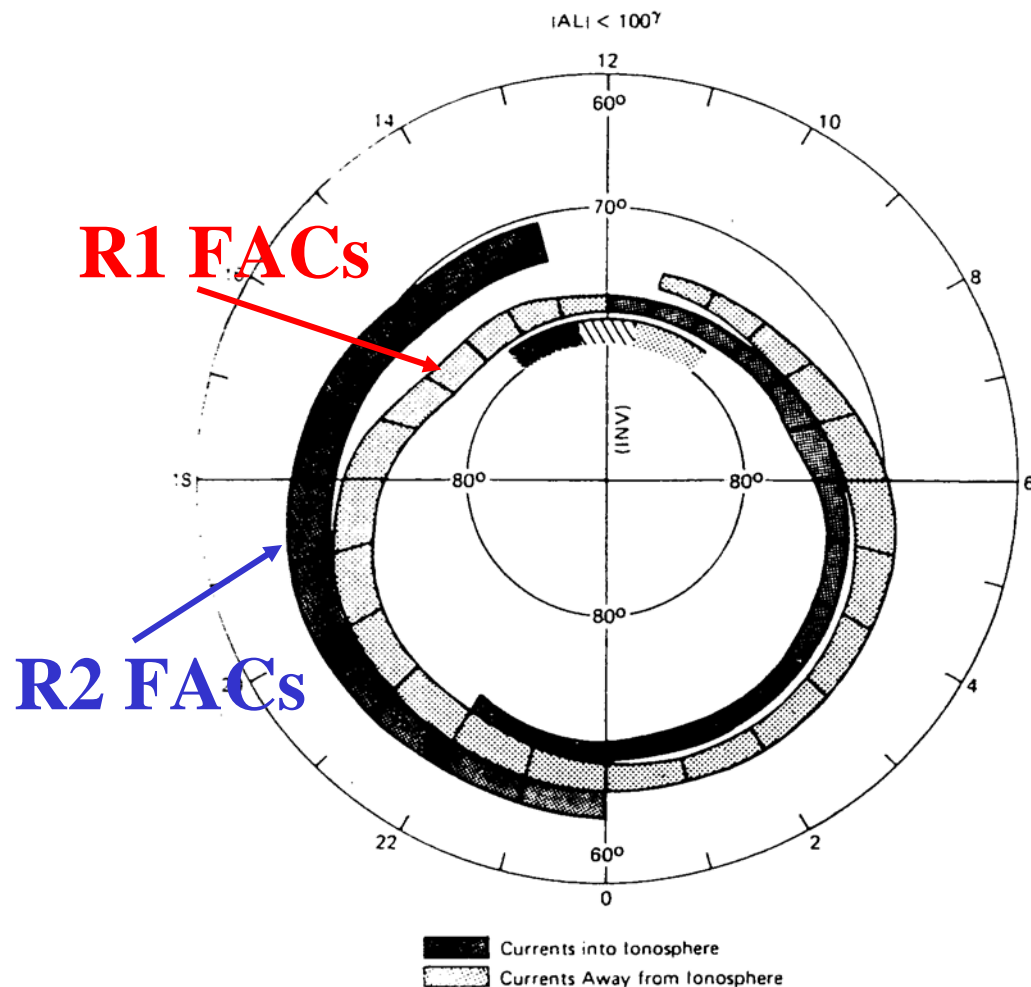
April 20, 1993



# 磁気圏ダイナモと電離層電流を結ぶ 沿磁力線電流 (R1, R2 FACs)

The magnetosphere and ionosphere are coupled by the field-aligned currents.

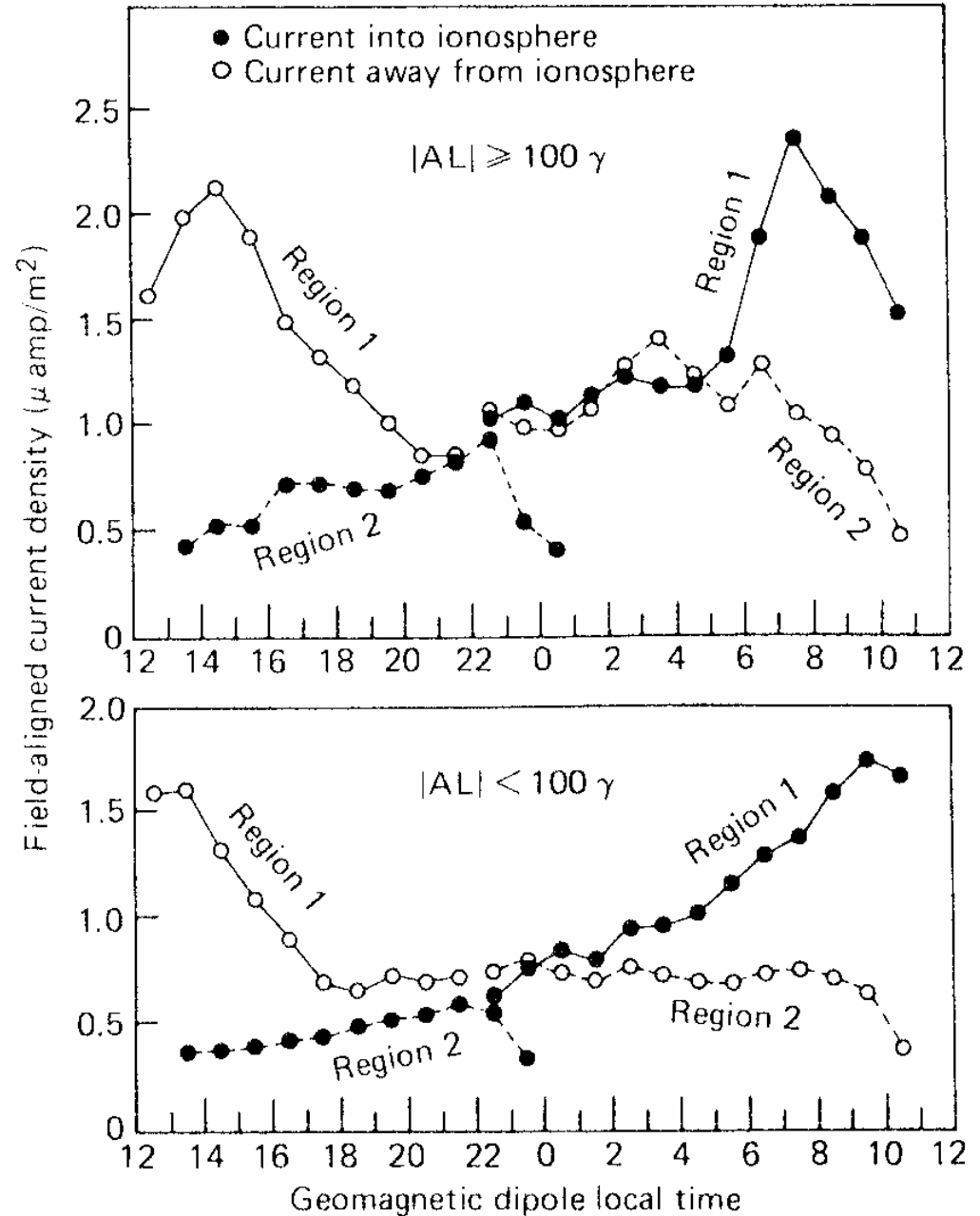
Iijima and Potemra  
(JGR 1976, p.5971)



# R1 and R2 FACs

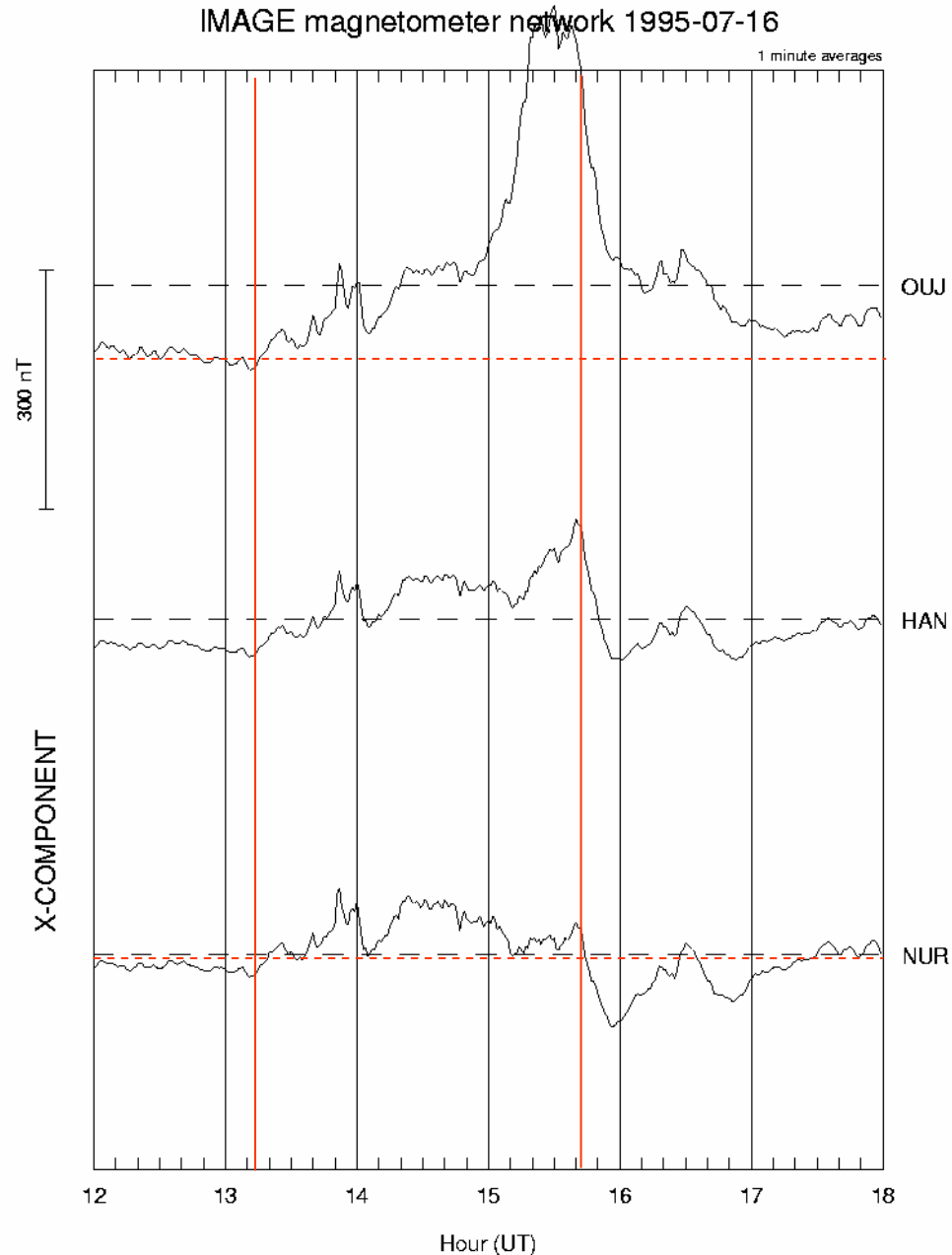
Iijima and Potemra (JGR 1978, p. 599)

The R2 FACs could overcome the R1 FACs on the nightside during substorms.



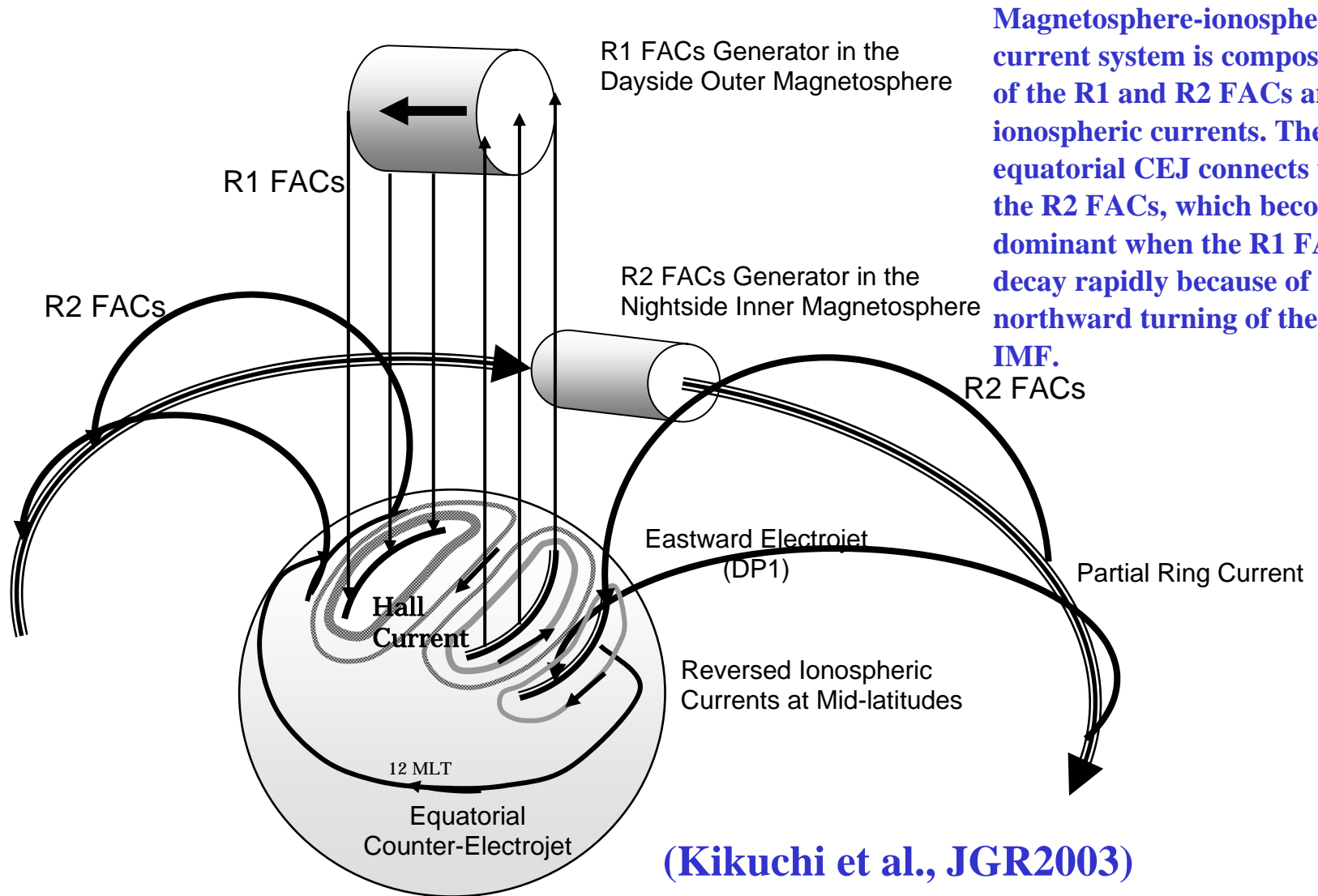
# Auroral and mid latitude magnetometers (afternoon sector) Over-shielding at mid latitude

The X-component at NUR started to increase in concert with the growth of the eastward electrojet at OIJ (1313 UT), but decreased substantially at 1543 UT to be well below the pre-event level at around 13 UT, while the X-component was well above the pre-event level at OIJ.

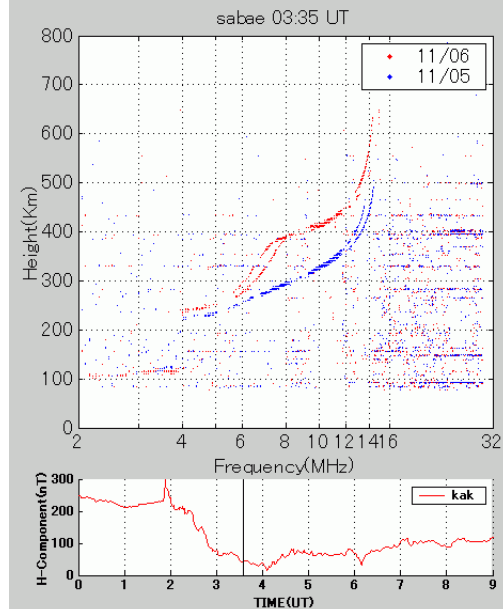
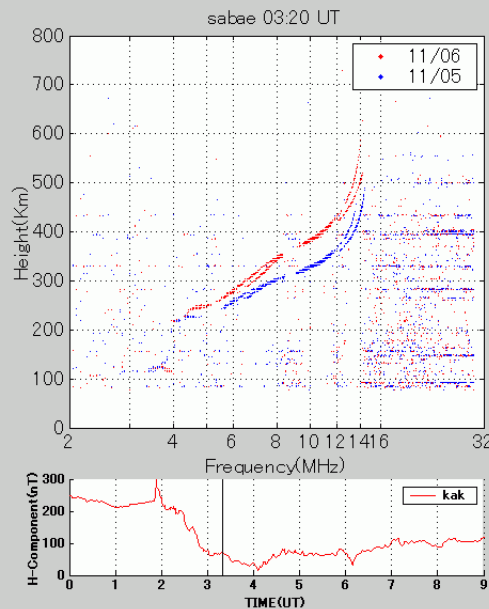
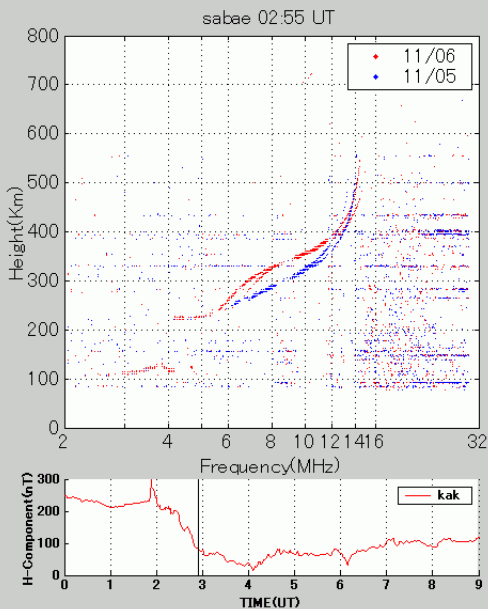
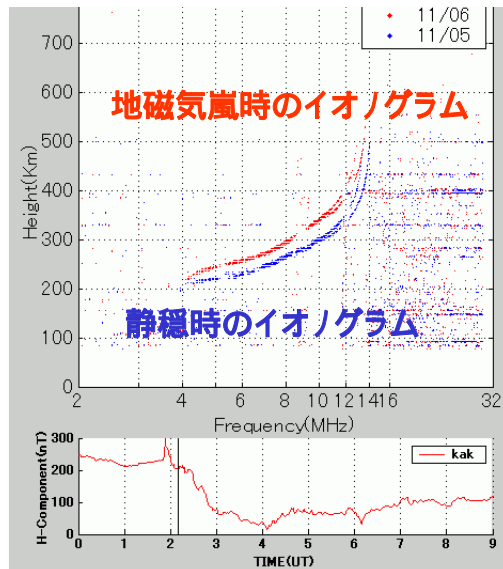
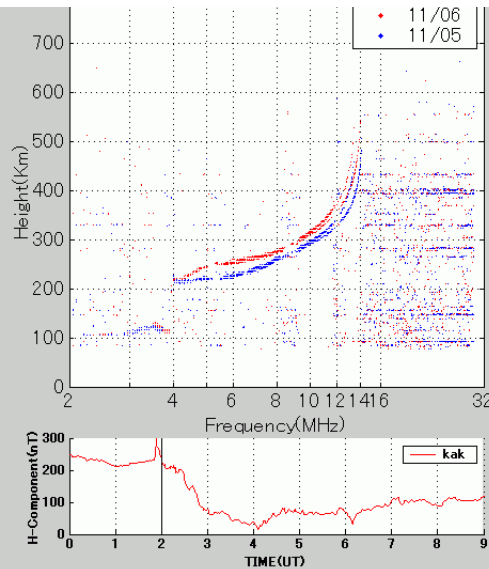
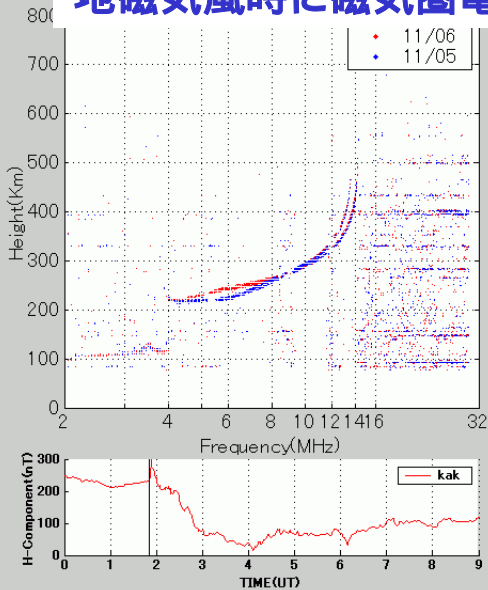


# サブストーム時の赤道counter-electrojet発生シナリオ

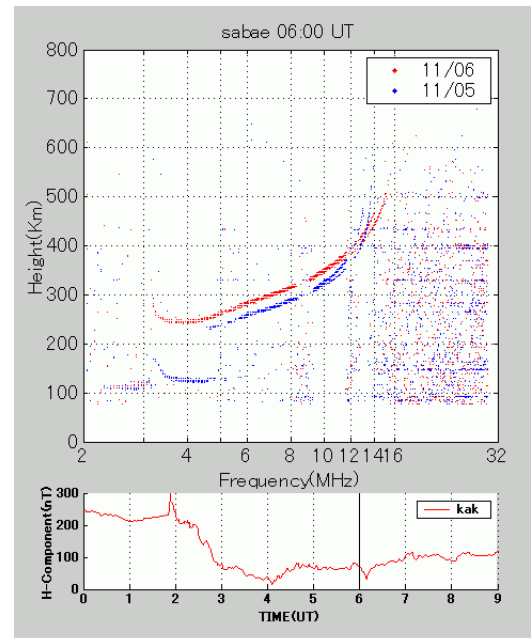
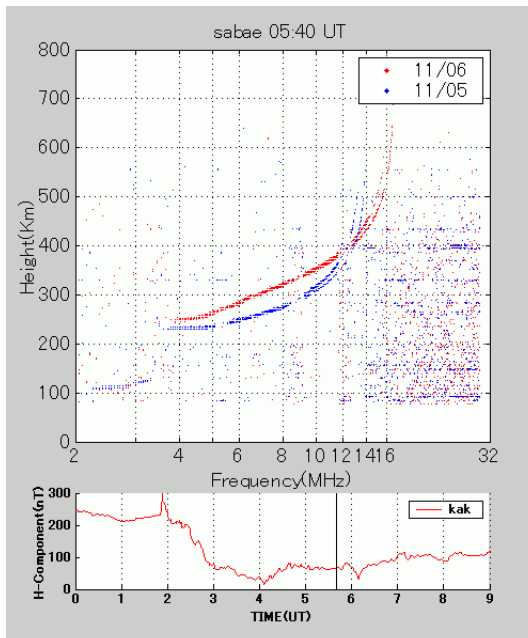
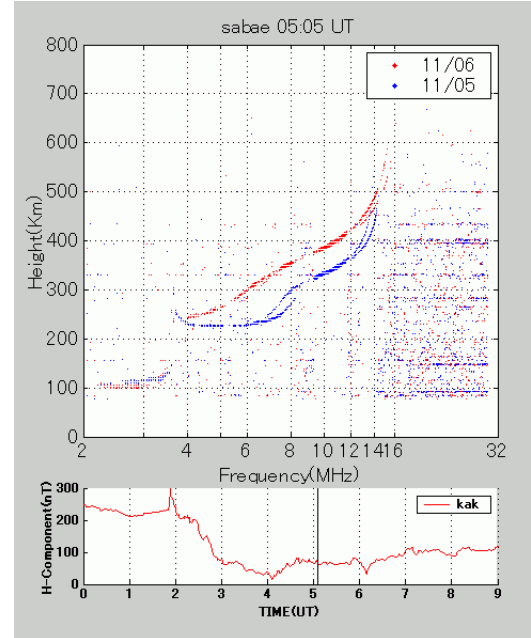
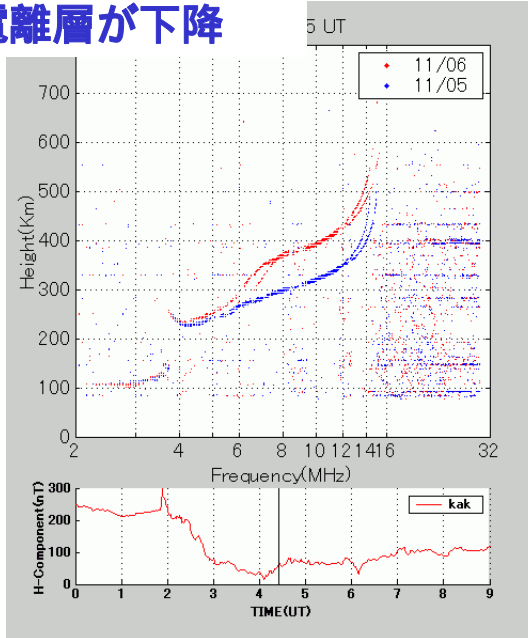
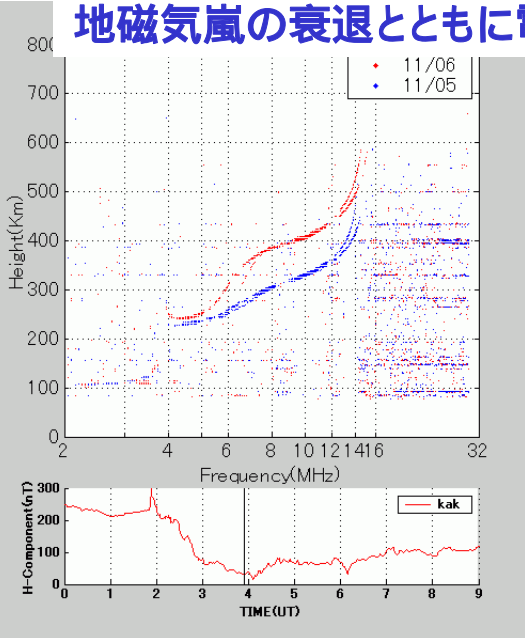
IMF  $B_z < 0$  で R1 FACs が成長し、遅れて R2 FACs が成長し遮蔽電場を発生。ついで  $B_z > 0$  により R1 FACs が急速に減少すると低緯度で R2 FACs はただちに減少しないために遮蔽電場が卓越し over-shielding 状態となる



# 地磁気嵐時に磁気圏電場が低緯度電離圏へ侵入し電離層の上昇運動が発生



# 地磁気嵐の衰退とともに電離層が下降

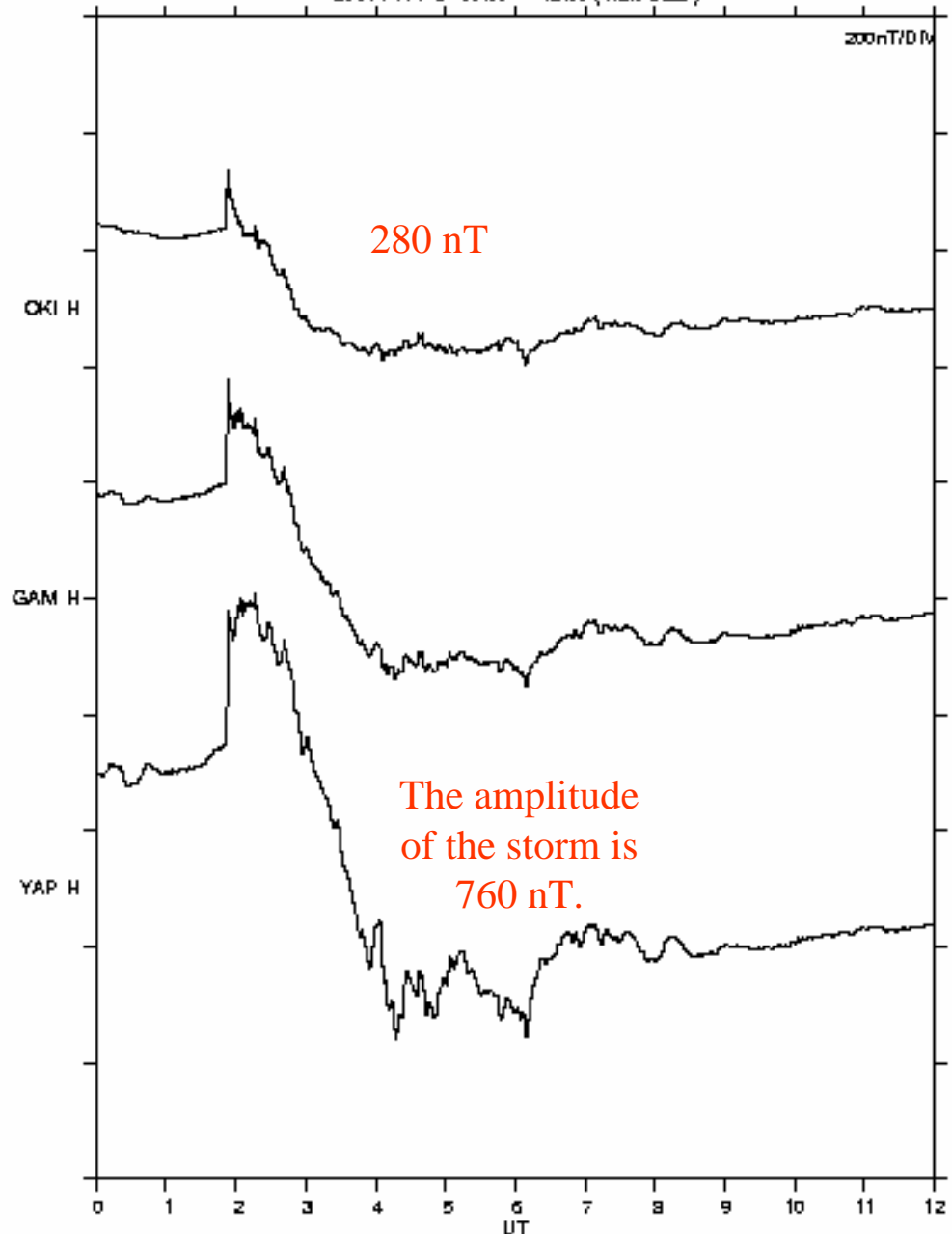


2001 / 11 / 6 00:00 - 12:00 (Raw Data)

# Geomagnetic storm at low latitudes (Okinawa) and dip equator (Guam, Yap)

The geomagnetic storm  
is enhanced at  
the dip equator.

The ratio of the equatorial  
enhancement is 2.7.

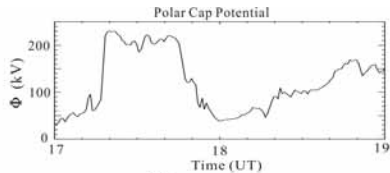
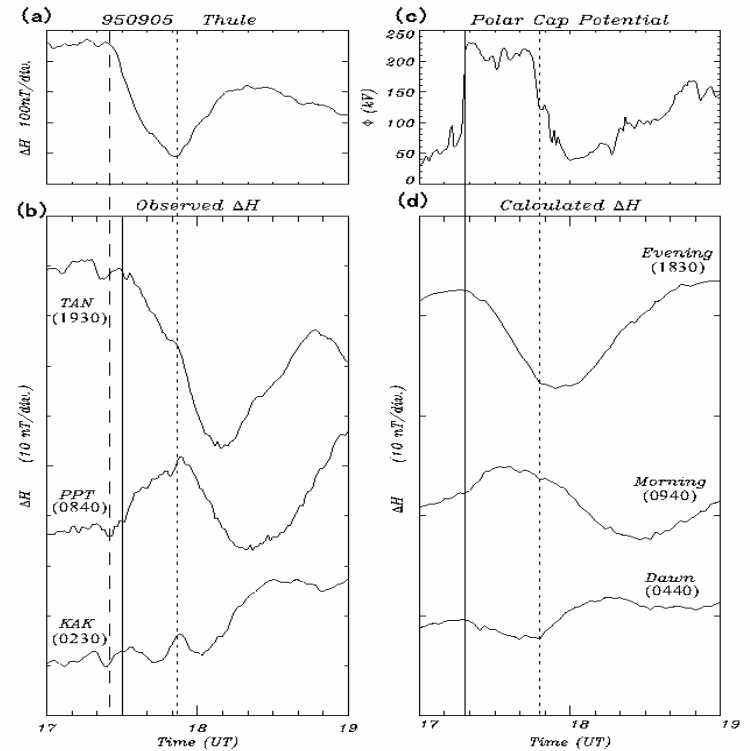




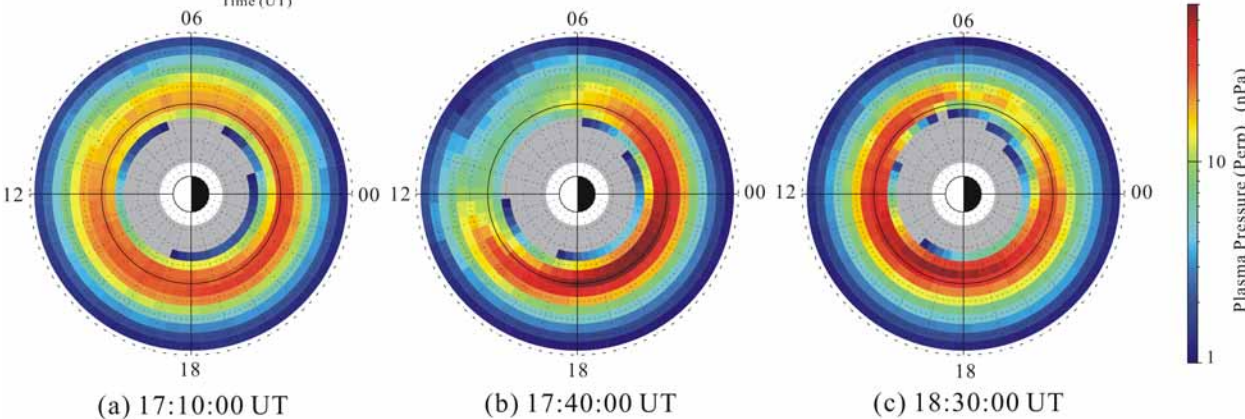
# Quick development of the ring current during a substorm

(Hashimoto et al., JGR 2002)

This fact suggests that the convection electric field was transmitted promptly to the inner magnetosphere.



September 5, 1995

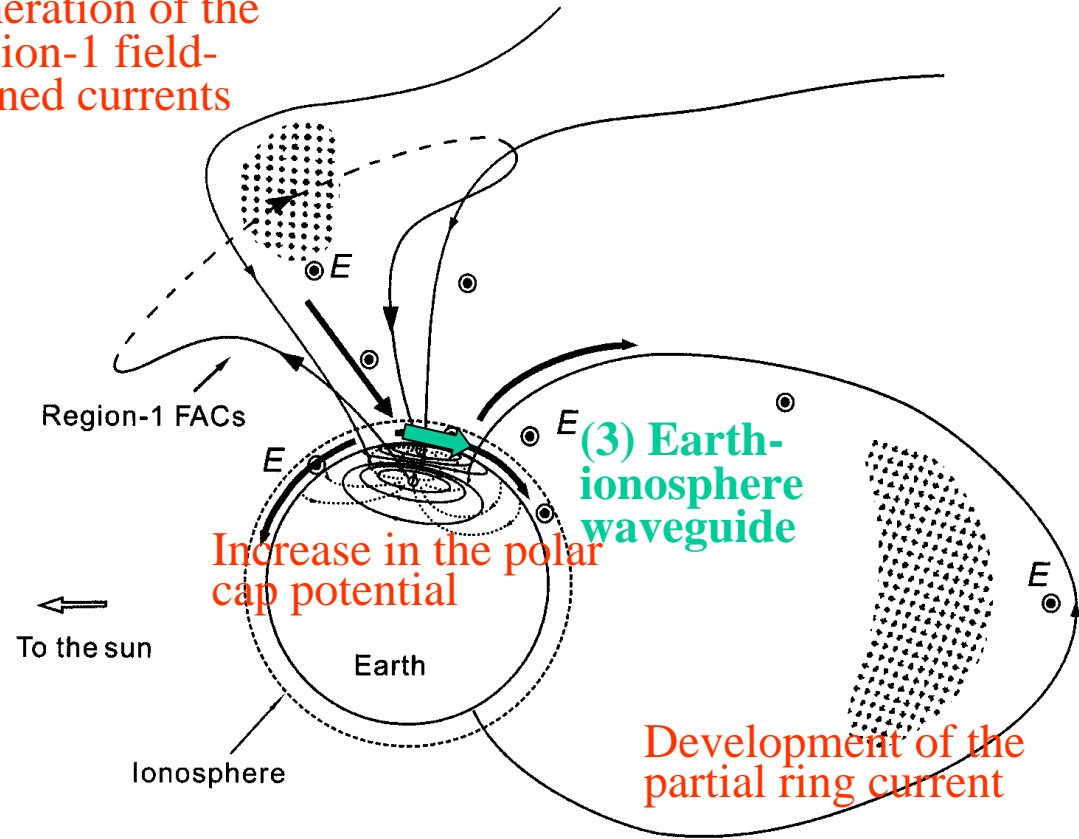


Simulated plasma pressure in the inner magnetosphere using the Ebihara model.

# Transmission of the convection electric field into the inner magnetosphere

- The prompt development of the partial ring current suggests that the convection electric field is transmitted from the current generator in the cusp to the inner magnetosphere through the Earth-ionosphere waveguide.

Generation of the Region-1 field-aligned currents



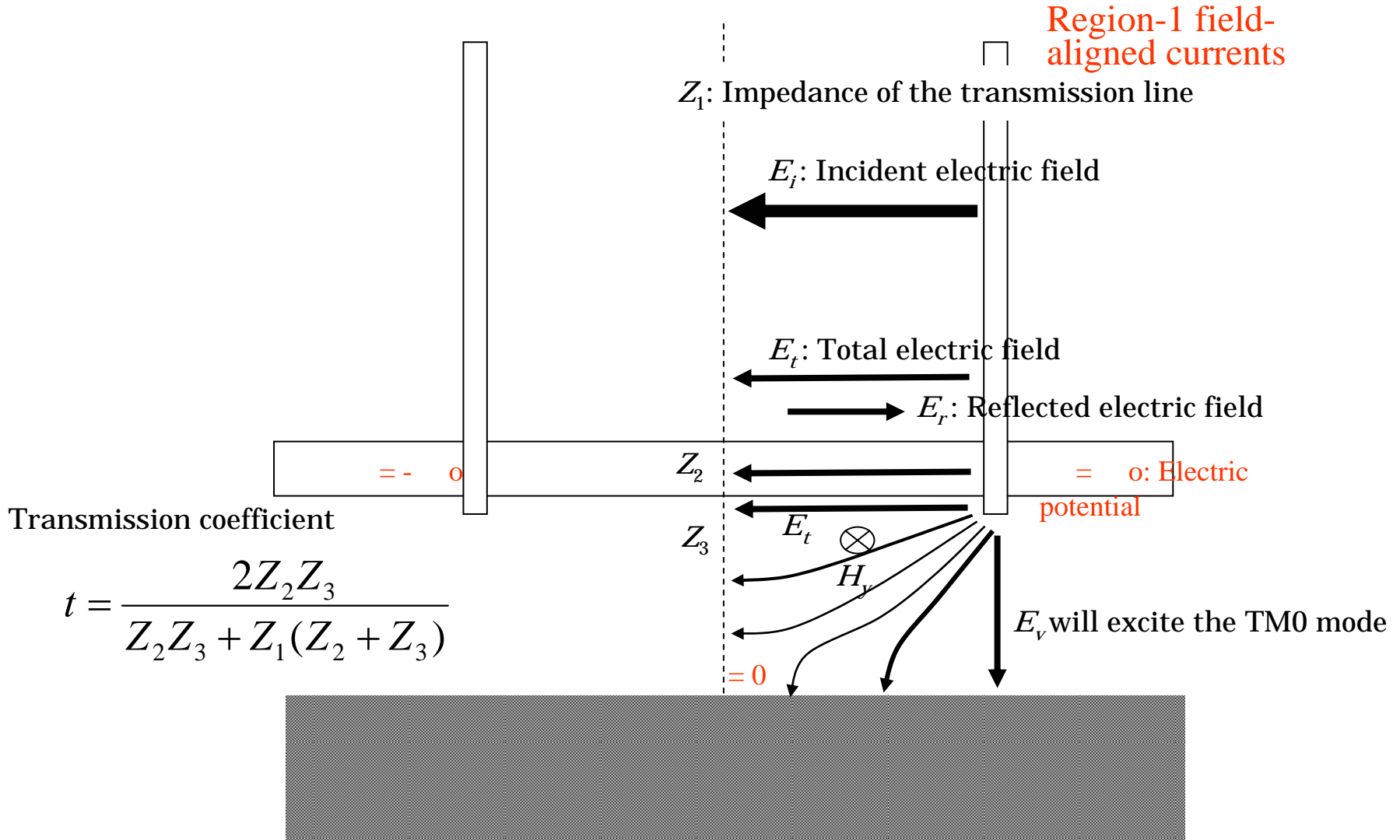
⋯ : High plasma pressure region

$E$  : Convection electric field (dawn-to-dusk)

$\rightarrow$  : Poynting flux

# Excitation of the TM<sub>0</sub> mode

## Transmission of EM energy into the Earth-ionosphere waveguide



# 地球電離層導波管TM0モードによりPoynting fluxが水平伝送され、極域電離圏電位が低緯度へ伝播する

The electric field and currents are transmitted to low latitudes by the TM0 mode waves in the Earth-ionosphere waveguide, and then transmitted upward to the inner magnetosphere by the Alfvén mode waves.

$$E_{xM}(x) = E_{xI}(x) \cdot U\left(t - \frac{z}{V_a}\right)$$

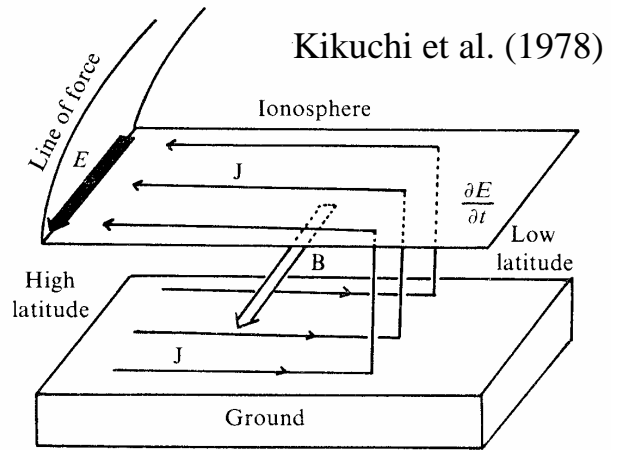
$$E_{xI}(x) = \frac{1}{\Sigma_A + \Sigma_I} H_{yV}(x)$$

$$\Sigma_A = \frac{1}{\mu_0 V_a} = \frac{1}{B_0} \sqrt{\frac{\rho}{\mu_0}}$$

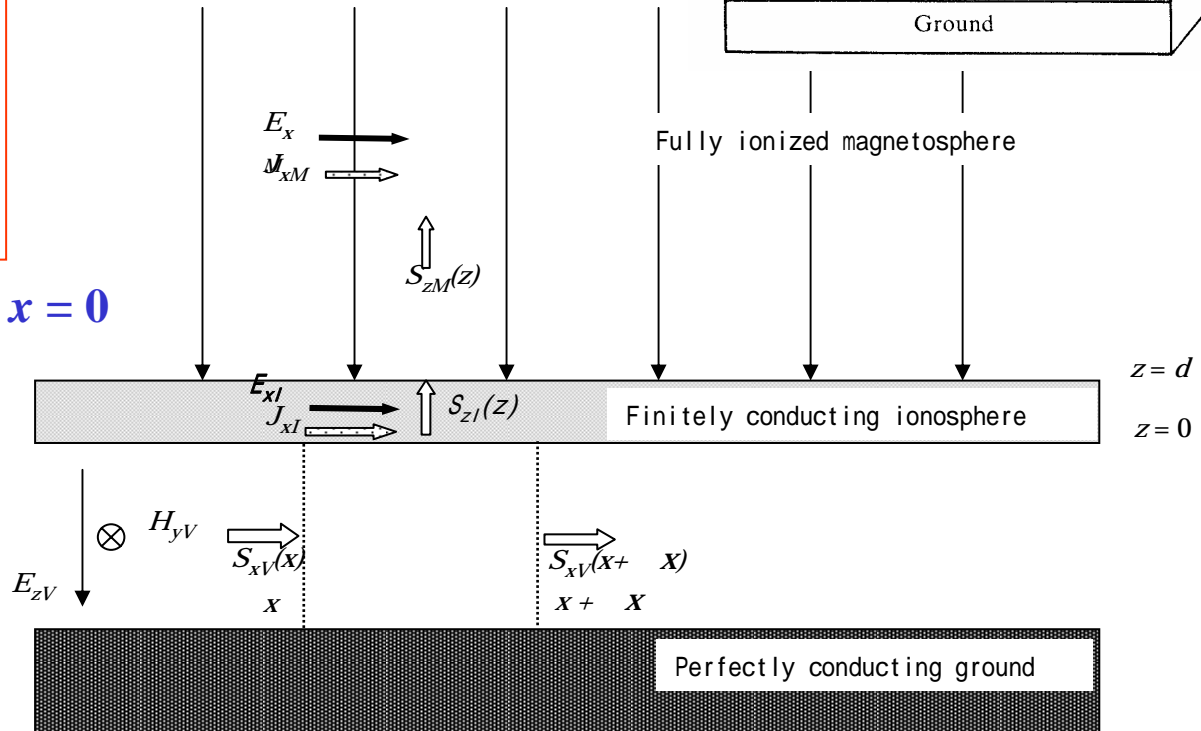
Boundary condition at  $x = 0$

$$H_{yV} = H_{y0} U(t)$$

$U(t)$ : Heaviside unit step function



Kikuchi et al. (1978)



# The ionosphere drives the convection in the inner magnetosphere

$$E_{xM}(x) = E_{xI}(x) \cdot U \left( t - \frac{z}{V_a} \right)$$

$$E_{xI}(x) = \frac{1}{\Sigma_A + \Sigma_I} H_{yV}(x)$$

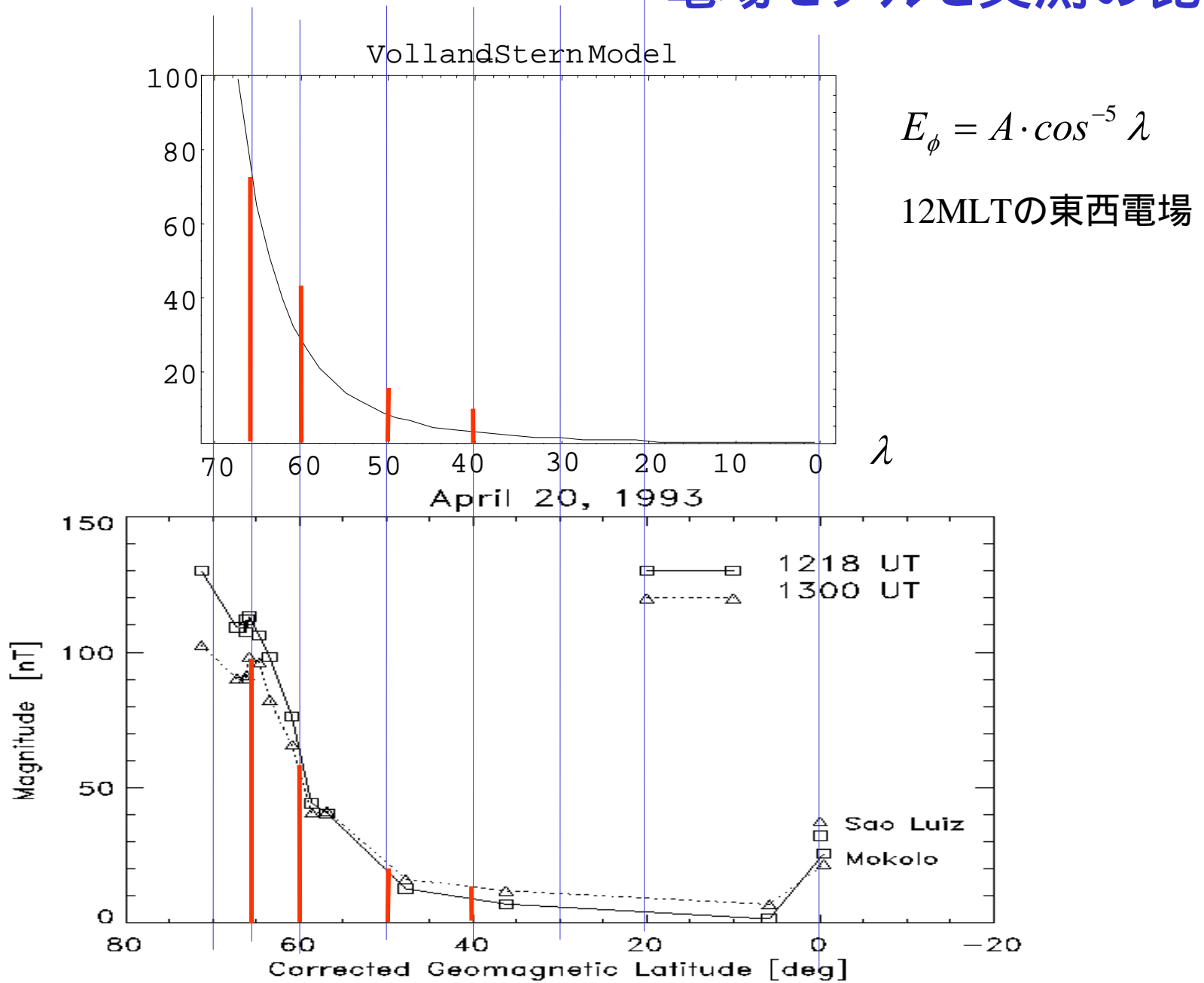
$$\Sigma_A = \frac{1}{\mu_0 V_a} = \frac{1}{B_0} \sqrt{\frac{\rho}{\mu_0}}$$

電離圏電場が  
磁力線沿いに  
内部磁気圏へ  
伝送され、対流  
を駆動する

The convection electric field in the inner magnetosphere depends on the ionospheric conductance and the plasma density of the inner magnetosphere.

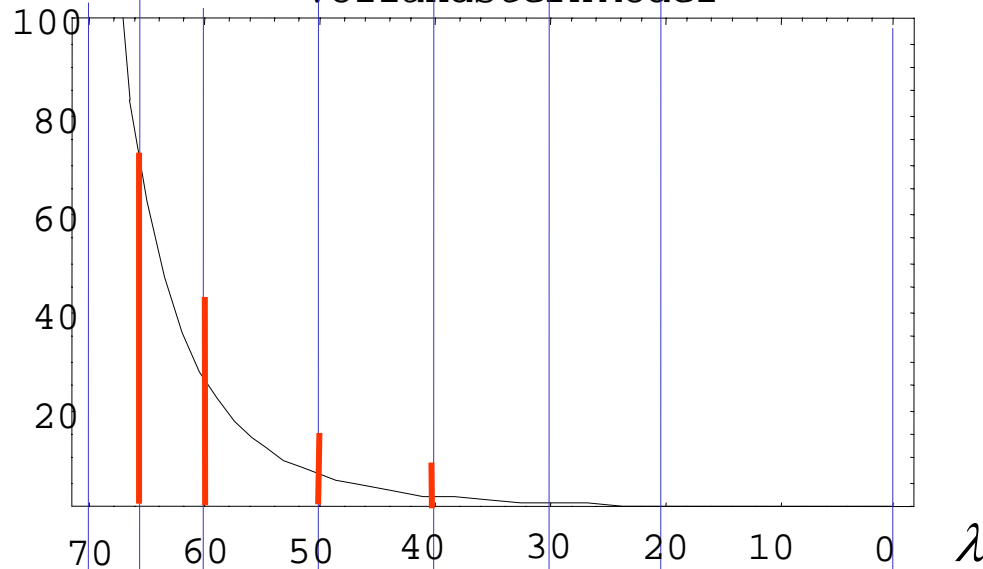
The velocity of the convection decreases with increasing ionospheric conductance and magnetospheric plasma density.

# 電場モデルと実測の比較



# 電場モデルと実測の比較

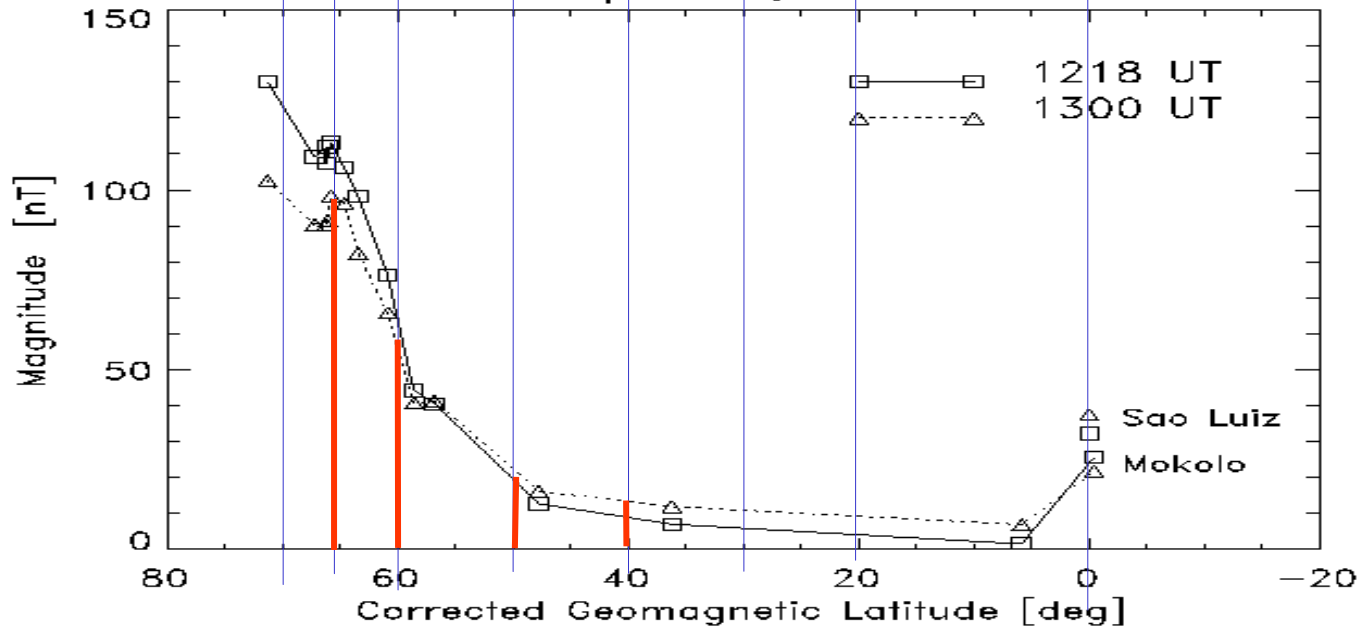
VollandSternModel



$$E_{\phi} = A \cdot \cos^{-5} \lambda \cdot \sin \lambda$$

6MLTの南北電場

April 20, 1993



# 北海道レーダー

- Region-1電流の強度と位置の移動、およびRegion-2電流の発達(時間遅れ)と位置に関する情報を得る。磁気嵐の発達・衰退におけるRegion-1, Region-2電流の役割の理解。
- 電離圏電場を磁力線沿いに投影することで内部磁気圏電場の推定を実現する。一方、磁気圏内の衛星観測により検証が必要。