極域から磁気赤道域を接続する 全球電磁結合系の研究 -ネットワーク観測とモデリング研究の融合-

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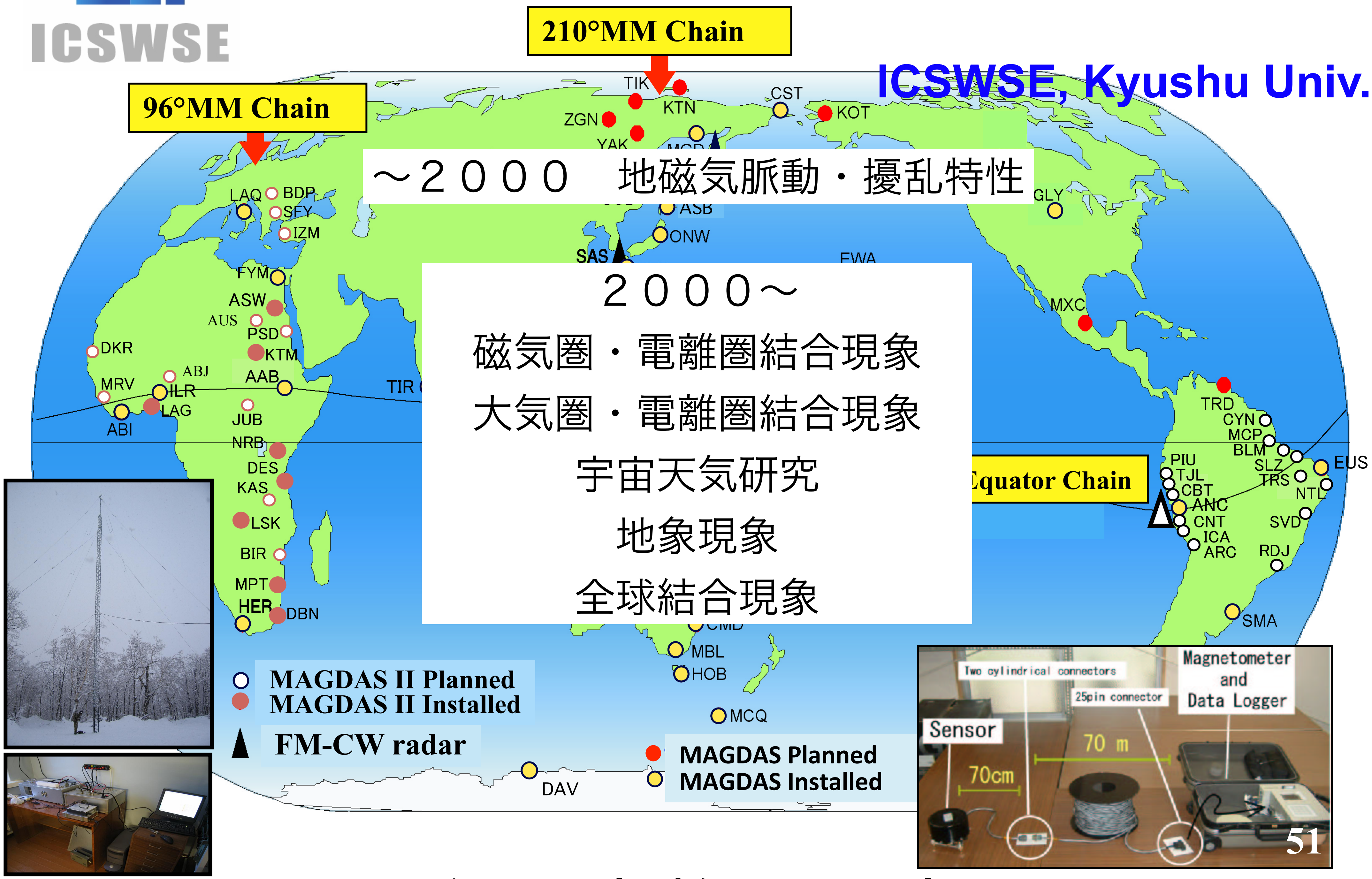
大谷晋一(4)、MAGDAS/CPMNグループ(2)

(1) 九大/EPS, (2)九大/ICSWSE, (3)FMI, (4)APL/JHU,

MAGDAS (MAGnetic Data Acquisition System) Network

ICSWSE, Kyushu Univ.



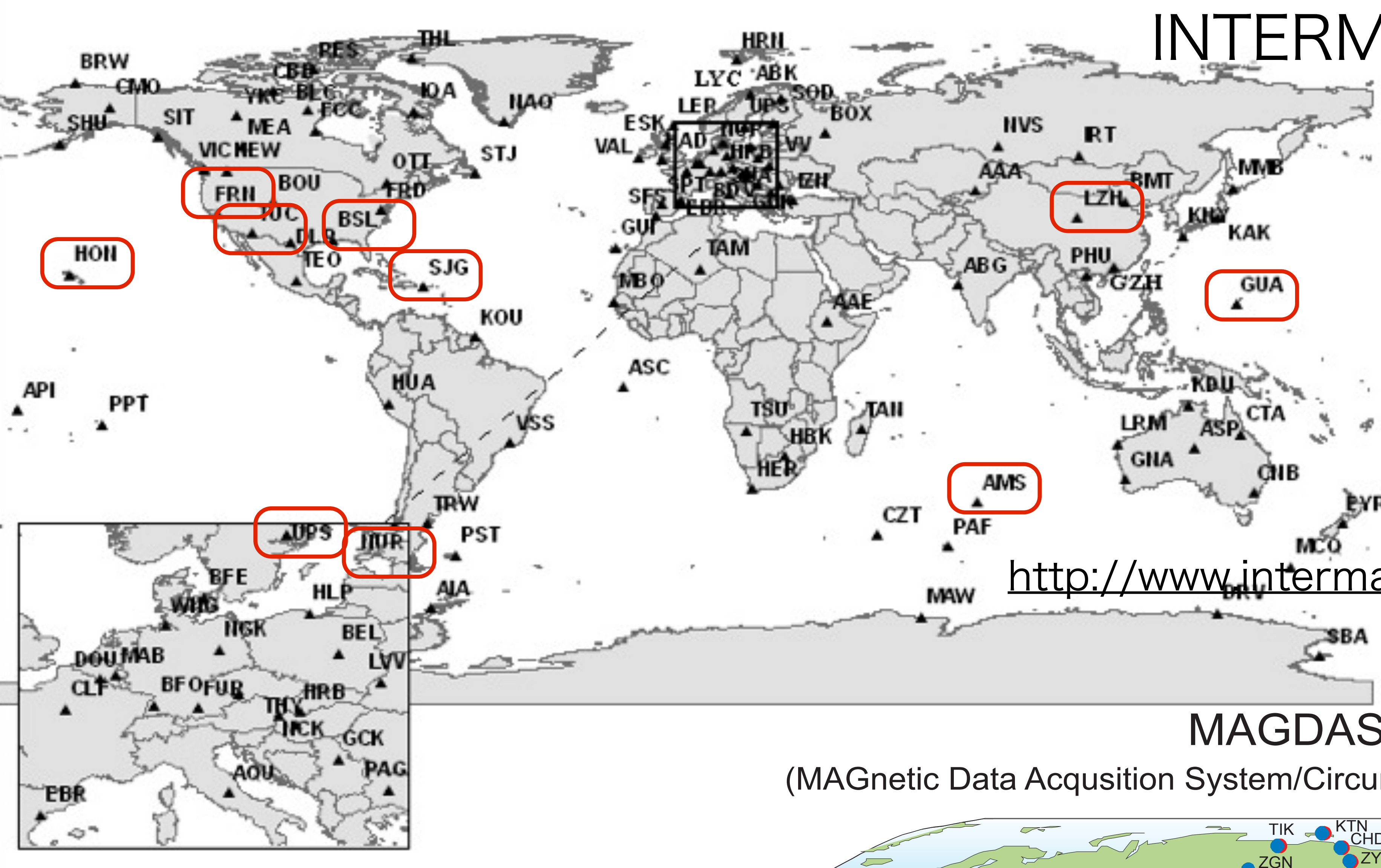
～２０００　地磁気脈動・擾乱特性

２０００～
磁気圏・電離圏結合現象
大気圏・電離圏結合現象
宇宙天気研究
地象現象
全球結合現象

現観測点数：72点

FM-CWネットワーク：CEB, SAS, ANC

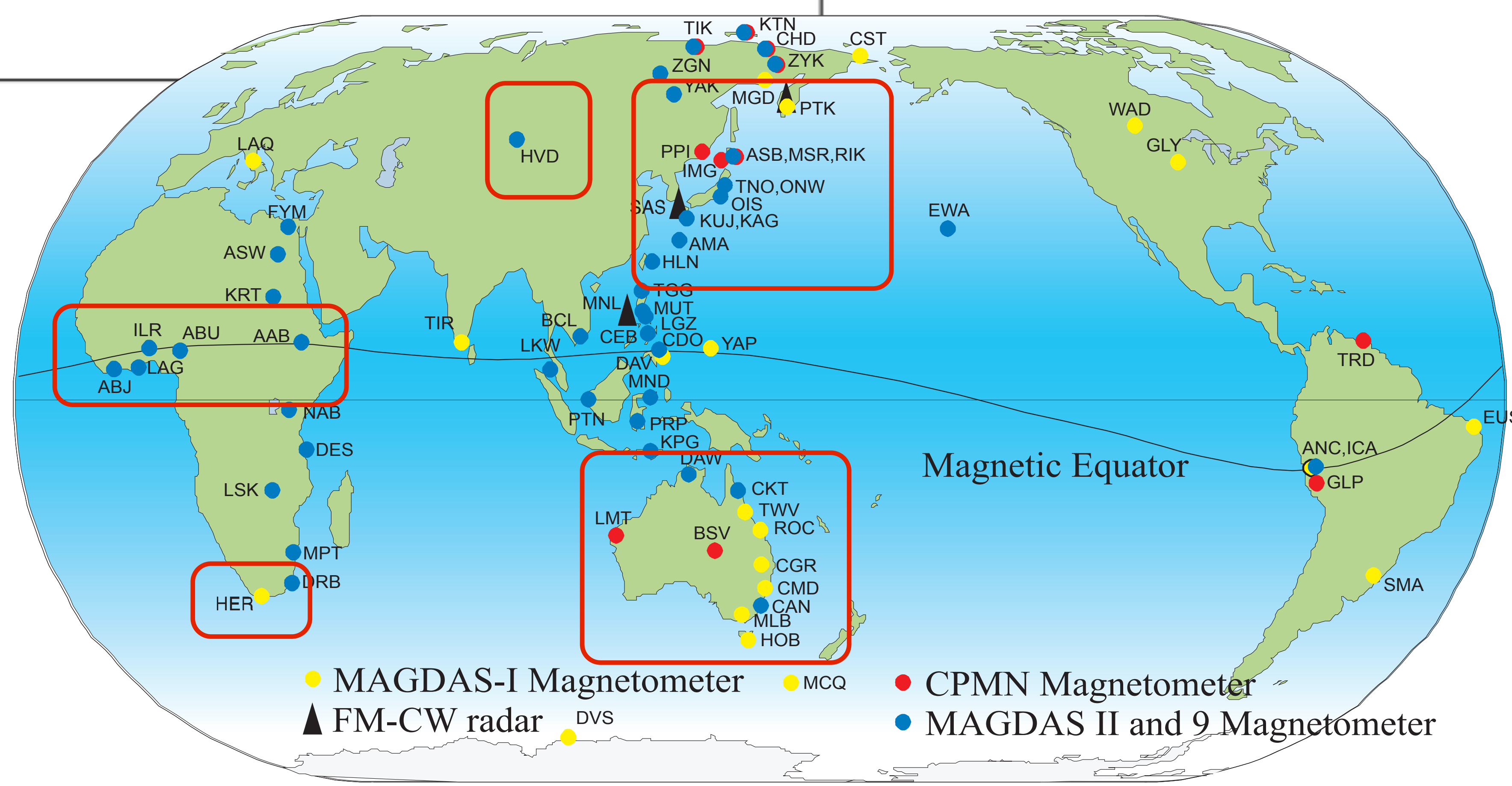
INTERMAGNET



http://www.intermagnet.org/imos/imomap-eng.php

MAGDAS/CPMN

(MAGnetic Data Acqusition System/Circum-pan Pacific Magnetometer Network)

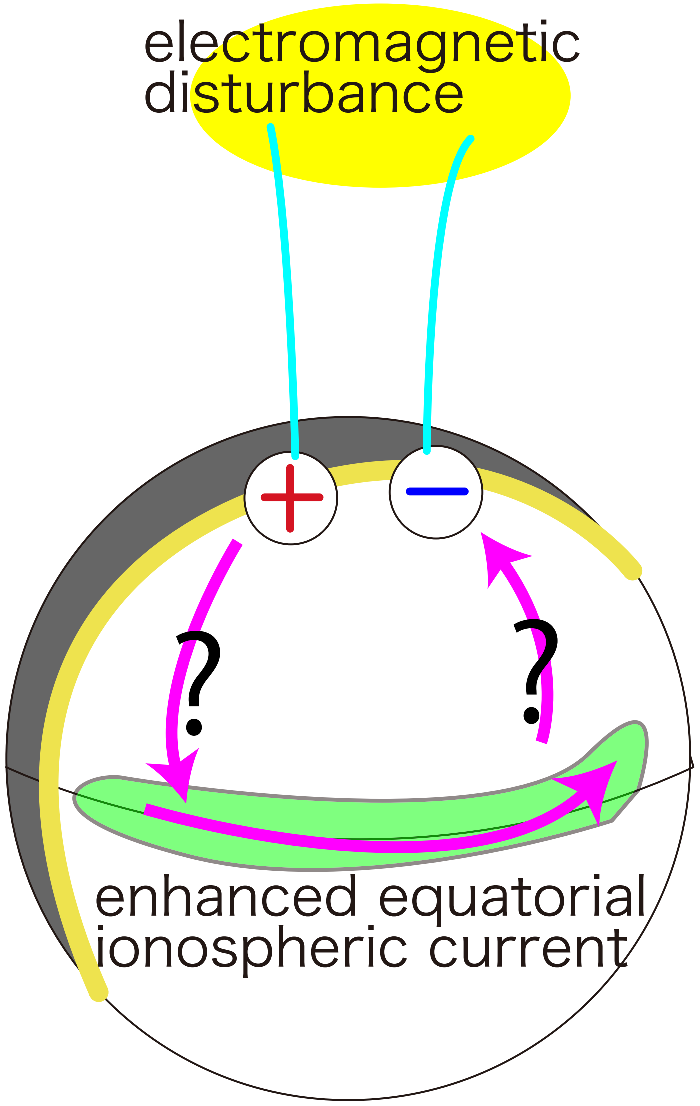


太陽擾乱ー磁気圏ー極域ー磁気赤道域
全球電磁力学結合系

- オーロラジェット電流系(AEJ)と赤道ジェット電流系（EEJ）の結合
  （極域・磁気赤道域で同期する磁場変動, Dp2, Pi2etc., →極域電場侵入の文脈で説明）

- 未解明な電場侵入メカニズムとその経路
  （弱電離気体系に於ける緯度間結合・経度間結合・上下間結合）

- 全球観測と理論・モデリングによる結合チャンネルの解明



Transmission of a polar electric field
[e.g. Kikuchi and Araki, 1979]

Outline

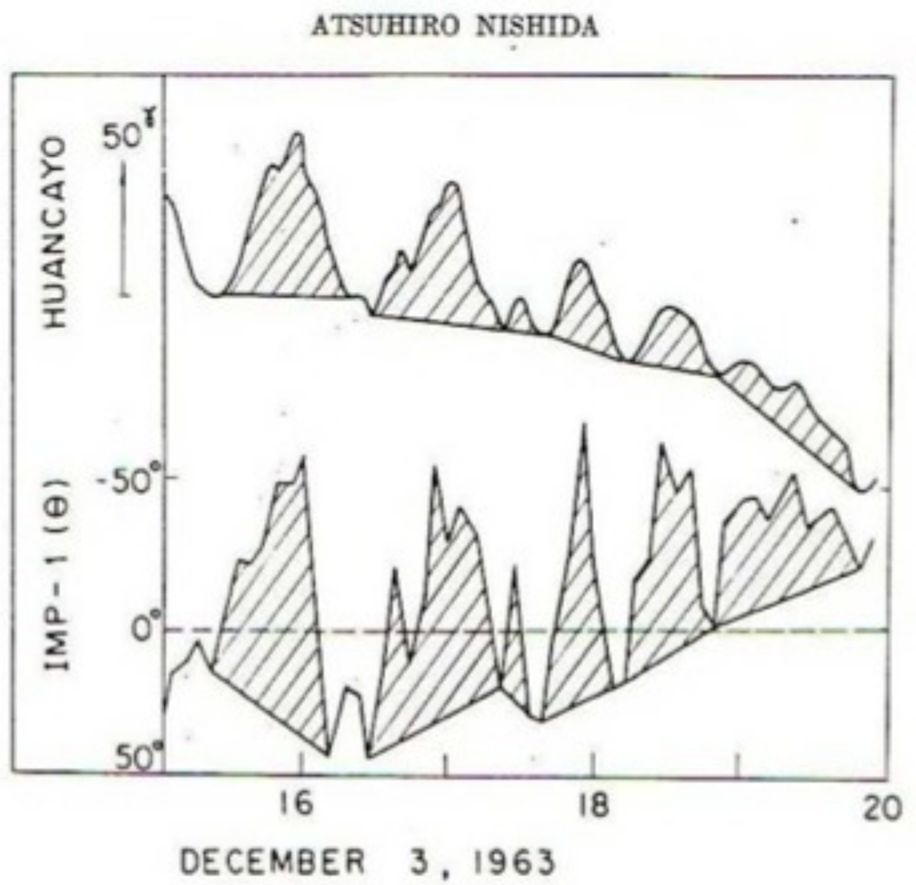
- 赤道Dp2 type 擾乱が示唆する電場の朝夕非対称性侵入 （太陽風ー極域ー昼側電離層電流系）

- 全球結合系記述のための基礎方程式

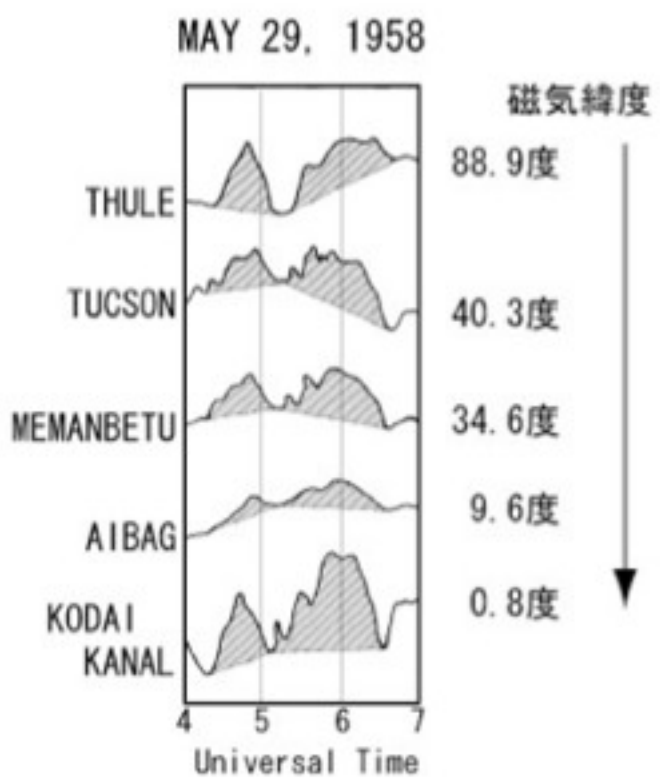
- 極域–磁気赤道域Cowling結合チャンネルの可能性

Dp2 variation (fluctuation of ionospheric convection by IMF change: Nishida, 1968a)

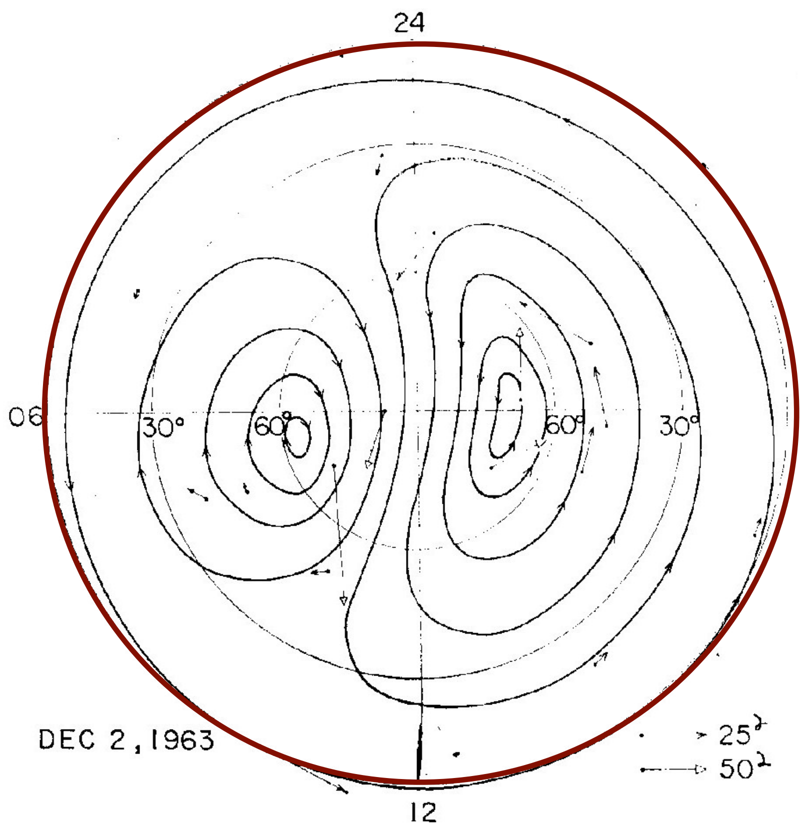
- Good correlation between IMF BZ and ground H-component
- Equatorial enhancement of DP2



Huancayo H and IMF BZ

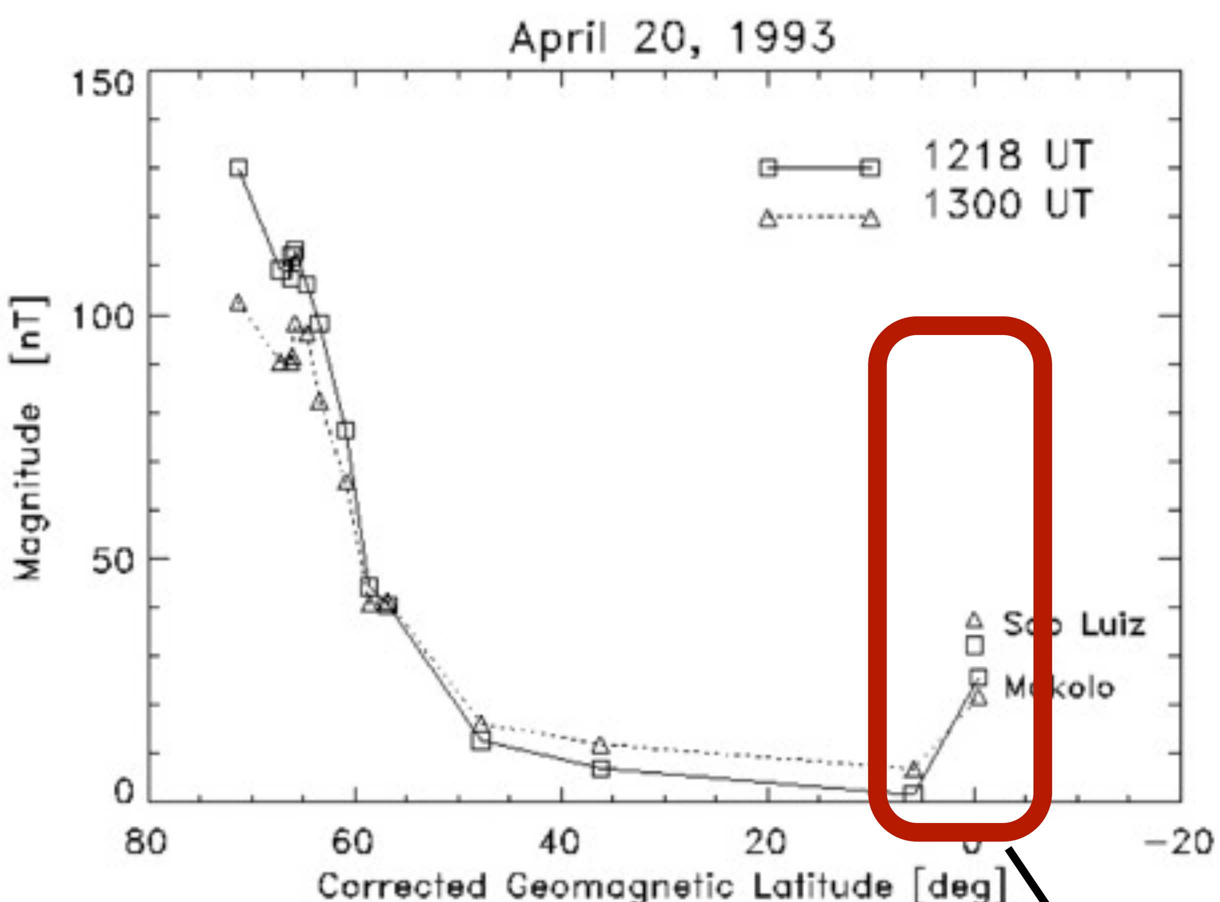


Latitudinal variation of DP2

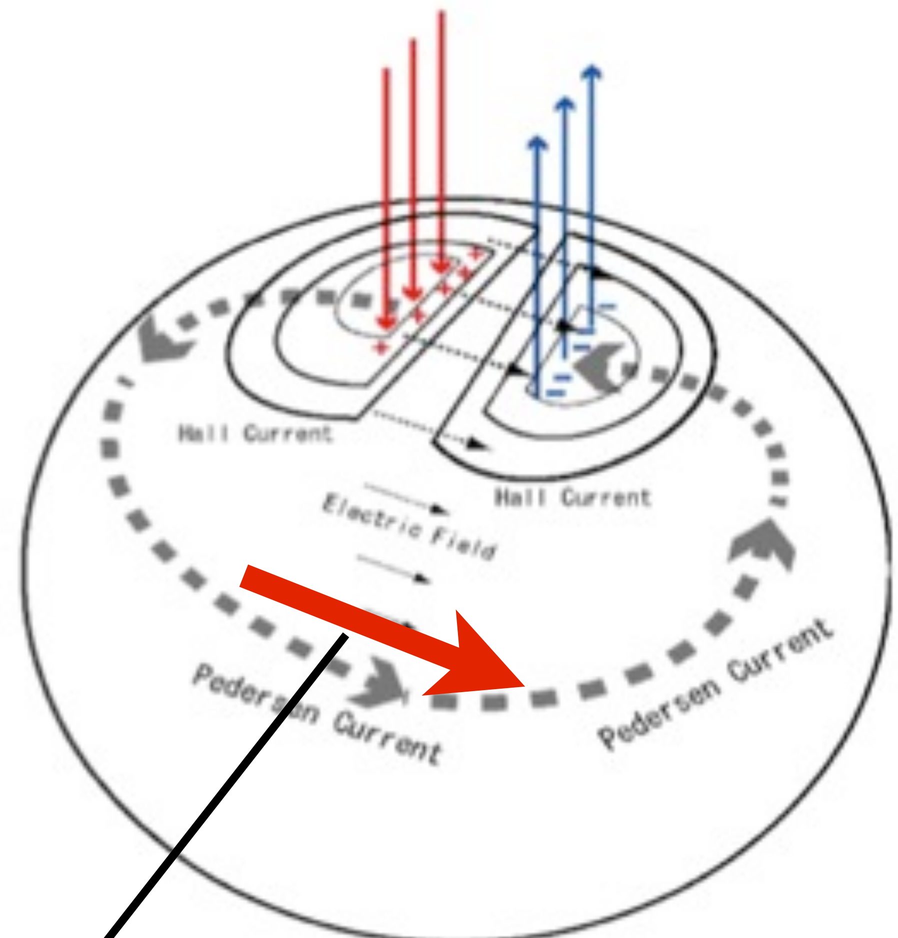


Equivalent current system
(~Hall current ~ convection stream line)

Dp2 type current system?



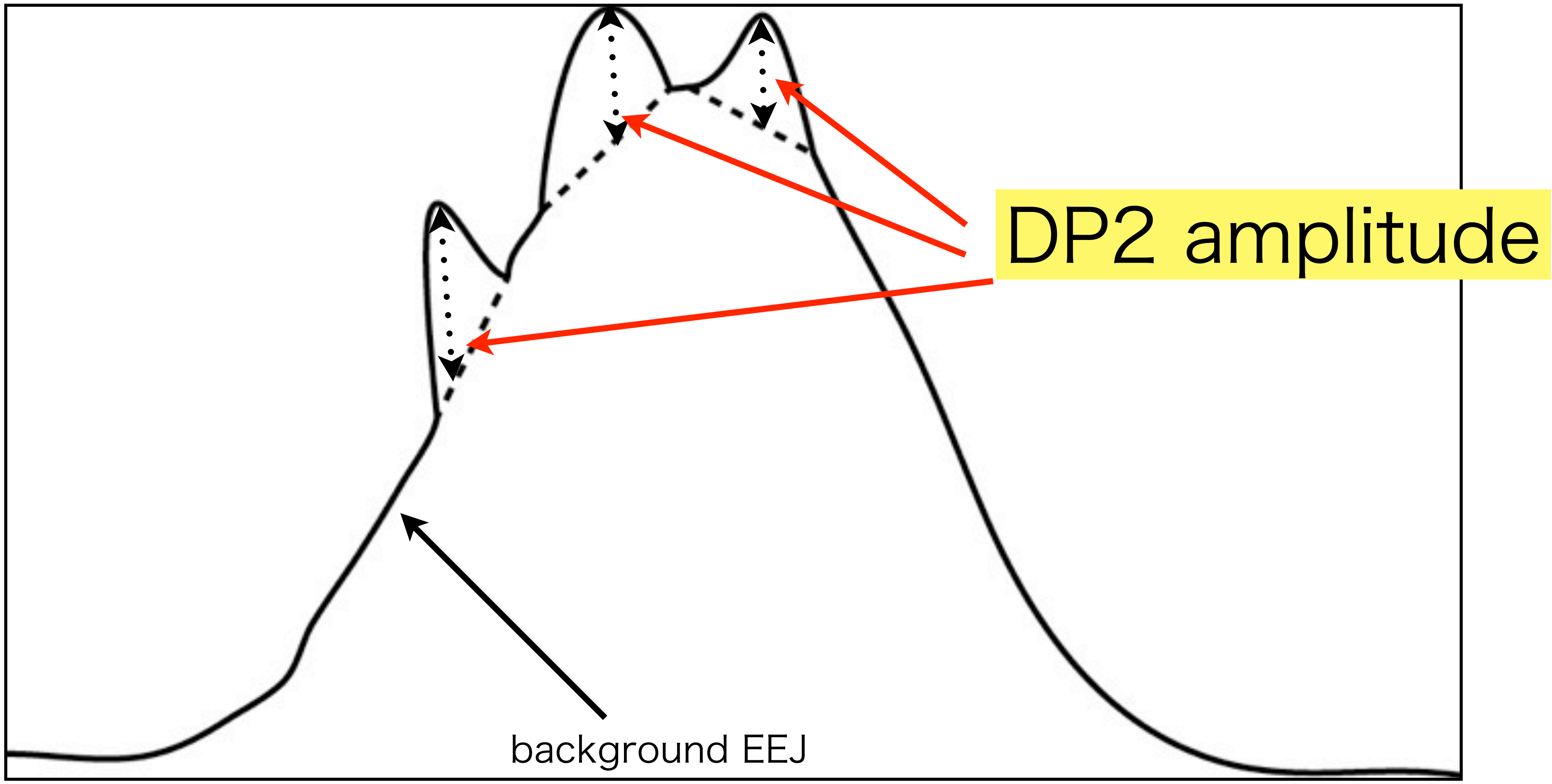
Latitudinal profiles of DP2
[Kikuchi et al., 1996]



Pedersen circuit model
[Kikuchi et al., 1996]

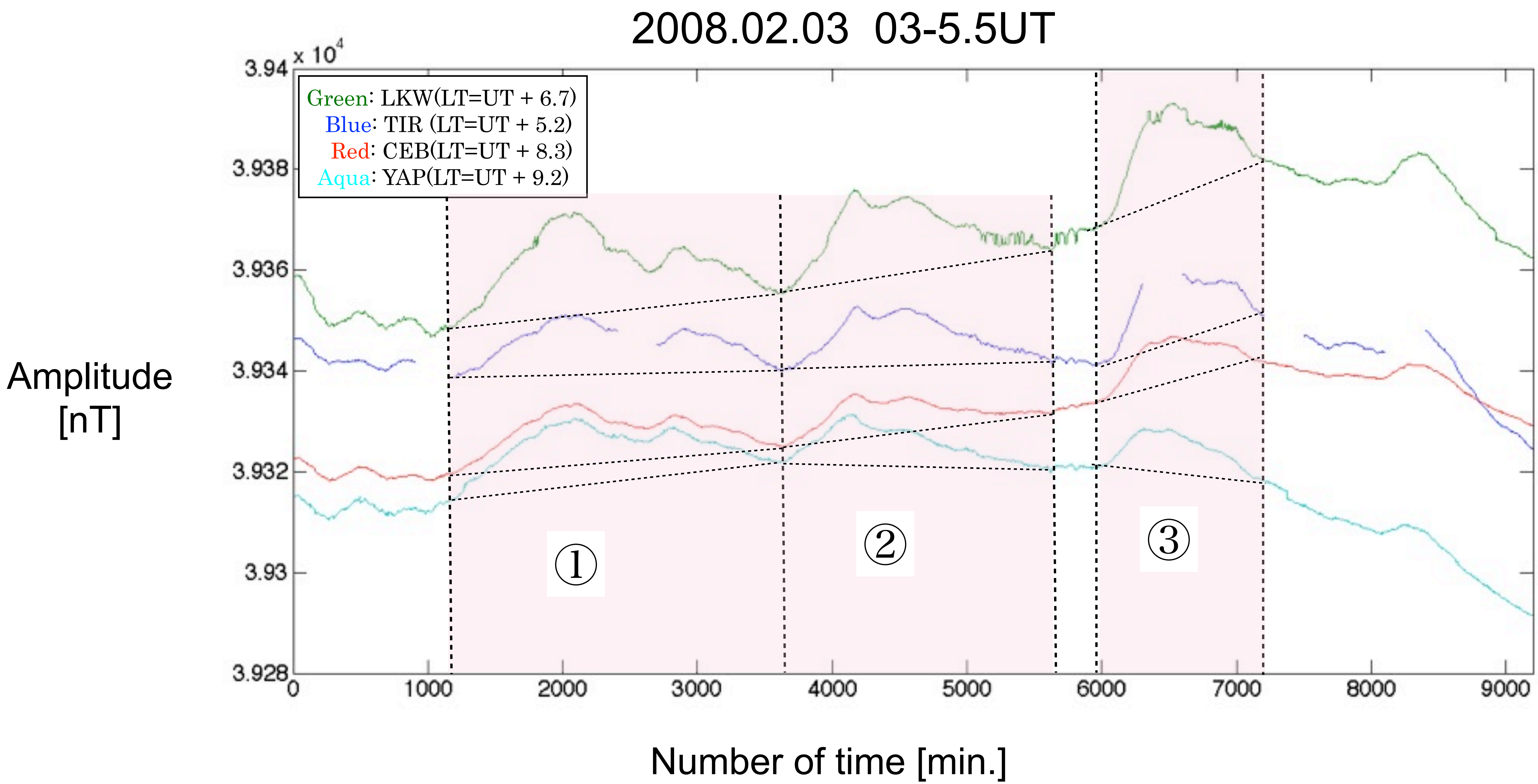
Cowling効果→１次Pedersen電流 + 2次的Hall電流によるジェット効果
→2次的Hall電流のクロージャー（電流供給）はどう説明するのか？

LT distribution of DP2 amplitudes:
Deviation of DP2 component from background EEJ



- Decide starting point and end point of DP2.
- Draw a line from the starting point to the end point
- Measure the value from straight line to peak of DP2

Local time vs DP2 amplitude (case study)

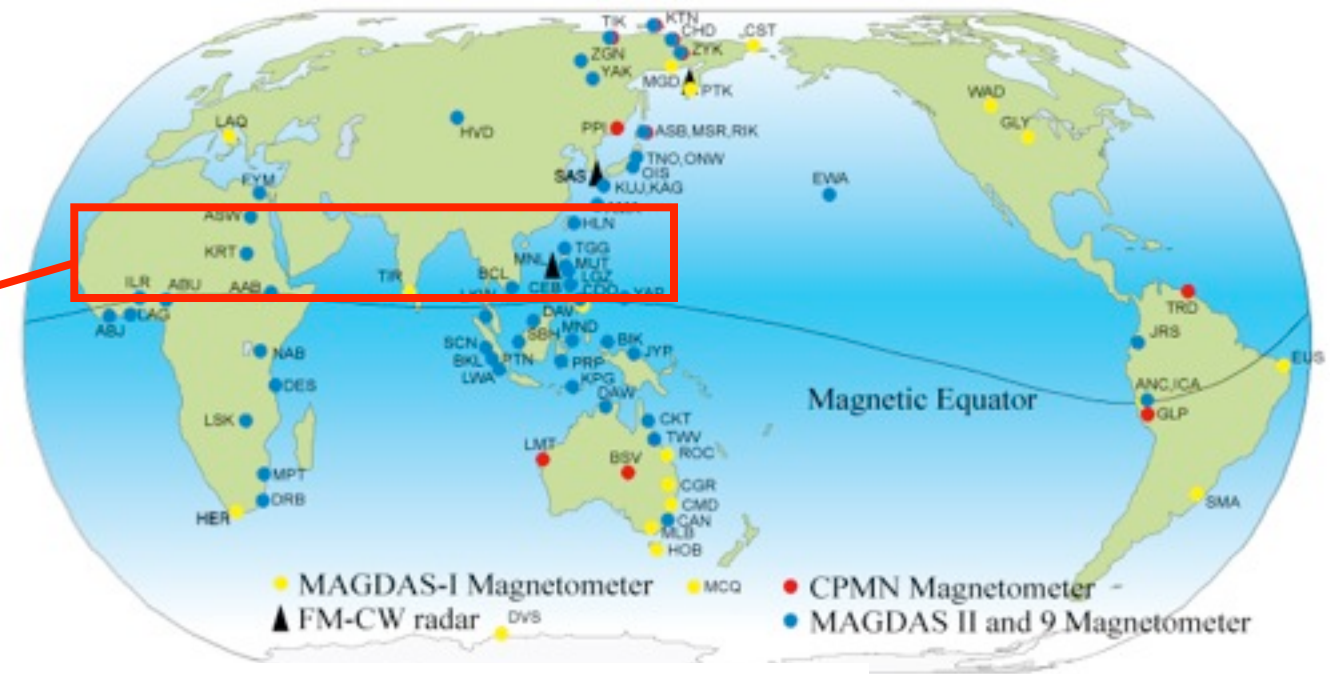


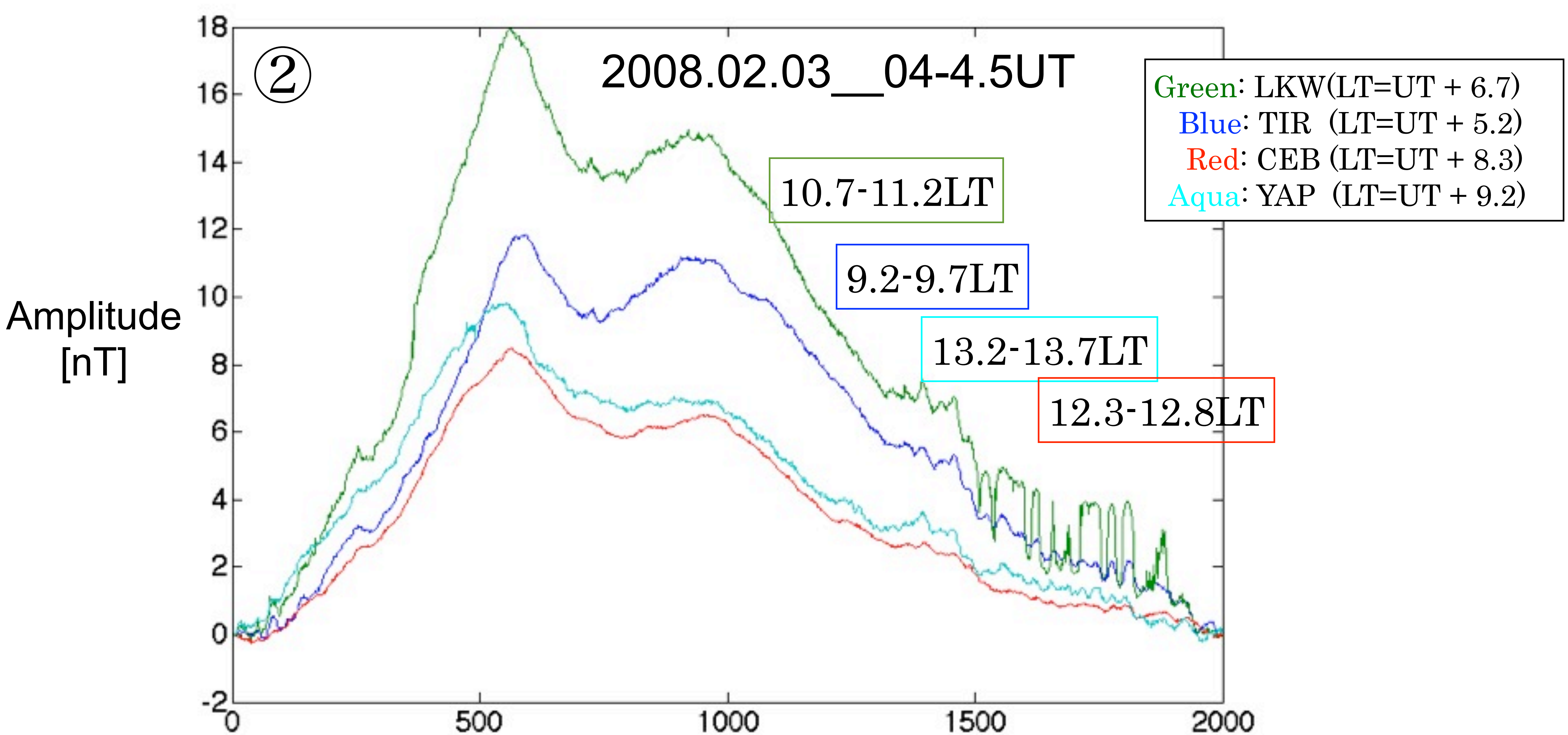
Data set

1. 2008.01.01~2008.12.31
2. Station lists

StationName	GM lat.	GM lon.	LT
ILR	-1.82	76.80	UT+0.3
AAB	0.18	110.47	UT+2.6
TIR	0.21	149.30	UT+5.2
LKW	-2.32	171.29	UT+6.7
CEB	2.53	195.06	UT+8.3
YAP	1.49	209.06	UT+9.2

MAGDAS/CPMN
(MAGnetic Data Acquisition System/Circum-pan Pacific Magnetometer Network)

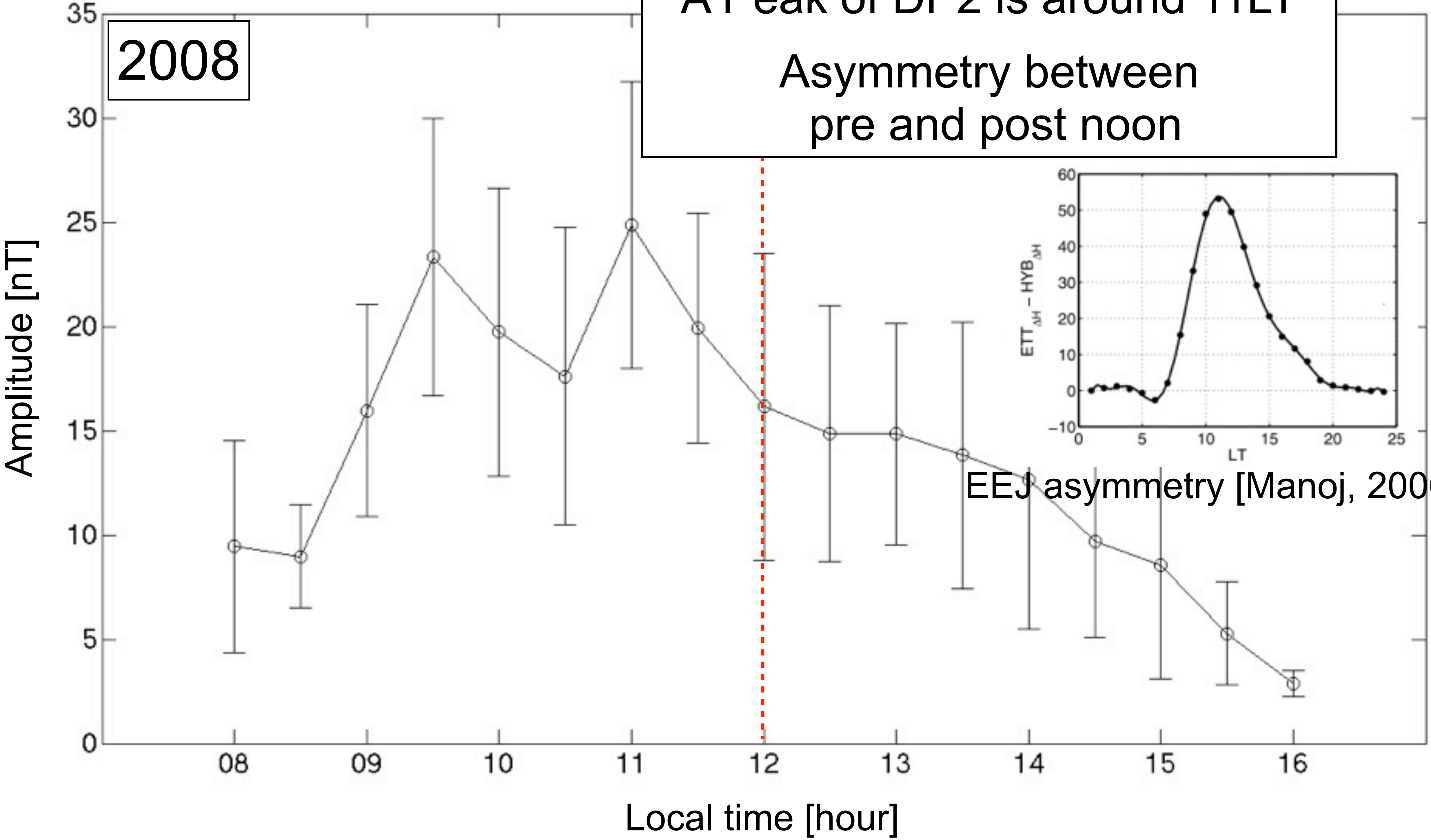




LT-distribution of DP2 amplitude (statistic

A Peak of DP2 is around 11LT

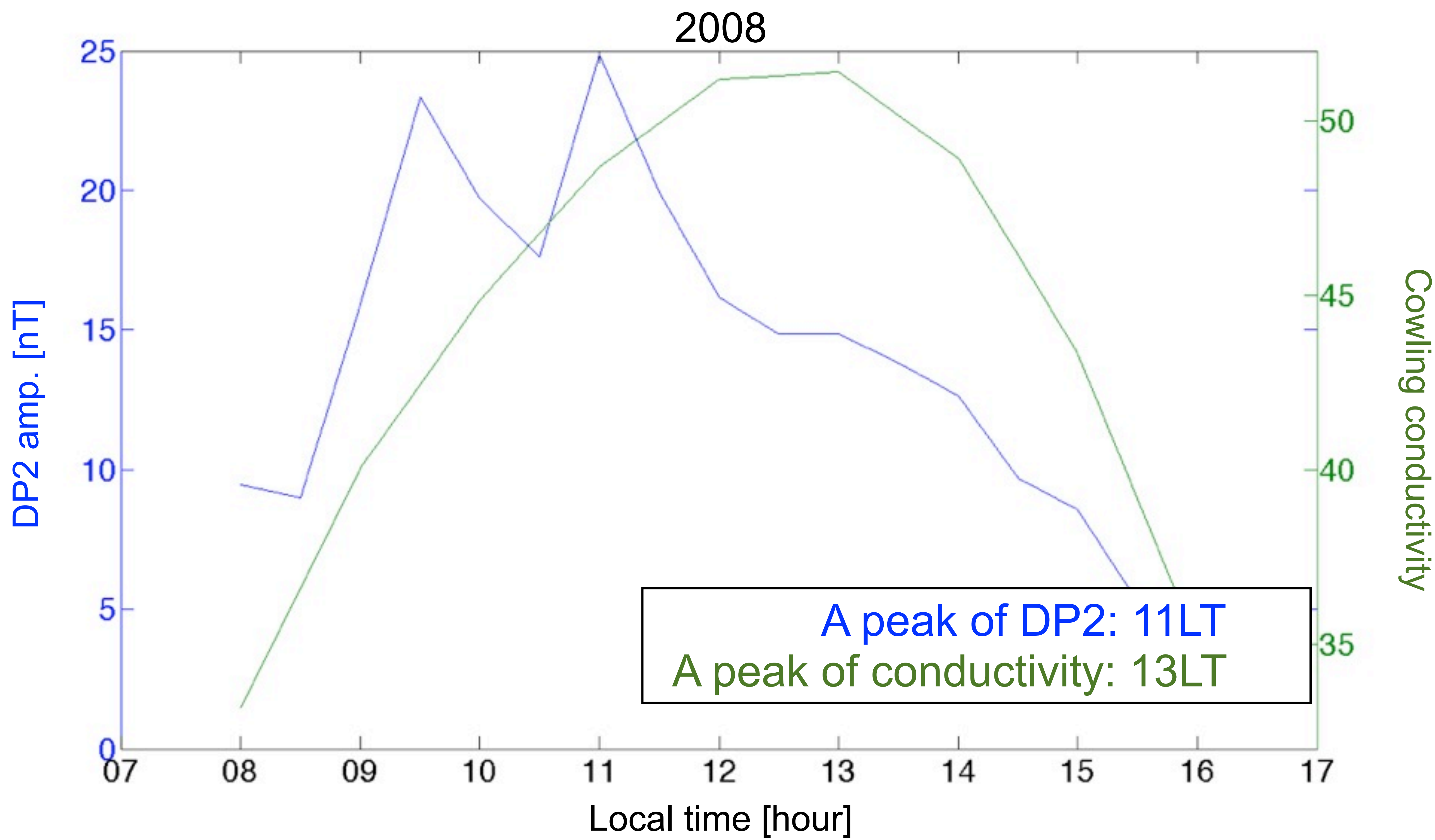
Asymmetry between pre and post noon



EEJ asymmetry [Manoj, 2006]

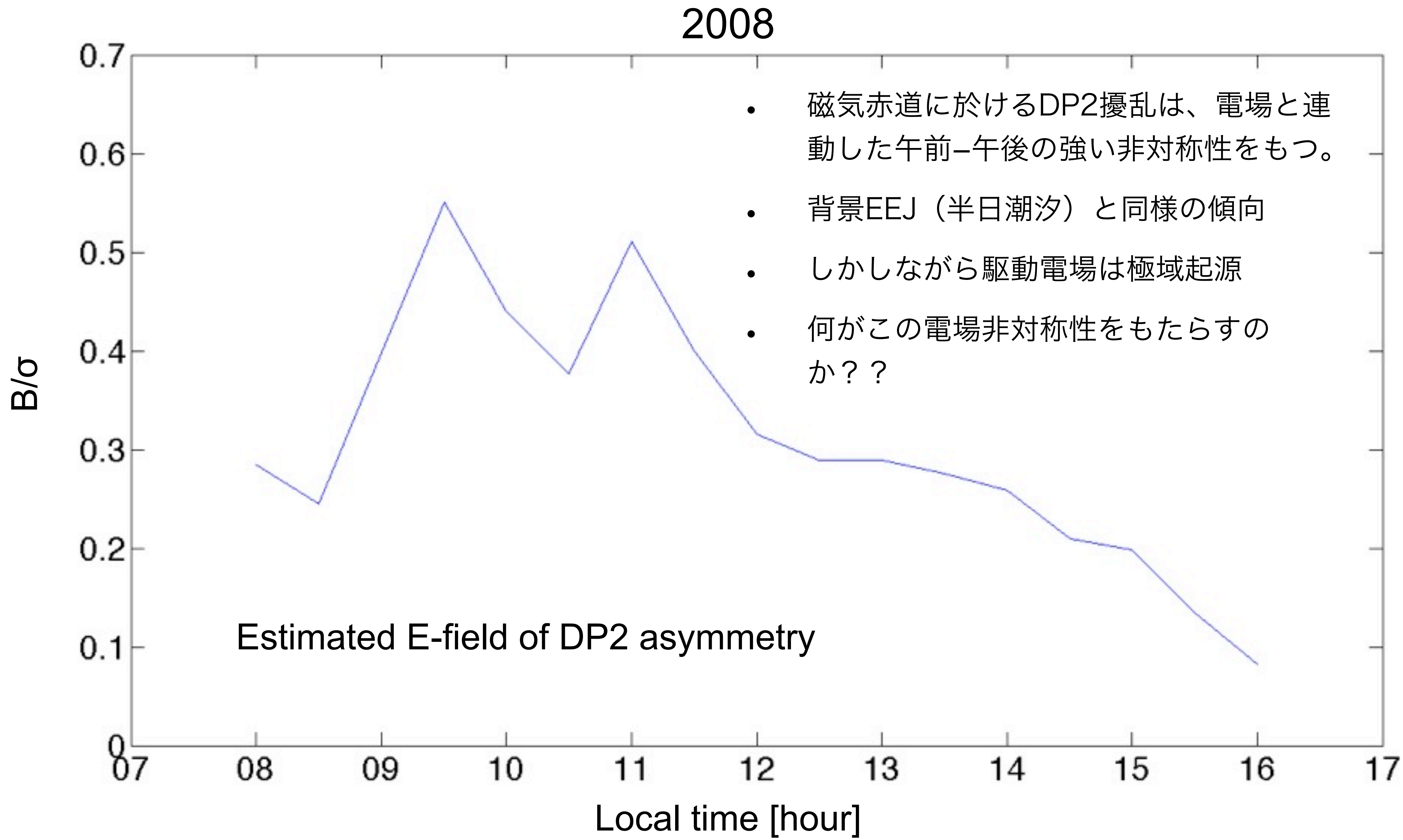
Amplitude of H-component DP2 at equator

Comparison with **B** and **σ**



→ This difference peak between DP2 and Con. indicates that electric field produces DP2 peak at morning side

E calculated from **B** and **σ**



- 磁気赤道に於けるDP2擾乱は、電場と連動した午前–午後の強い非対称性をもつ。
- 背景EEJ（半日潮汐）と同様の傾向
- しかしながら駆動電場は極域起源
- 何がこの電場非対称性をもたらすのか？？

3 D multi-fluid Ohm's law

電離層電流の時間発展

起電力

Hall 電場

$$\frac{\partial}{\partial t}\mathbf{j} = \varepsilon_0 \omega_{pe}^2 \left\{ \mathbf{E} + \overrightarrow{emf} - \left(\frac{B}{ne}\right)\left(\frac{\nu_{en}+\nu_{ei}}{\Omega_e}\right)\mathbf{j} - \left(\frac{B}{ne}\right)\left(\mathbf{j}\times\hat{\mathbf{b}}\right) \right\}$$

電場

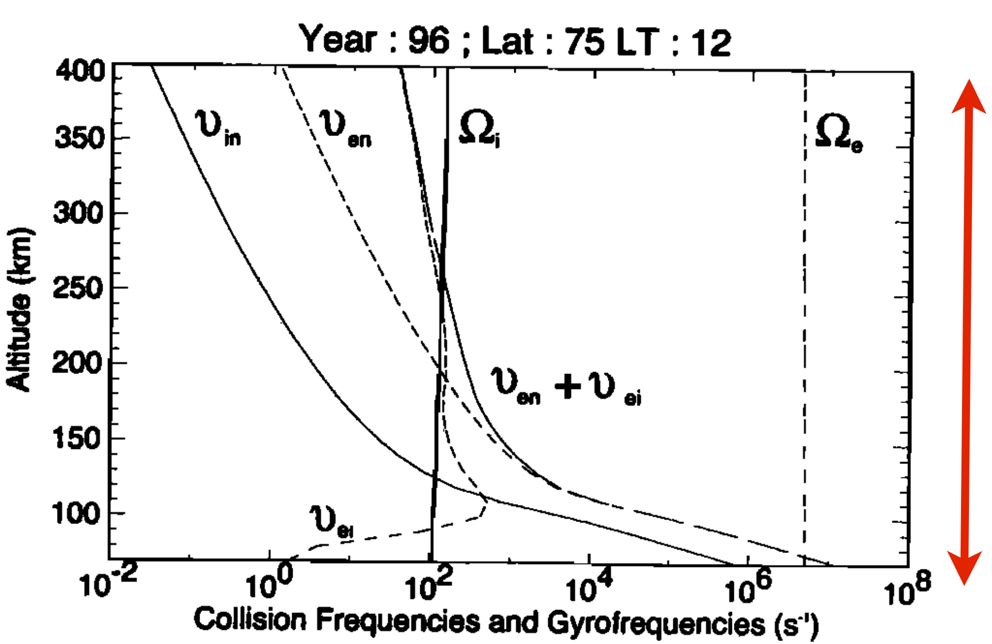
衝突による電圧降下

荷電粒子–中性大気の運動量交換

$$\overrightarrow{emf} = \mathbf{V}\times\mathbf{B} + \frac{B\left(\nu_{in}-\nu_{en}\right)}{\Omega_e}\left(\mathbf{V}-\mathbf{v}_n\right) - \frac{\nabla p_e}{ne}$$

電磁対流電場

電子圧力勾配



電磁流体・中性流体の力学によって決定される起電力

IUGONET 結合

Ohm's law

$$\frac{\partial}{\partial t}\mathbf{j} = \varepsilon_0 \omega_{pe}^2 \left\{ \mathbf{E} + \overrightarrow{emf} - \left(\frac{B}{ne}\right)\left[\left(\frac{\nu_{en}+\nu_{ei}}{\Omega_e}\right)\mathbf{j} + \mathbf{j}\times\hat{\mathbf{b}}\right]\right\}$$

$$\overrightarrow{emf} = \mathbf{V}\times\mathbf{B} + \frac{B(\nu_{in}-\nu_{en})}{\Omega_e}(\mathbf{V}-\mathbf{v}_n) - \frac{\nabla p_e}{ne}$$

Maxwell eq

$$\mu_0 \frac{\partial}{\partial t}\mathbf{j} = -\varepsilon_0\mu_0 \frac{\partial^2}{\partial t^2}\mathbf{E} + \nabla\times(\nabla\times\mathbf{E})$$

radiation of EM-field by electromotive force

$$\lambda_e^2 \equiv \left(\frac{m_e c^2}{ne^2}\right)$$

electron inertial length

$$-\lambda_e^2 \nabla\times(\nabla\times\mathbf{E}) - \omega_{pe}^2 \frac{\partial^2}{\partial t^2}\mathbf{E} = \left(\mathbf{E} + \overrightarrow{emf} - \overleftrightarrow{\sigma}^{-1}\mathbf{j}\right)$$

in a time scale $\gg \omega_{pe}^{-1}$

in a spatial scale $\gg \lambda_e$

$$\mathbf{j} = \overleftrightarrow{\sigma}\left(\mathbf{E} + \overrightarrow{emf}\right)$$

Current closure

$$\nabla\cdot\mathbf{j} = 0$$

$$\frac{\nabla\times\mathbf{E}_T}{\nabla\cdot\mathbf{E}_L} \sim \frac{E_T}{E_L} \sim \left(\frac{l}{t}\frac{\delta b}{\delta E_L}\right) \sim \left(\frac{10^7[m]}{10^3[s]}\frac{10^{-8}[T]}{10^{-2}[V\cdot m^{-1}]}\right) \sim 100$$

$l \sim 10000[km]$ $\quad \delta b \sim 10[nT]$

$t \sim 1000[\mathrm{sec}]$ $\quad \delta E \sim 10[mV]$

Quasi-steady state

$$\mathbf{E} = -\nabla\Phi$$

$$\nabla_\perp\cdot\mathbf{E} = -\nabla_\perp\cdot\overrightarrow{emf} - \frac{j_{//}}{\Sigma_P} + \frac{\left(\nabla_\perp\Sigma_P - \hat{\mathbf{b}}\times\nabla_\perp\Sigma_H\right)\cdot\left(\mathbf{E}+\overrightarrow{emf}\right)}{\Sigma_P}$$

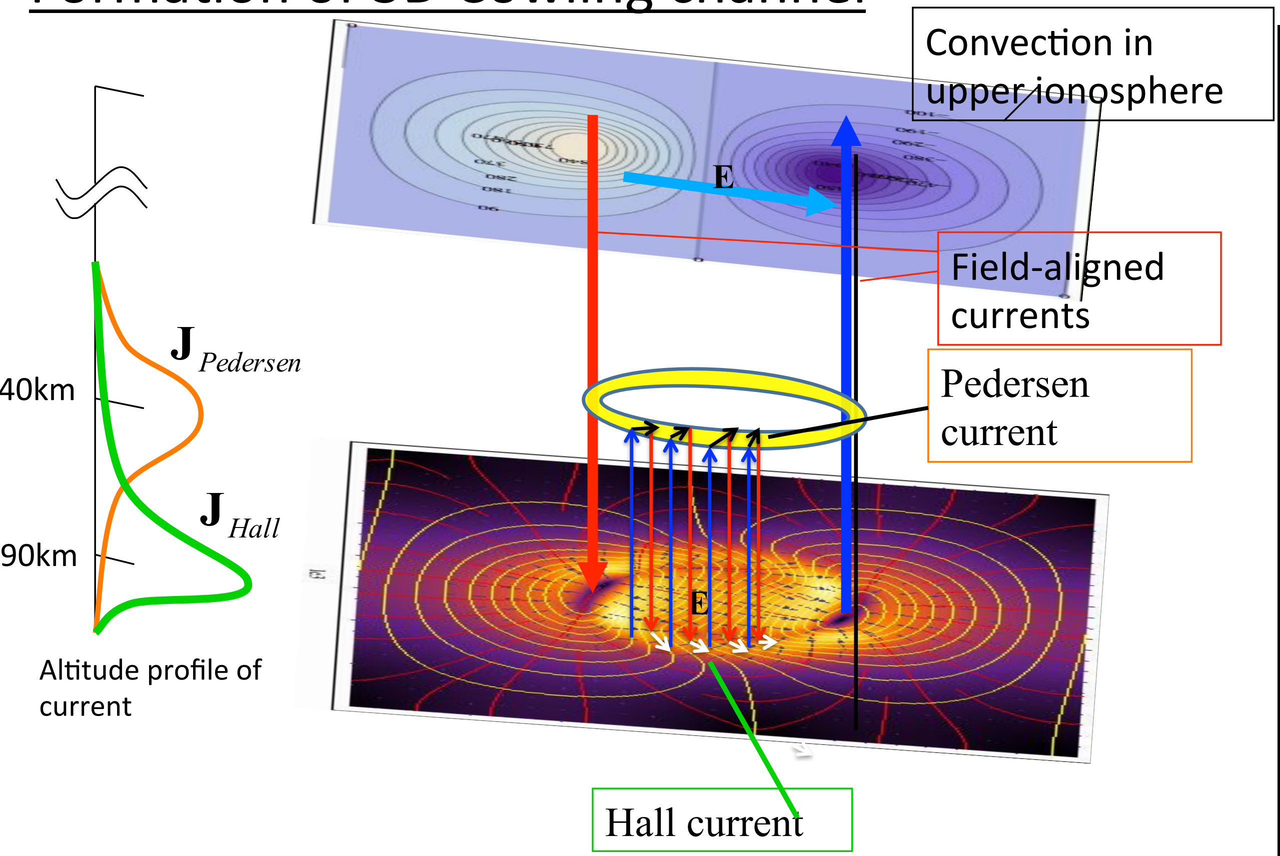
分極電場の重要性

基本場 $\mathbf{E}_0 + \overrightarrow{emf}$ $\quad \nabla_\perp \cdot \left(\mathbf{E}_0 + \overrightarrow{emf}\right) = -\frac{j_{//}^{(emf)} + \cancel{j_{//}^{(0)}}}{\Sigma_P}$

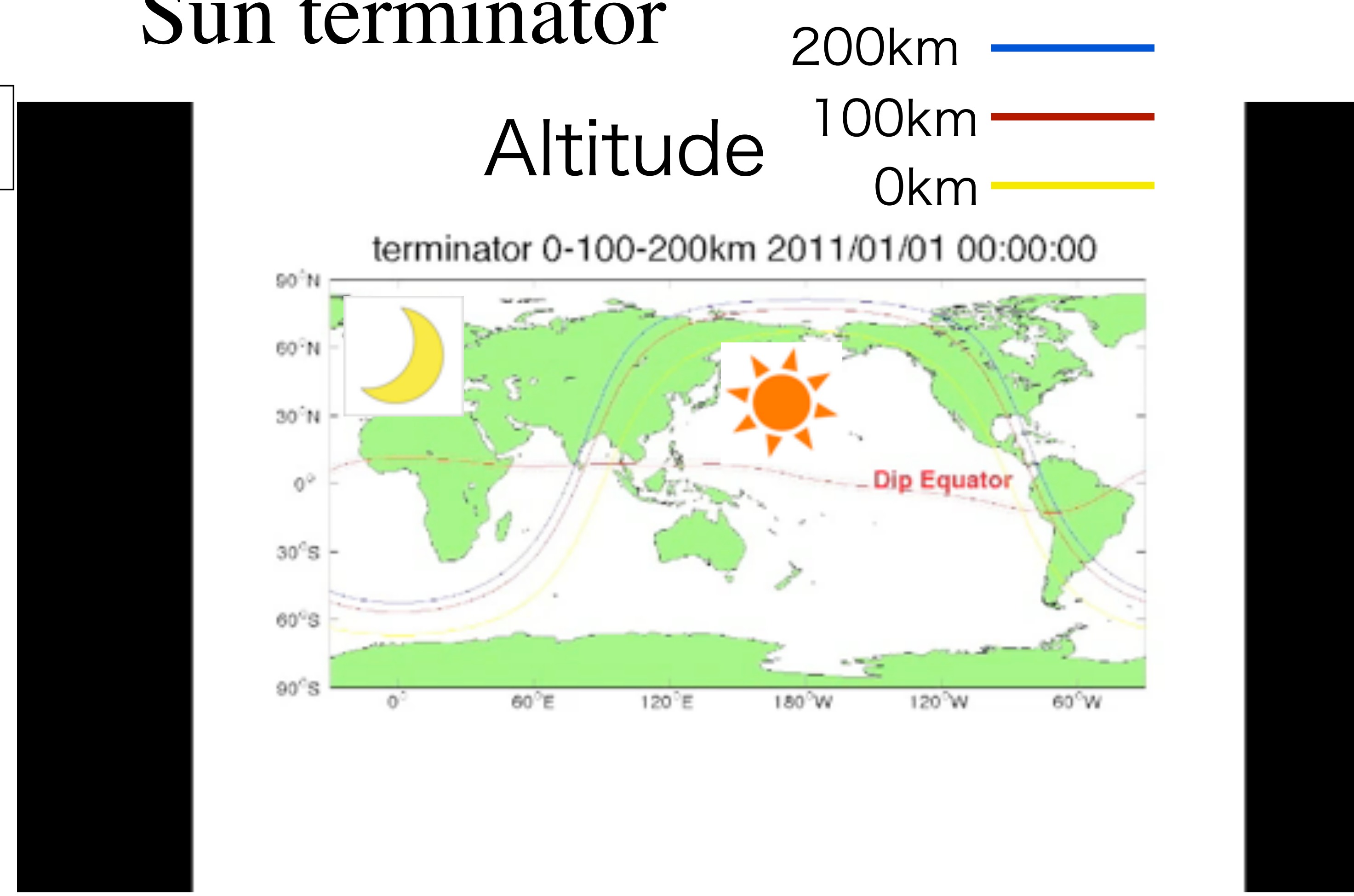
分極場 $\mathbf{E}^{(pol)}$ $\quad \nabla_\perp \cdot \mathbf{E}^{(pol)} = \frac{\left(\nabla_\perp \Sigma_P - \hat{\mathbf{b}} \times \nabla_\perp \Sigma_H\right)\cdot\left(\mathbf{E} + \overrightarrow{emf}\right)}{\Sigma_P} - \frac{\cancel{j_{//}^{(pol)}}}{\Sigma_P}$

Auroral oval

Formation of 3D Cowling channel



Sun terminator



Numerically investigate, how the dawn-dusk conductivity terminator and dip-equator modify the Dp2 current system

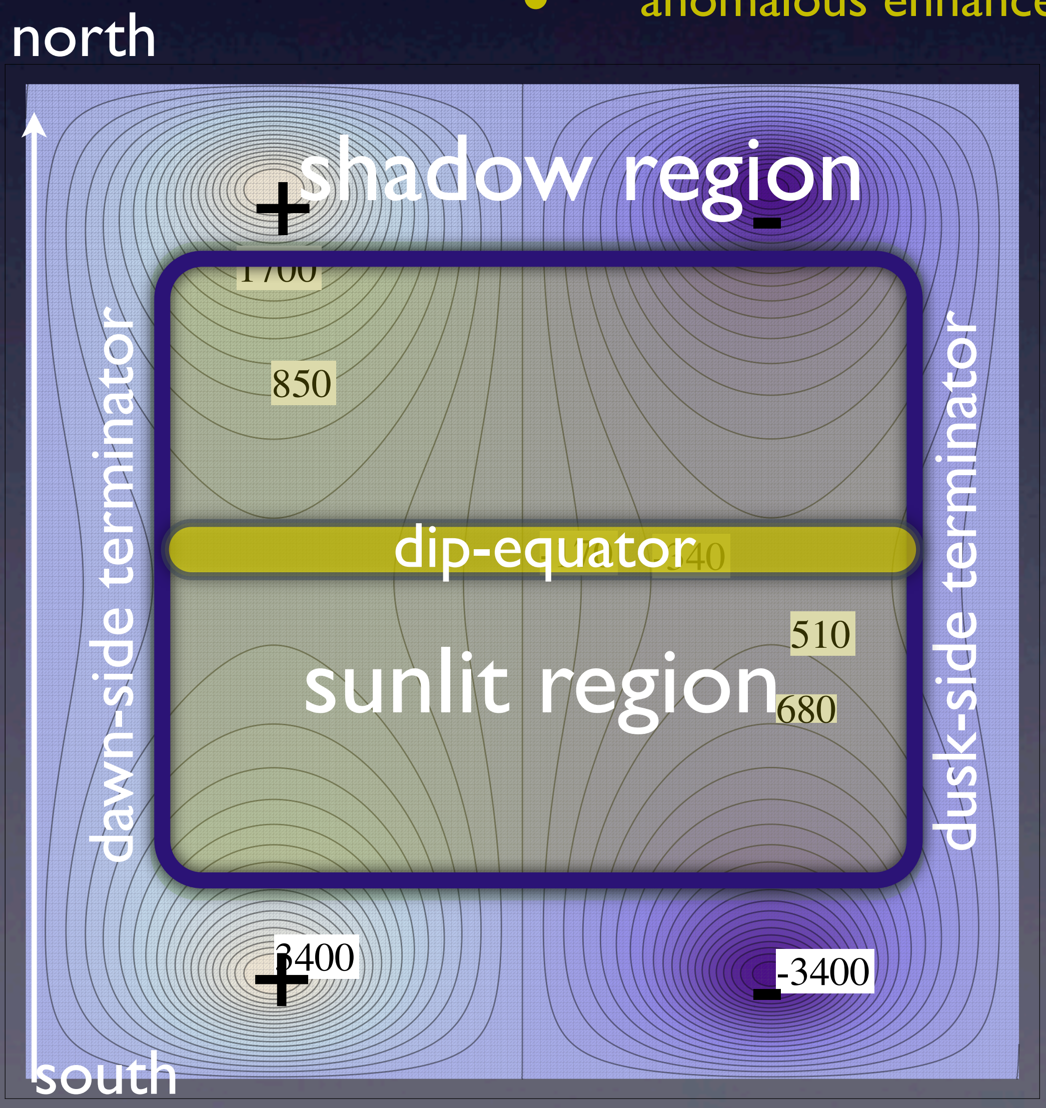
- R1-type FAC located in the night-region
- no R2-FAC
- vertical geomagnetic field
- neglect geometrical effect
- auroral conductance
- day-side and night side regions are divided by the terminator (sharp conductivity gradient) region
- anomalous enhancement of zonal conductivity along the dip-equator

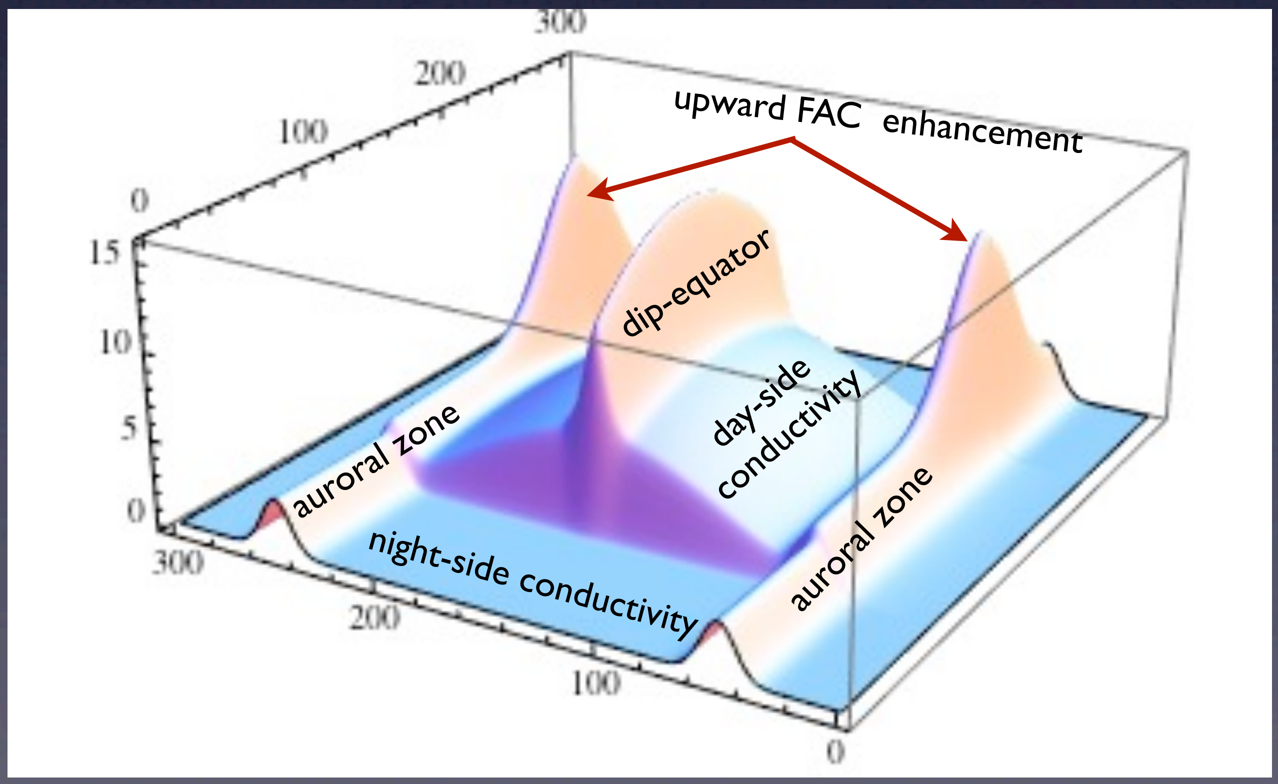
$$\nabla_\perp \cdot \left(\overleftrightarrow{\Sigma} \nabla_\perp \Phi \right) = j_{//}^{(0)}$$

input conductance

calculated potential

input FAC





?

How to approach to this problem?

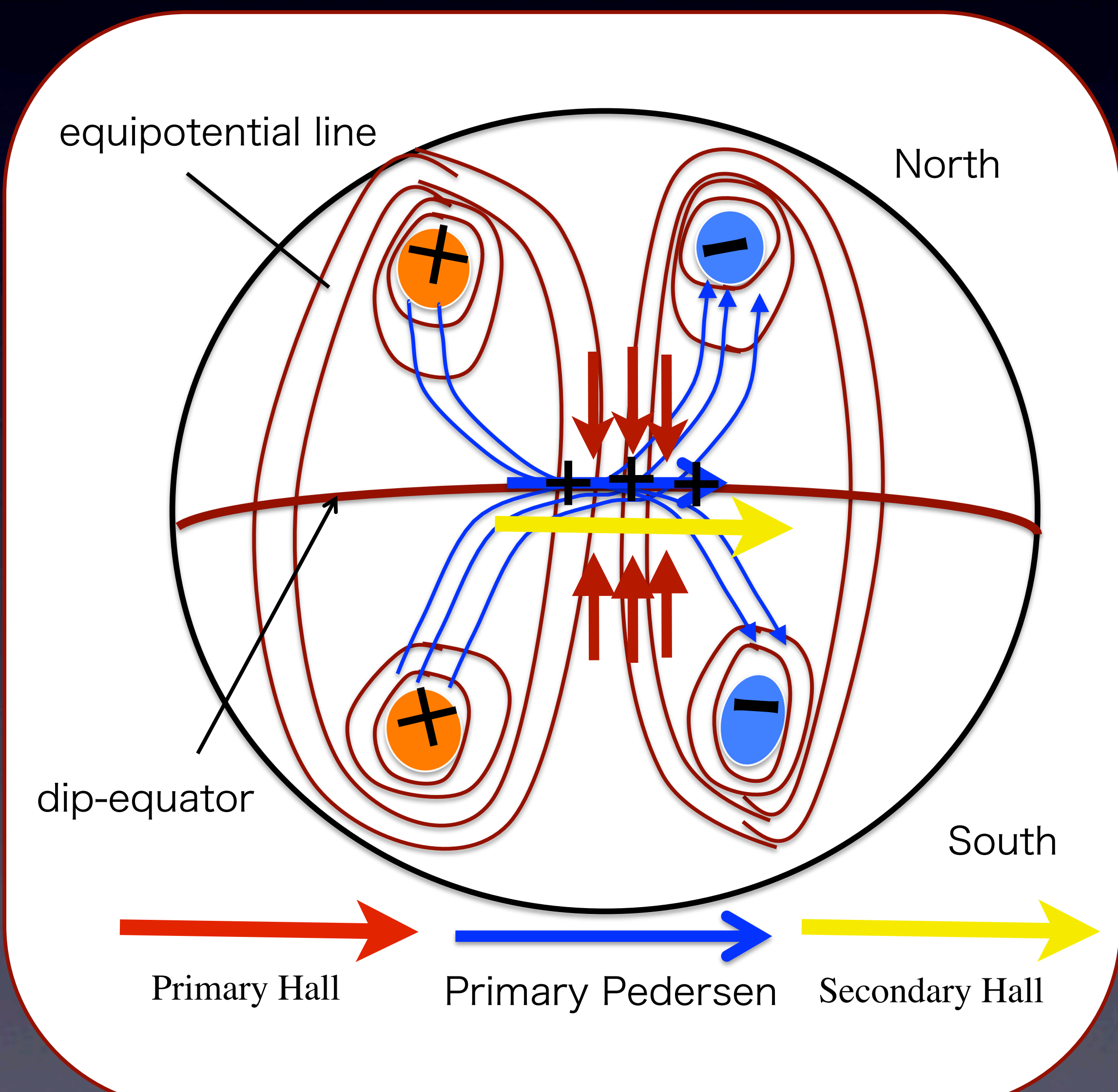
distribution of electric field is determined by

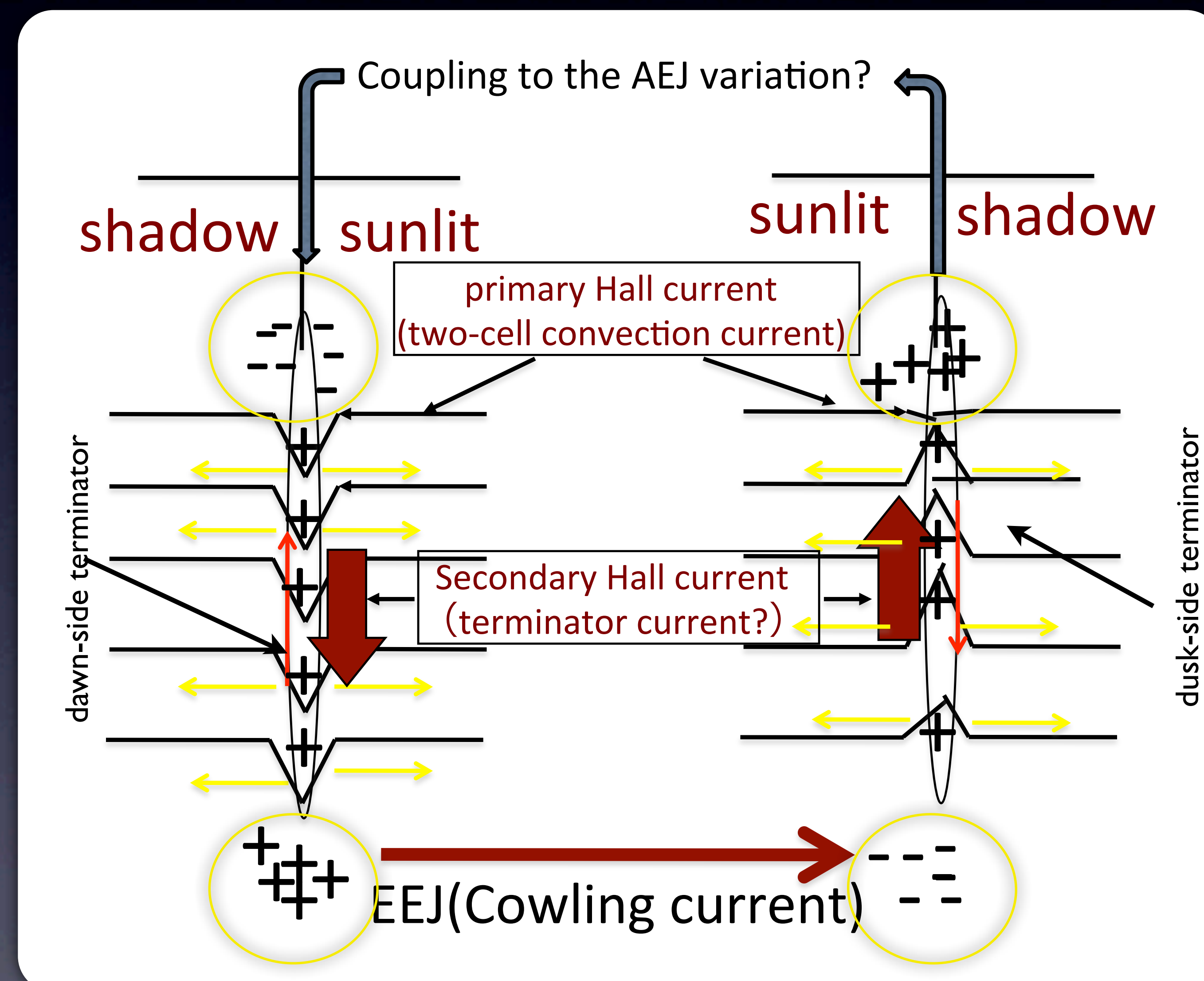
- distribution of potential source

→ consider two-cell type convection accompanied by the R1-current system

- polarization field at the conductivity edge

→ consider polarization effect at dawn-dusk conductivity terminator and dip-equator





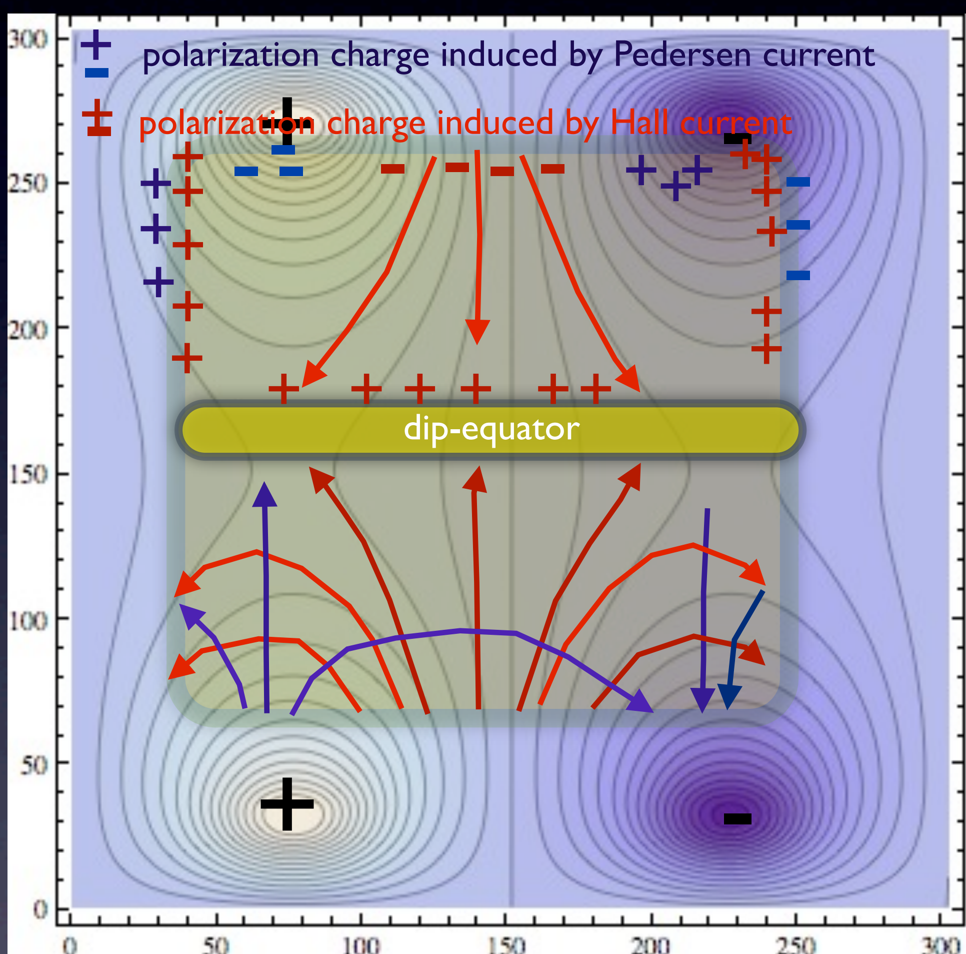
・ if equipotential-lines of convection cell can cross the magnetic dip equator, as they surround the dawn side and dusk side convection shell, a resultant eastward electric field drives the downward Hall current

・global Hall current flows from polar to equatorial region induces positive polarization charge at the bottom dip-equator and upward polarization fields ehhances the EEJ by the Cowling effect

・Hall current flow along the convection cell produces the polarization charge at the dawn-dusk terminator, and this polarization field generates the secondary Hall current along the terminator, which possibly produces accumulated charge at the dip-equator

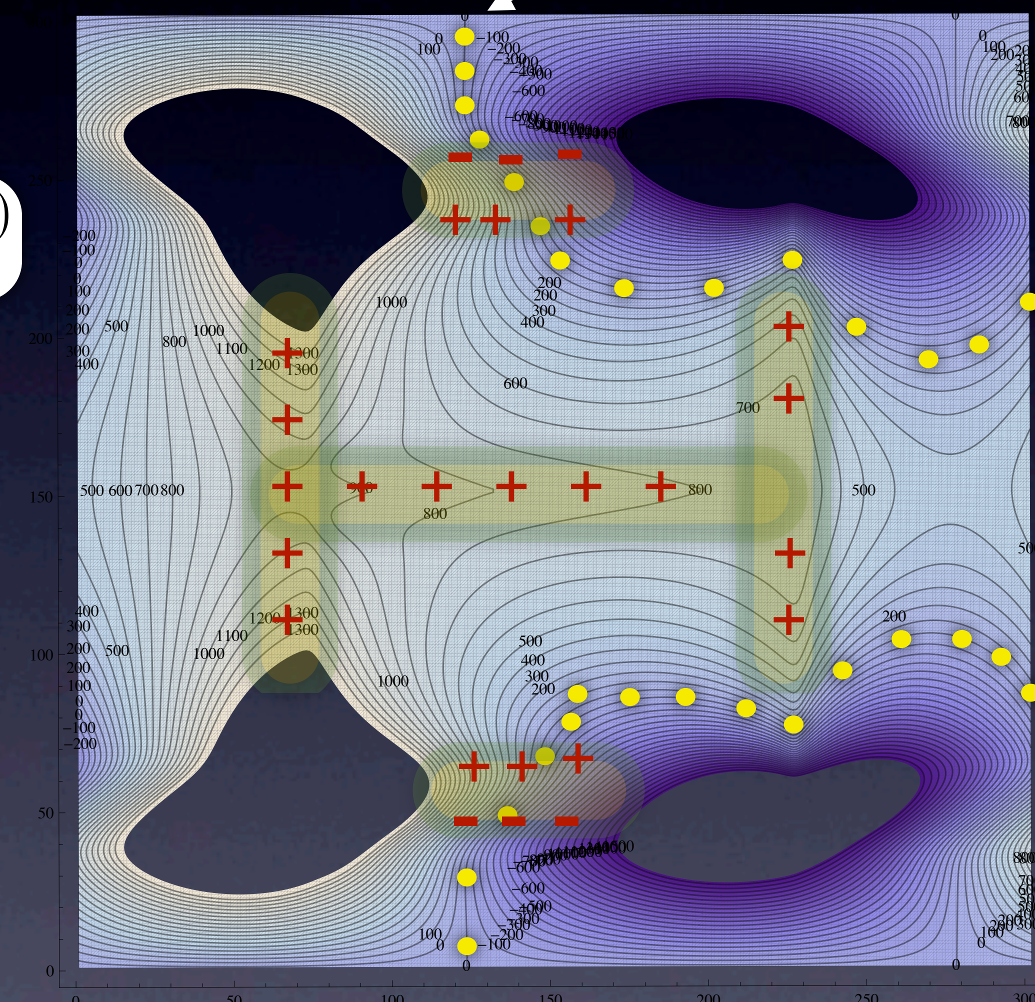
・resultant eastward electric filed may drives the EEJ variation in the calssical manner

Modification of Potential structure by the polarization charge



$$\nabla_{\perp} \cdot \left(\overleftrightarrow{\Sigma} \nabla_{\perp} \Phi \right) = j_{//}^{(0)}$$

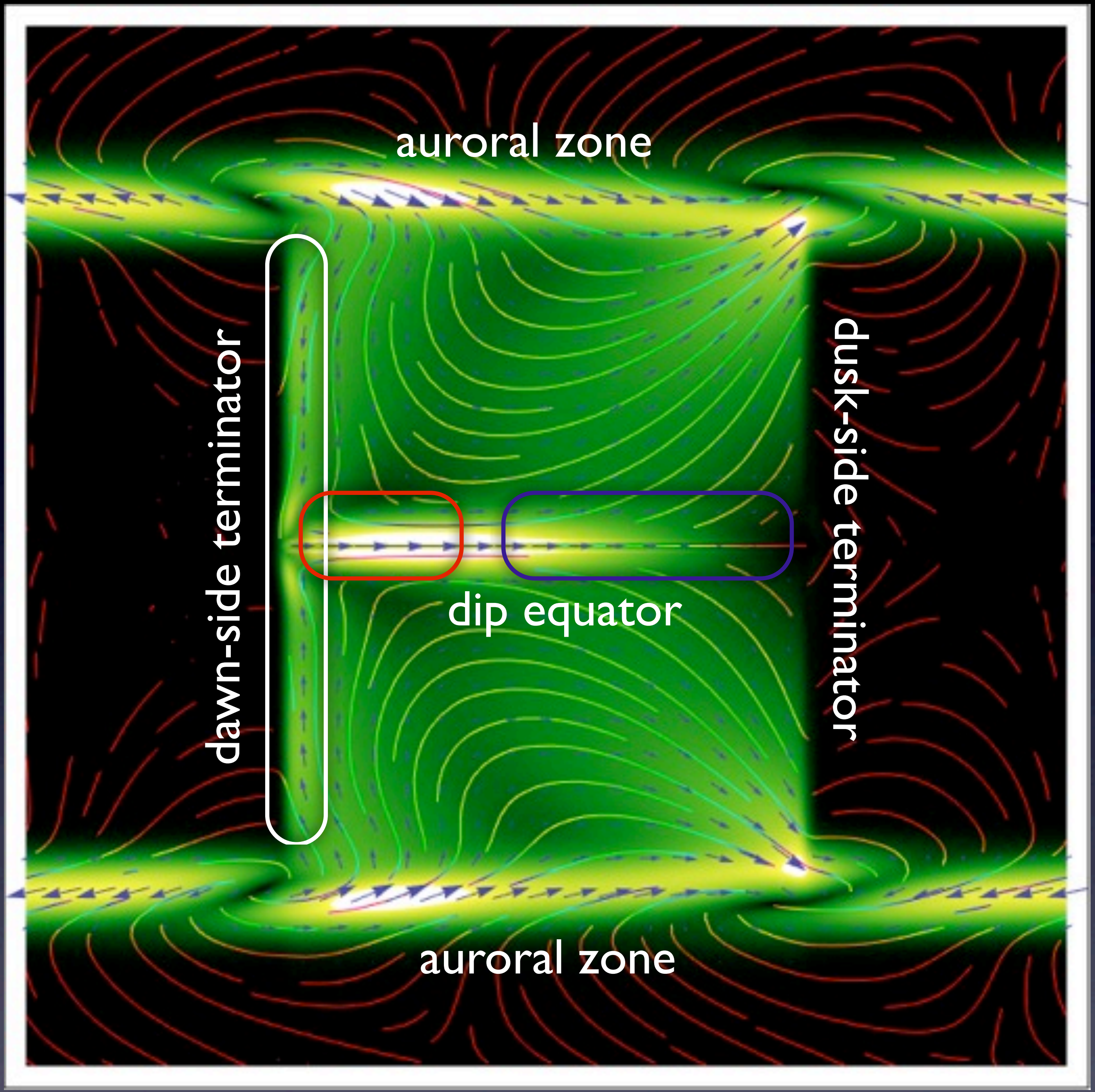
trace of zero potential



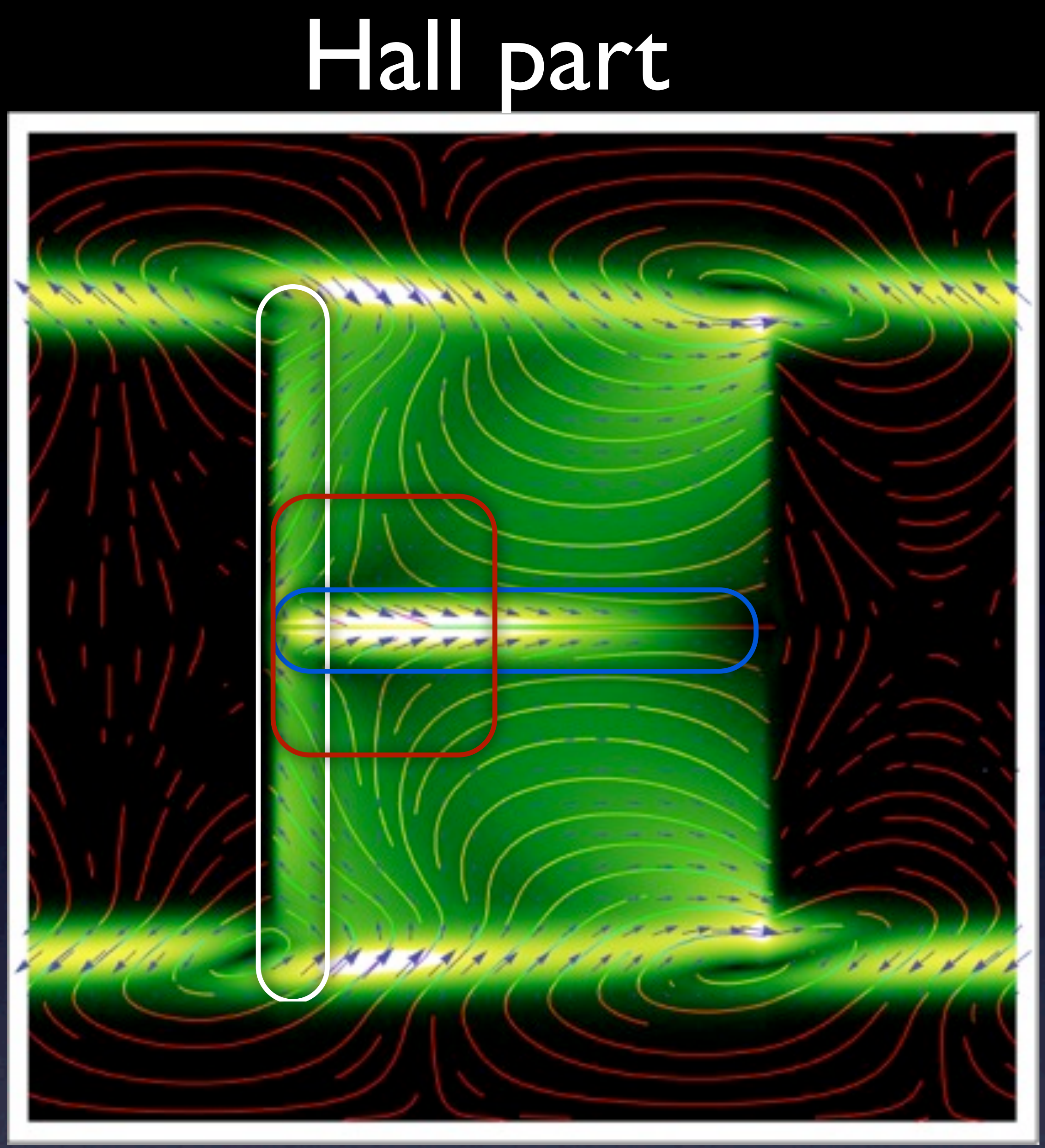
・negative R1-potential stick out to the morning side because of the “ negative charge separation” along the high-latitude terminator

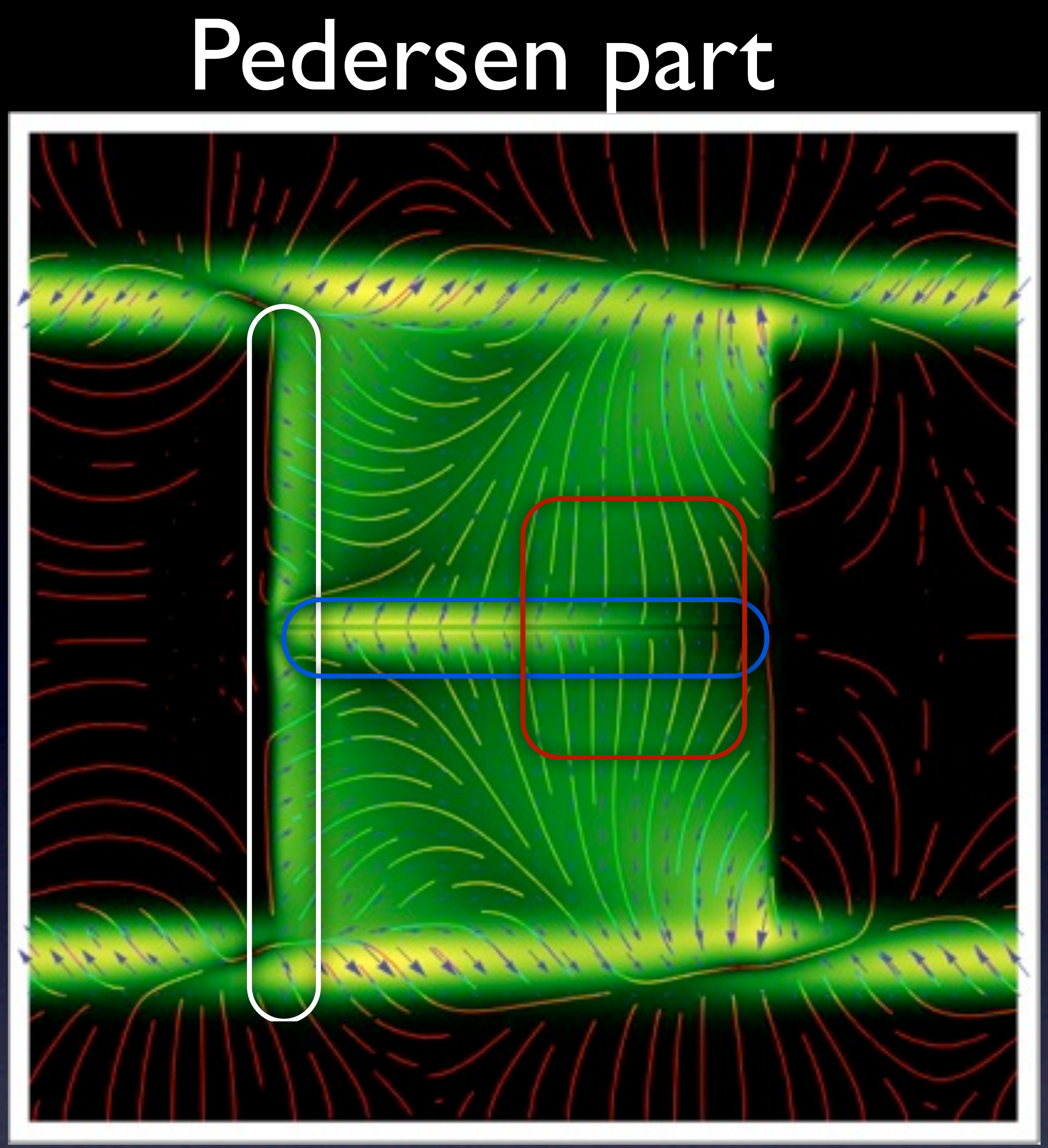
・positive R1-potential stick out to the evening side because of the “ positive charge separation” along the terminator and dip-equator

total ionospheric current



- equator ward meridional current flows along the dawn-side terminator line and connecting between AEJ and EEJ
- equator ward meridional current at morning side also runs into the equator, and enhances the EEJ
- EEJ gradually decreases through diversion to the poleward current at evening side

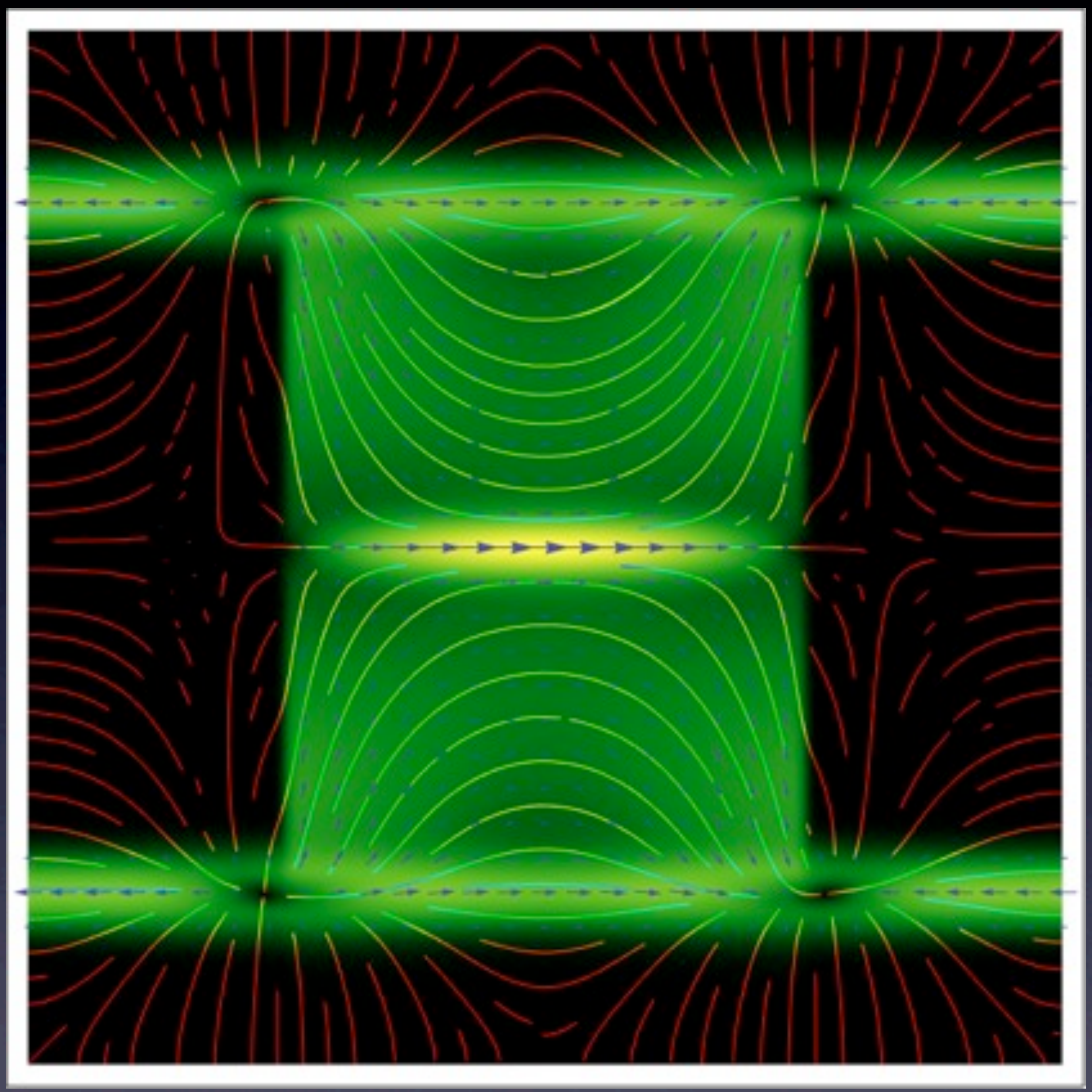




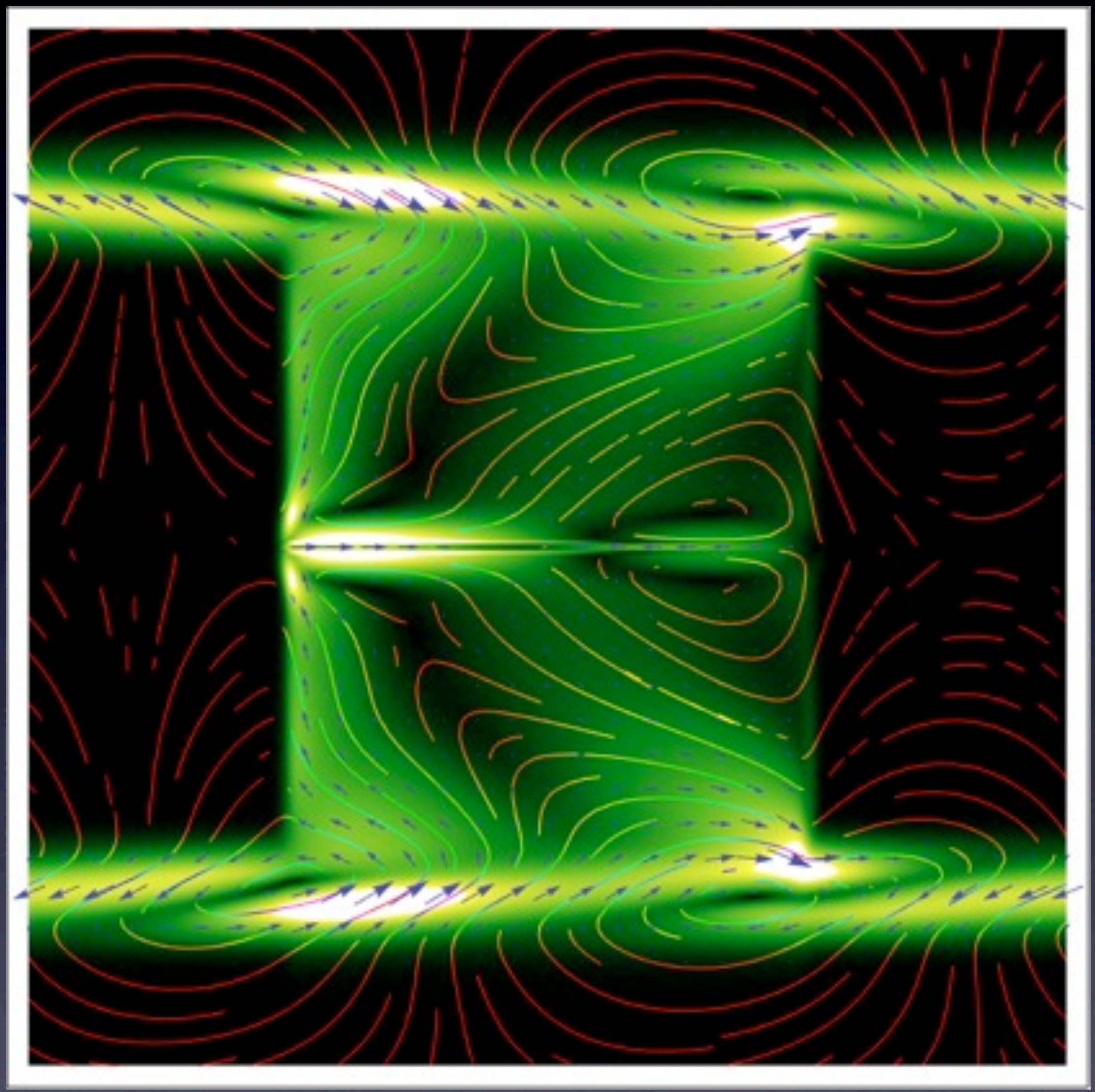
- at the dawn side terminator, Hall and Pedersen currents in the east-west direction are cancelled out each other, while equatorward Hall and Pedersen currents flow in the same direction
- at the dip-equator, Hall and Pedersen currents in the north-south (downward and upward) direction are cancelled out each other, while eastward Hall and Pedersen currents flow in the same direction
- Hall current runs into the equator at the morning side, while the Pedersen current diverging to the poleward at the evening side

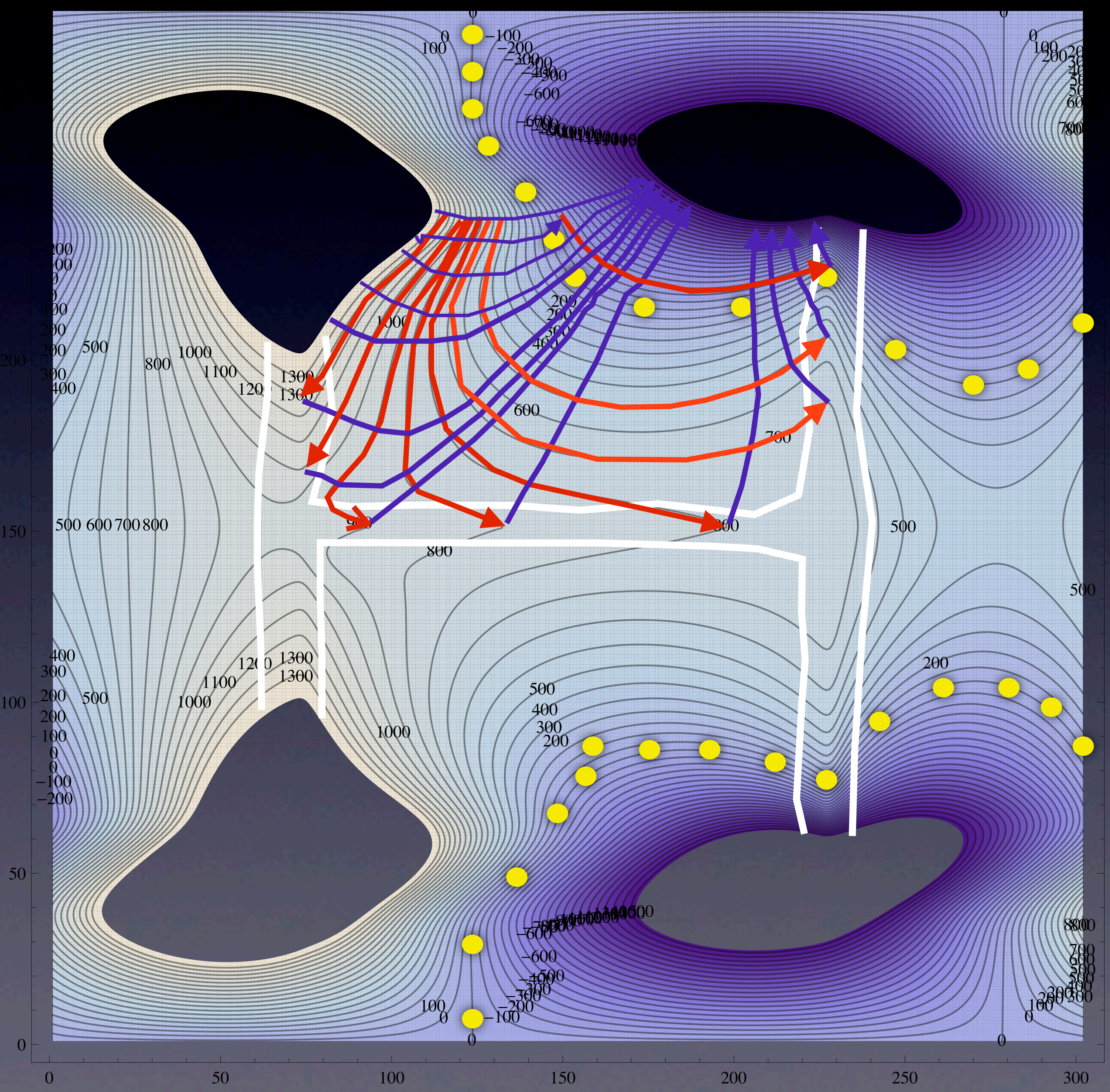
The EEJ is the Cowling current of which continuity is preserved by connection via Cowling current along the dawn-terminator, Hall current converging from polar to dip-equator, and Pedersen current diverging from dip-equator to polar region !!

Current in the case of no Hall effect



Current additionally excited by the Hall effect





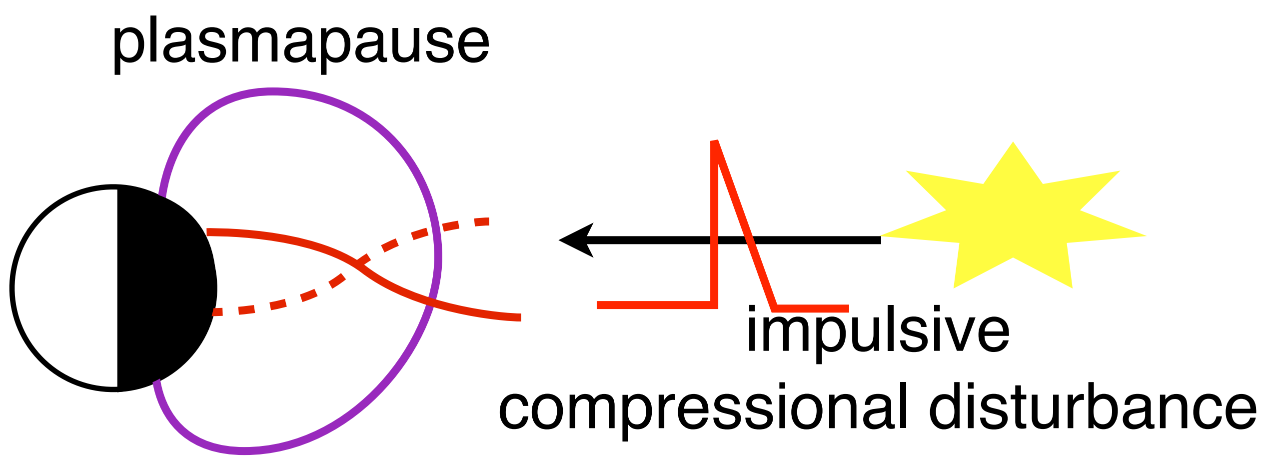
・the curl free Hall current flow along the equi-potential line is connected to the curl-free Pedersen current, which converging into the

Discussion

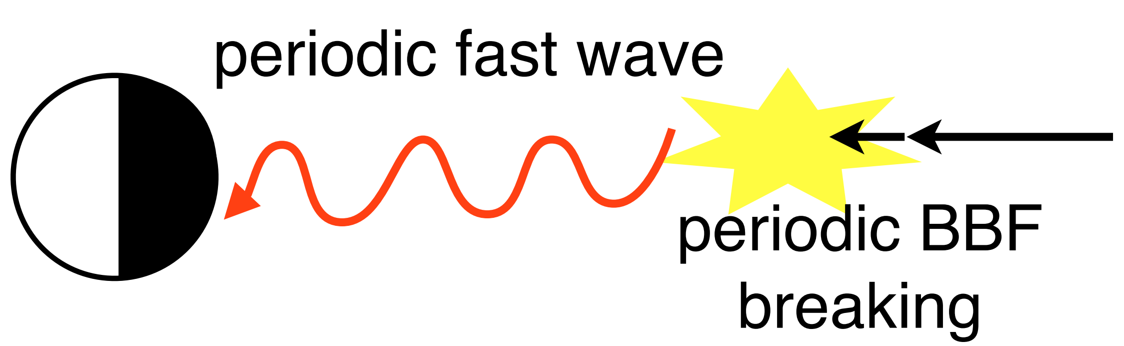
Existing models for low- and mid- latitude Pi 2

Cavity resonance, BBF driven

- These models cannot explain east-west polarization.
- There has been no report that one of the nodes of the cavity mode resonance is located around dawn sector.



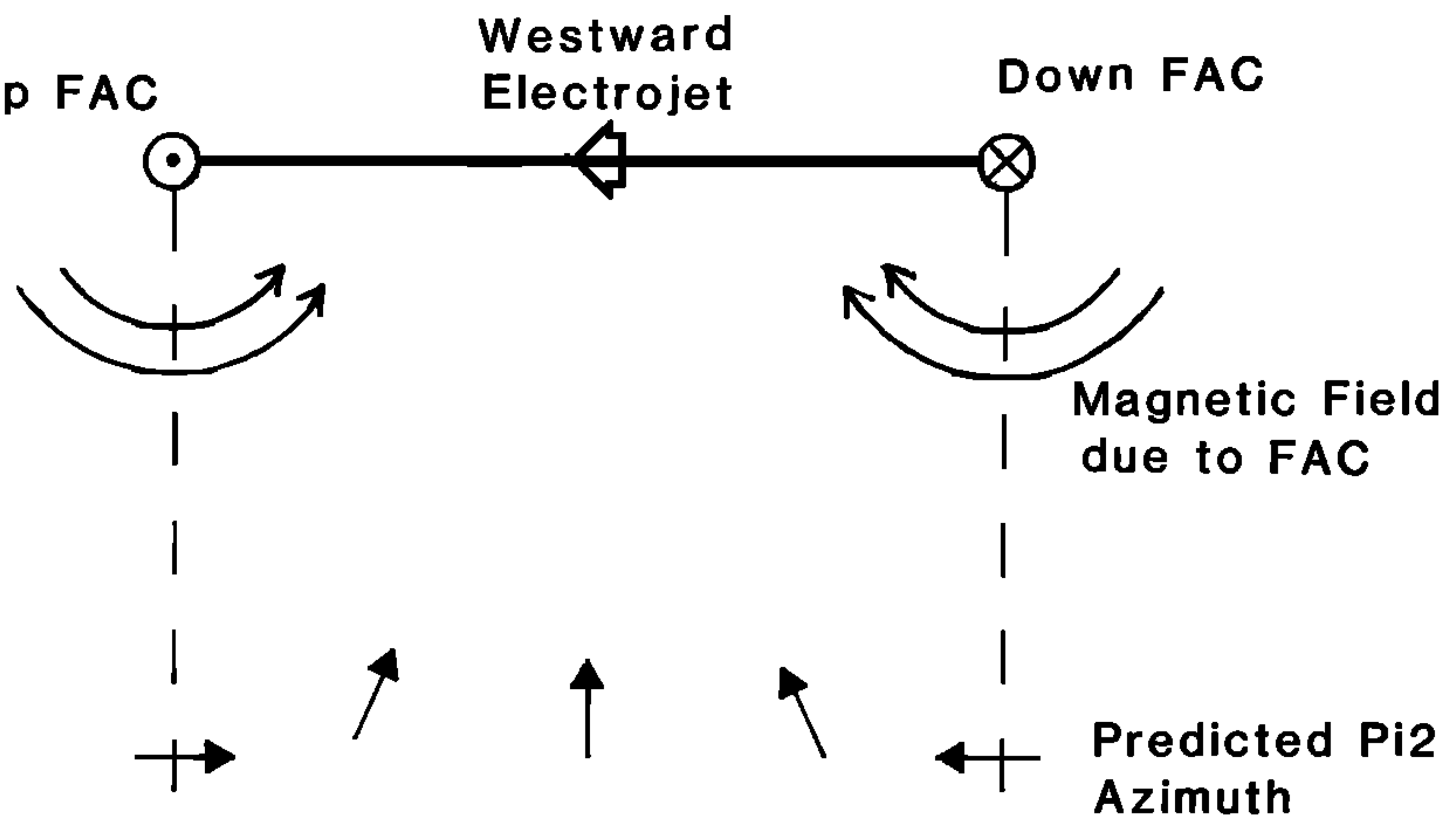
Cavity resonance



BBF driven

SCW oscillations

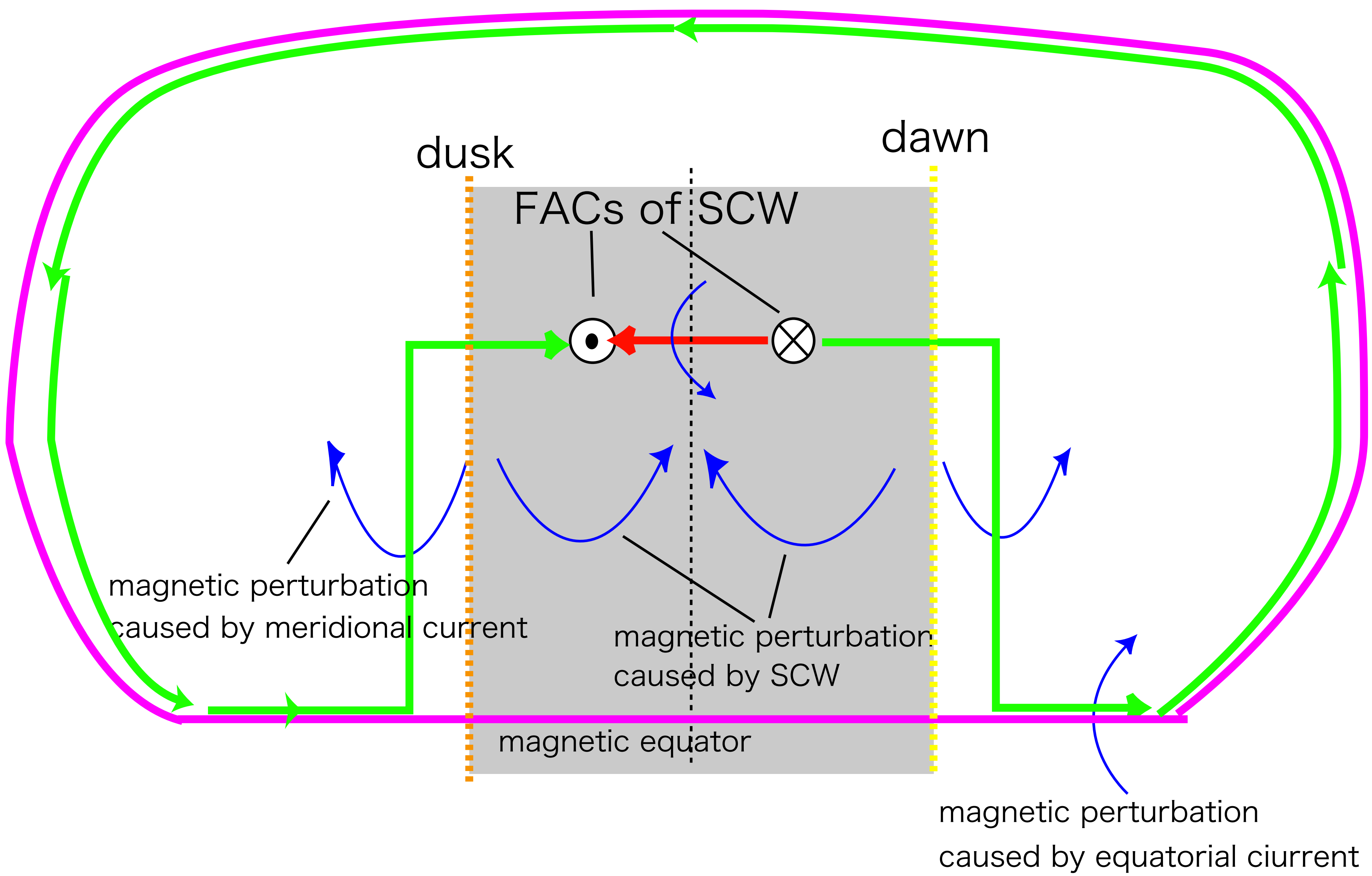
- Since D-component Pi 2s are induced by an oscillating pair of FACs around the midnight, phase change around the dawn terminator is not expected.



[Lester et al., 1983]

Existing models is not the case.

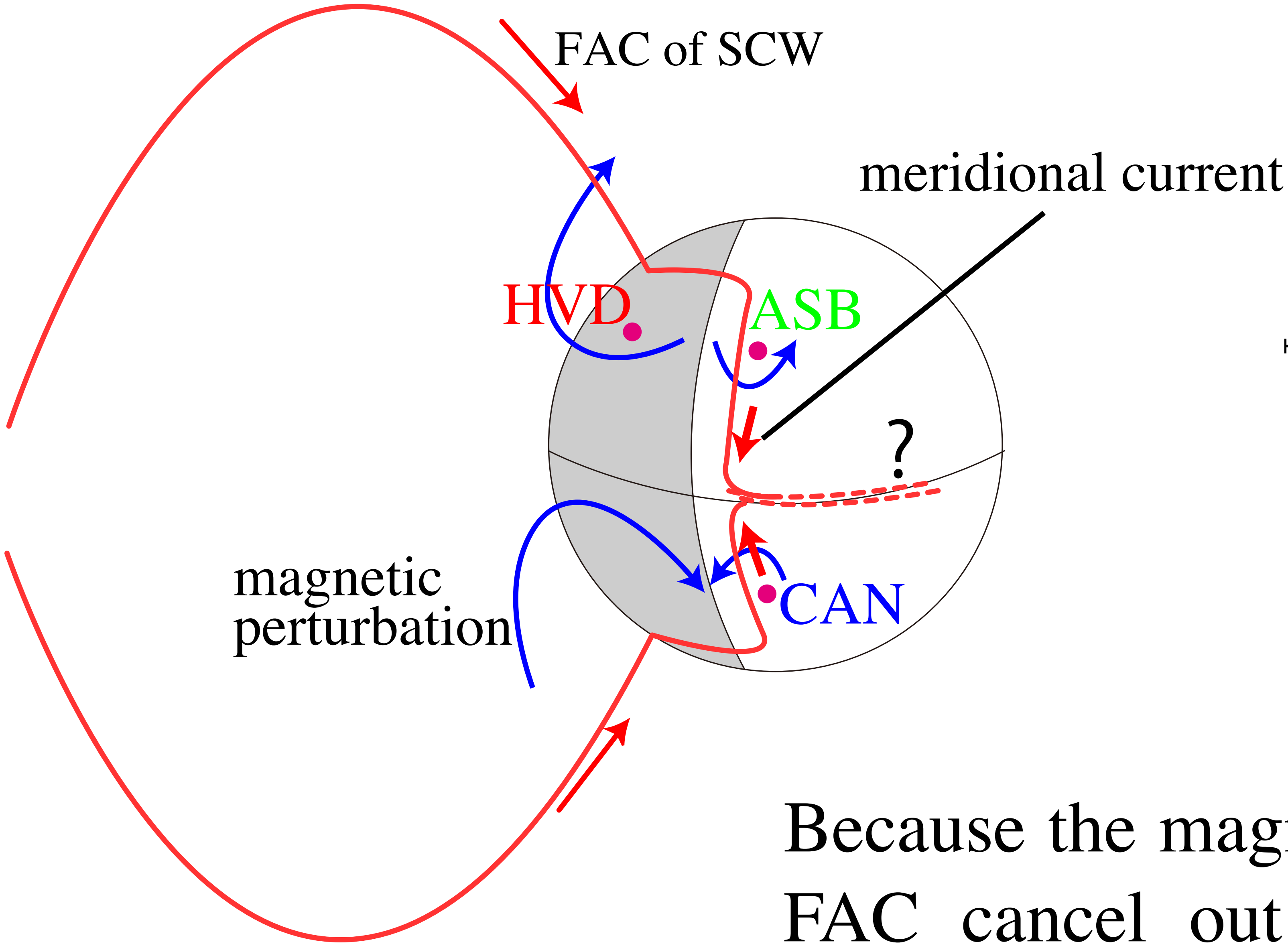
Pi 2 current system

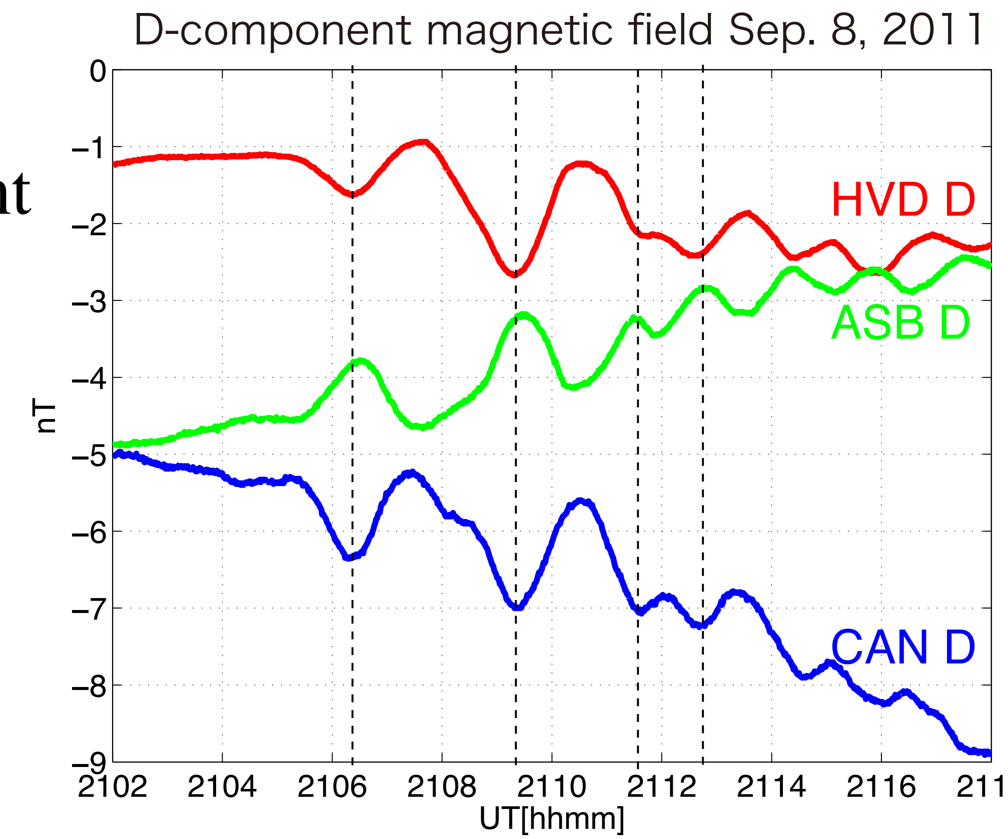


The results imply the existence of global current system for Pi 2 pulsations similar to the current systems for DP 2 [Kikuchi et al., 1996] or Pc 5 [Motoba et al., 2002]. We will verify the current system in the future study.

New conceptual model

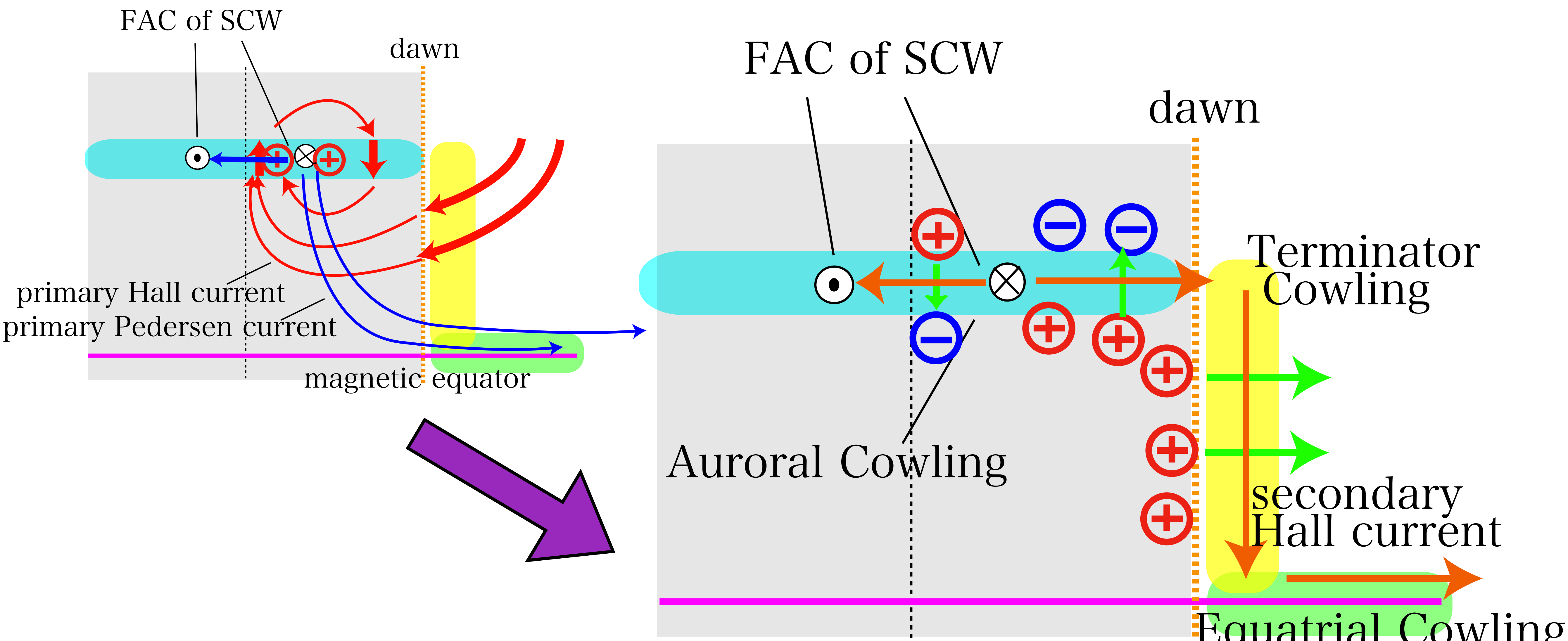
Connection between SCW and meridional ionospheric current





Because the magnetic perturbation due to the FAC cancel out the magnetic perturbation due to the meridional ionospheric current, the position where both perturbations are comparable behaves like a node.

Theoretical interpretation



Connection of secondary Hall current among auroral, terminator and equatorial region (Global Cowling Channel [Yoshikawa et al., 2013])

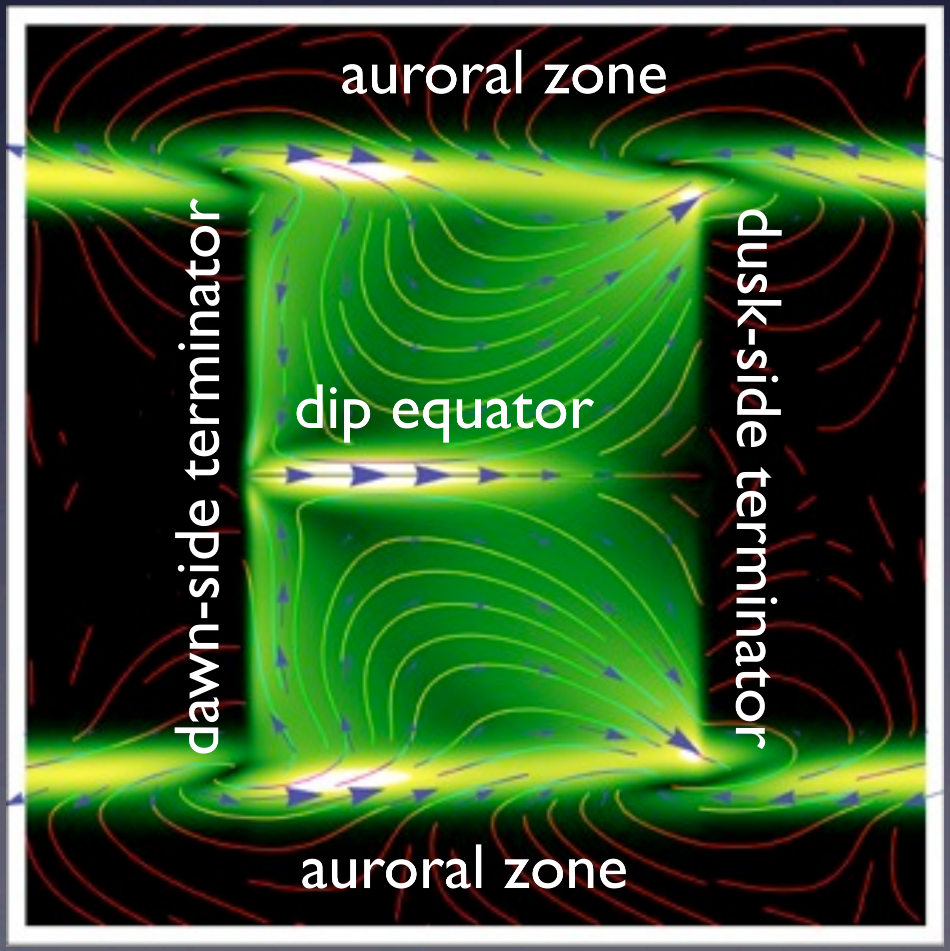
Conclusion

- Connection between northern and southern convection causes penetration of Hall current from polar to equatorial ionosphere that induces Hall polarization charge and resultant Cowling current flows along the dip-equator .

- The Hall current flows along the convection cell closed in each hemisphere induces positive polarization charge at the dawn-dusk conductivity terminators, which drive the equatorward Cowling current along dawn-side terminator and poleward Cowing current along dusk-side terminator. (in totally poleward dusk-side Cowling current seems to cancel out by the equatorward primary Hall current)

Thus, the auroral and equatorial ionosphere are connected by the global Cowling channel

- The EEJ is mainly sustained by the converging Hall current into the dip-equator at the morning side, and diverging Pedersen current at the evening side



今後の展開

- 全球構造、季節依存性
- ＦＭ−ＣＷレーダー、赤道Muレーダー、SuperDARNレーダーとの連携
- ダイナモ領域〜Ｄ領域で稼働可能な3D-強磁場・弱電離気体系シミュレータの開発