Modeling of the Storm Time Electrodynamics: Progress and Future Challenges

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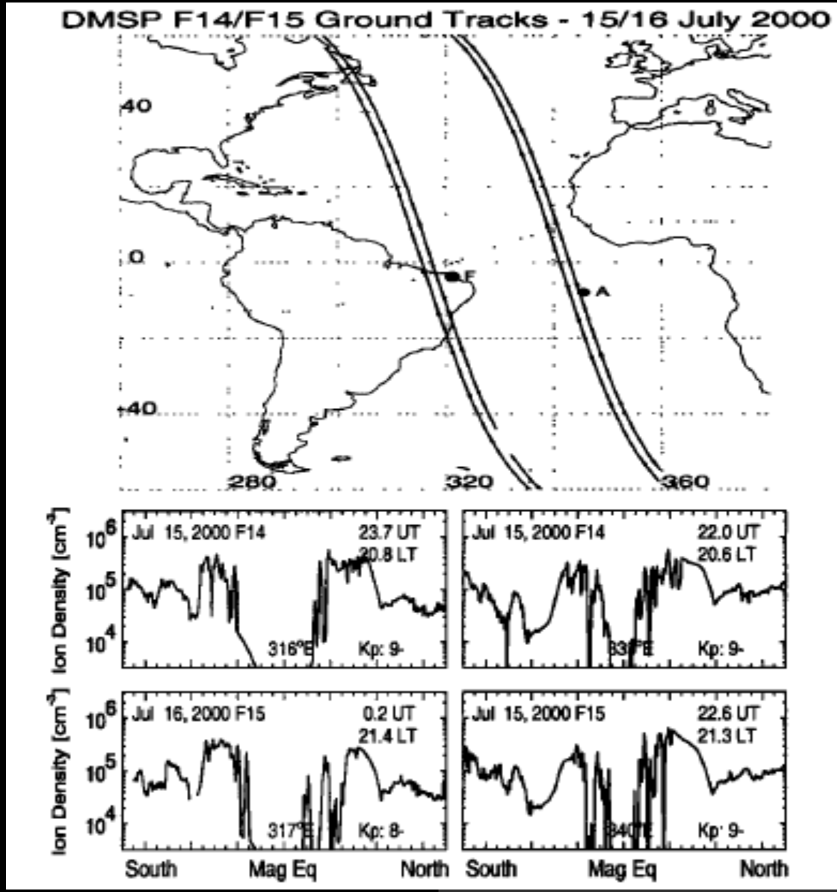
Acknowledgements: Art Richmond,
Astrid Maute, Tim Fuller-Rowell, Dave Anderson,
Stan Sazykin, Dick Wolf, Frank Toffoletto, Bob Spiro, and more

Outline

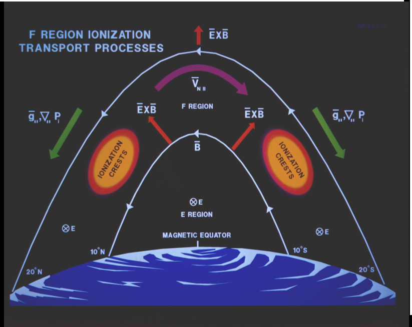
- Why study low latitude E -field and drifts?
- Source of the low-/mid-latitude storm time E-field: Prompt penetration(PP) and Disturbance Dynamo(DD)
- Prompt penetration(PP): Jaggi and Wolf, 1973
- Disturbance Dynamo(DD): Blanc and Richmond, 1980
- Empirical DD model
- Non-Linear Effect caused by combining PP&DD
- Possible feedback from DD to PP
- Unsolved Problems
- Summary and Future Work

Why Study Low-Latitude Electric Fields and Drifts?

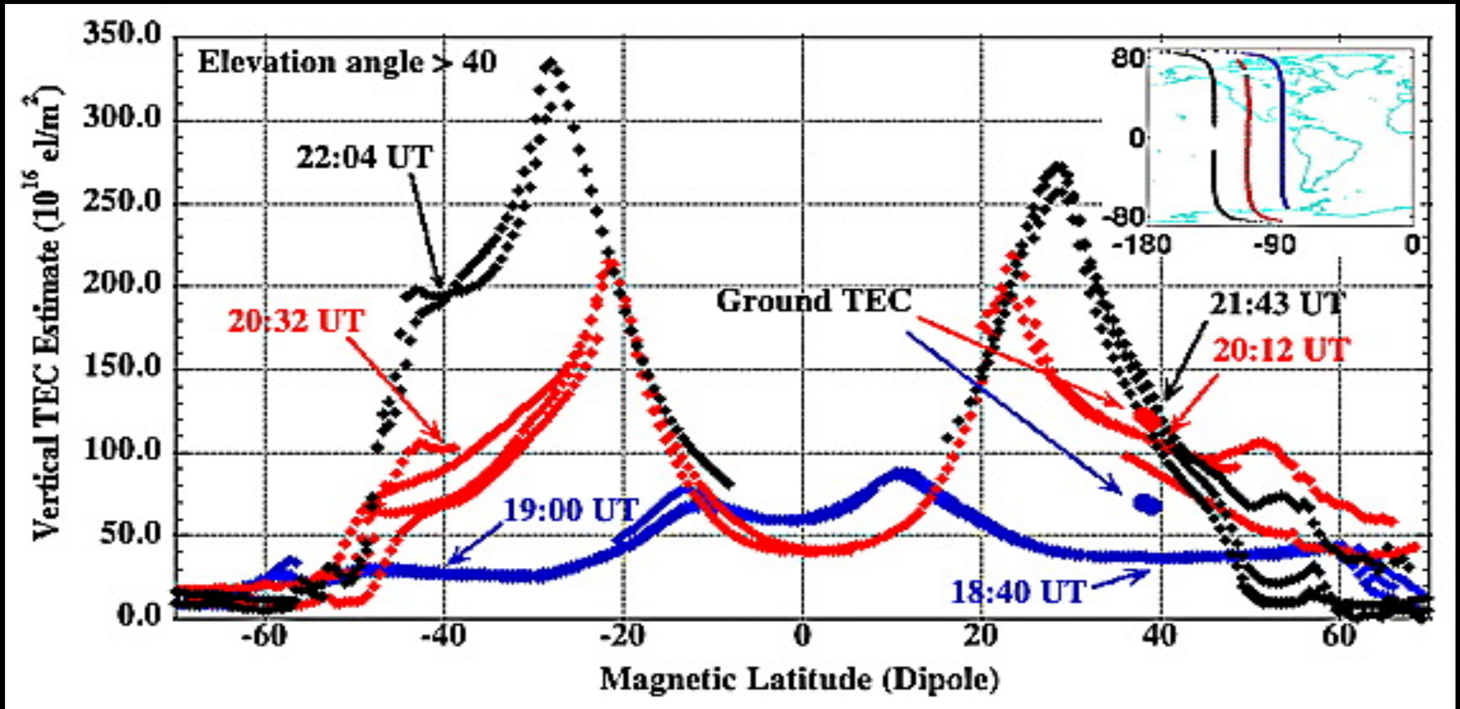
F-layer biteout: 2000-7-15 (Bastille day Storm)



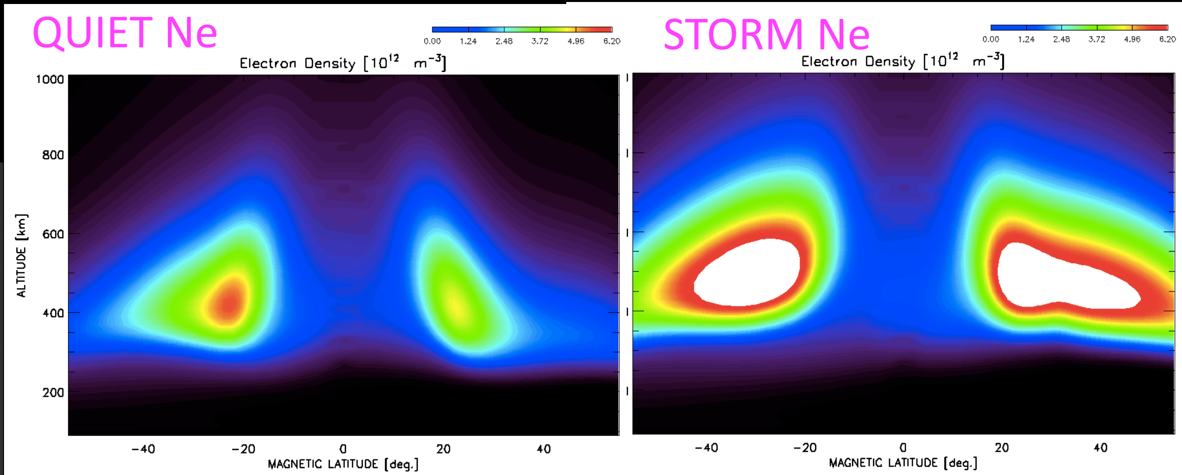
[Basu et al 2001]



Massive plasma redistribution: 2003-10-30 (Halloween Storm)

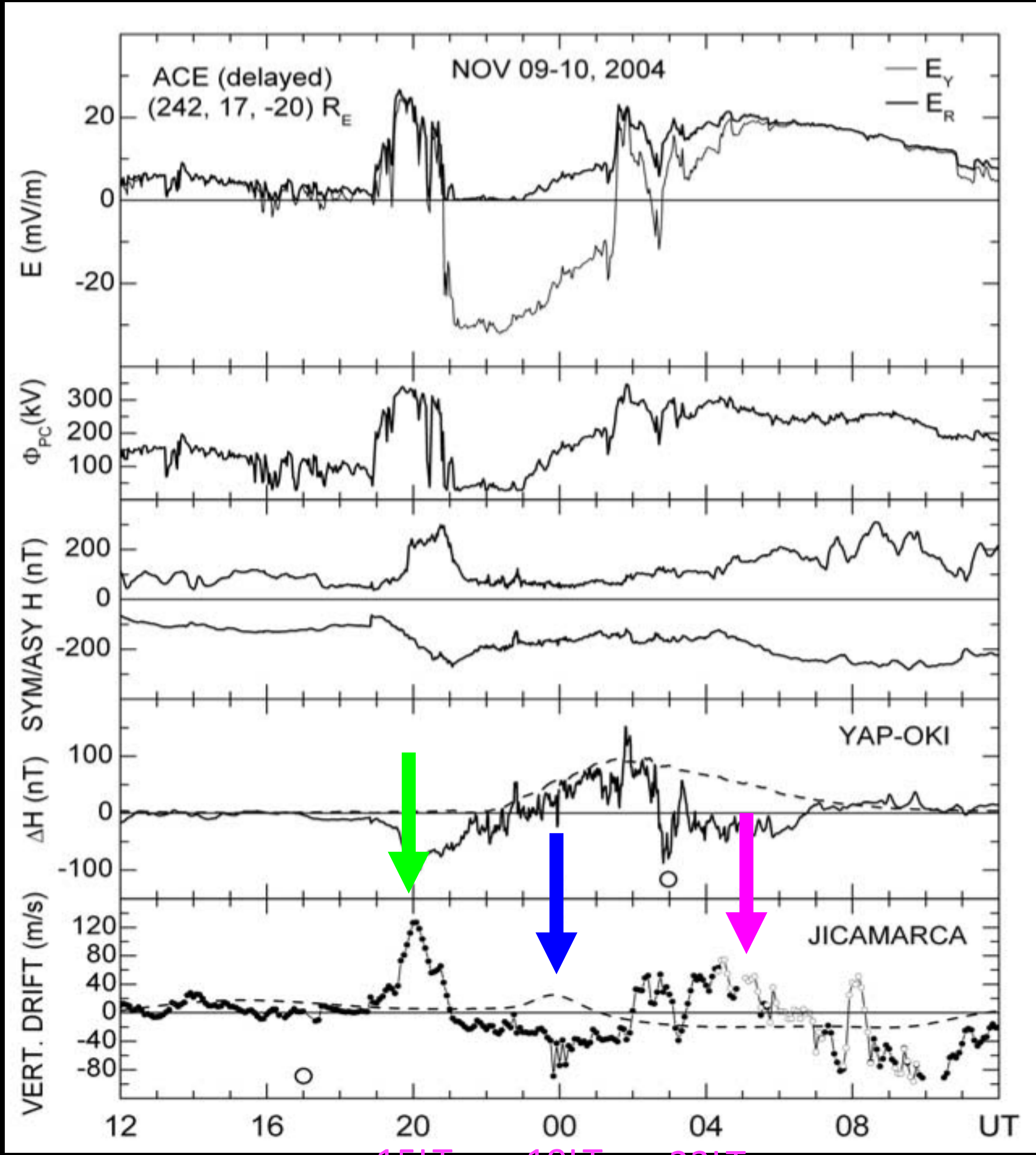


[*Mannucci et al*., 2005]



- caused mainly by the storm time E-field [*Lin et al., 2005*].
- Accurate prediction of the storm time E-fields is needed

Equatorial Storm Time Plasma Drift: 2004-11-9



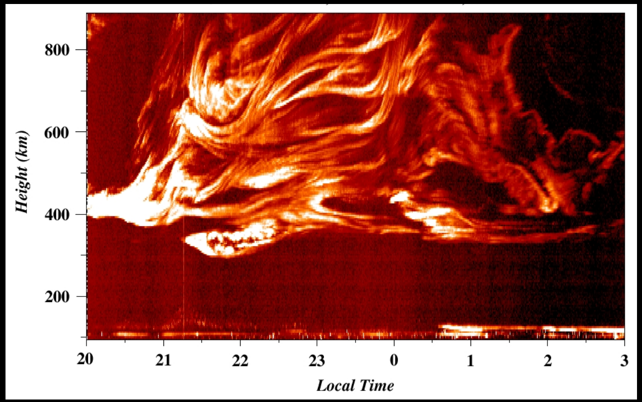
15LT 19LT 23LT

[Fejer et al., 2007]

Jicamarca Radio Observatory, JRO
Incoherent Scatter Radar

120m/s largest daytime drift ever measured by radar
At ionospheric heights:
E=1mV/m => V=40m/s (equator)

Equatorial Spread-F



[Woodman and LaHoz 1976]

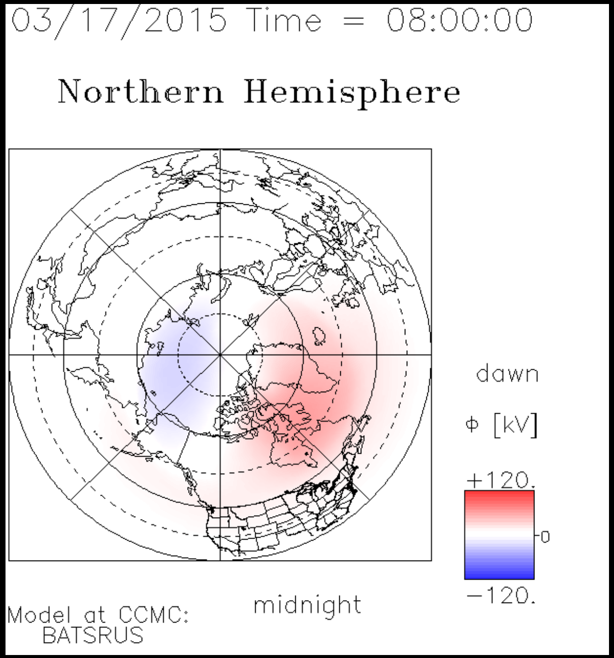
Large post midnight ionospheric depletions cause scintillations

Low-/Mid-Latitude Disturbance E-field 2 Processes:

- **Prompt Penetration (PP)** [*Jaggi and Wolf*, 1973]
- **Disturbance dynamo (DD)** [*Blanc and Richmond*, 1980]

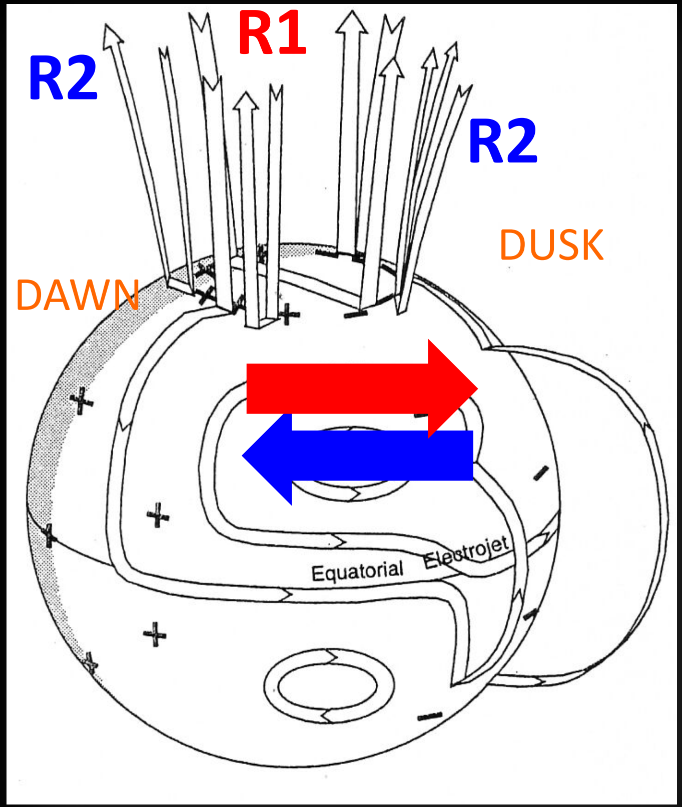
Prompt Penetration (PP) [*Jaggi and Wolf*, 1973]

High Latitude Potential



[courtesy from CCMC: SWMF+RCM]

Ionospheric Current System



[Richmond et al]

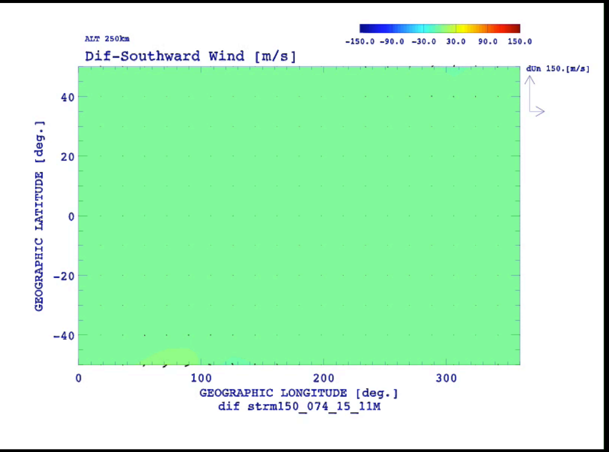
IMF Bz Southward Turning
R1 > R2 (Undershielding)
Dawn to Dusk E-field
Day: Eastward E-field
Night: Westward

IMF Bz Northward Turning
R2 > R1 (Overshielding)
Dusk to Dawn E-field
Day: Westward
Night: Eastward

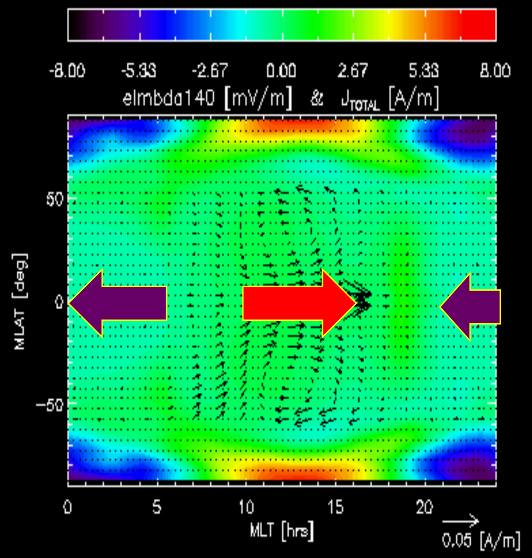
PP time scale < ~ 1hr (shielding established)

Disturbance Dynamo(DD) [*Blanc and Richmond*,1980]

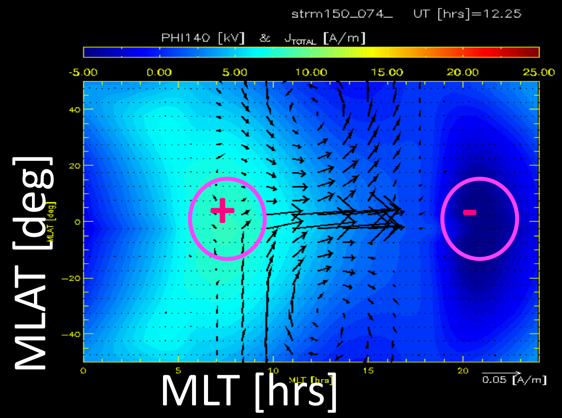
Disturbed Neutral Wind



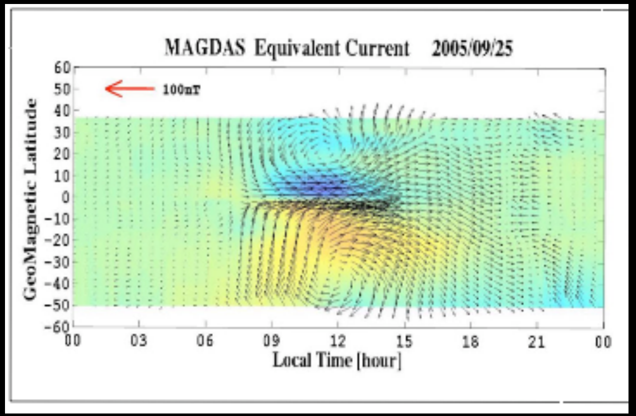
QUIET E_{EAST} [mV/m]



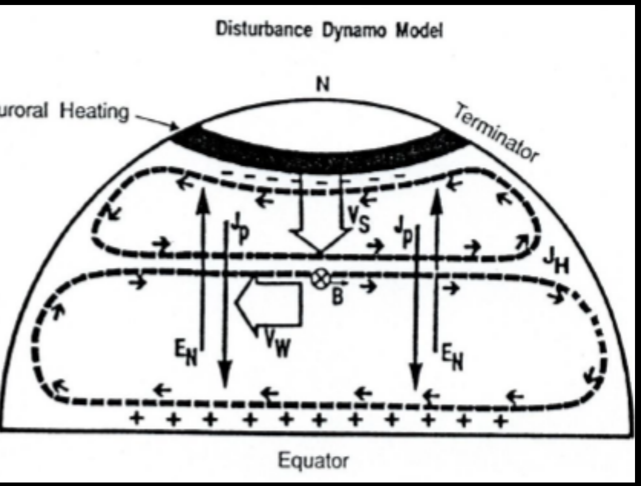
Sq current Φ [kV]



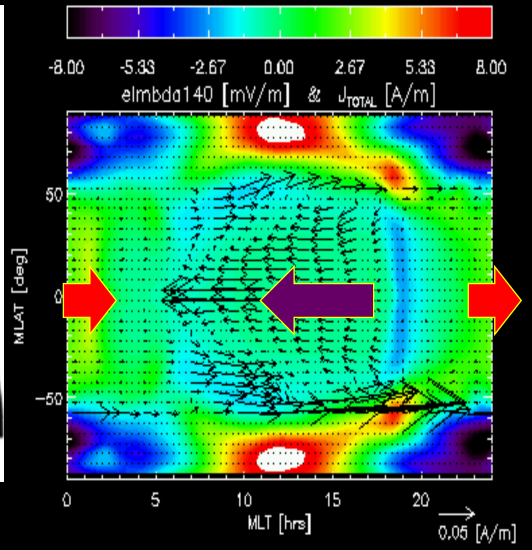
Magnetometer Equivalent Current



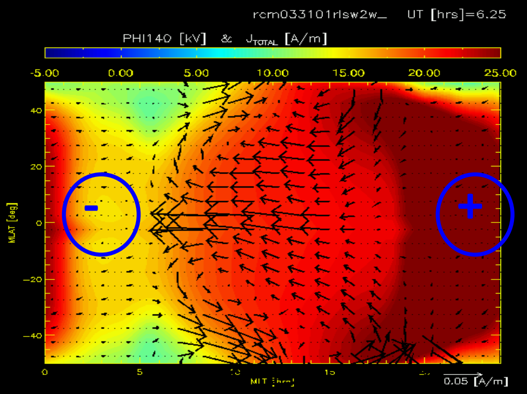
Disturbance Dynamo Model

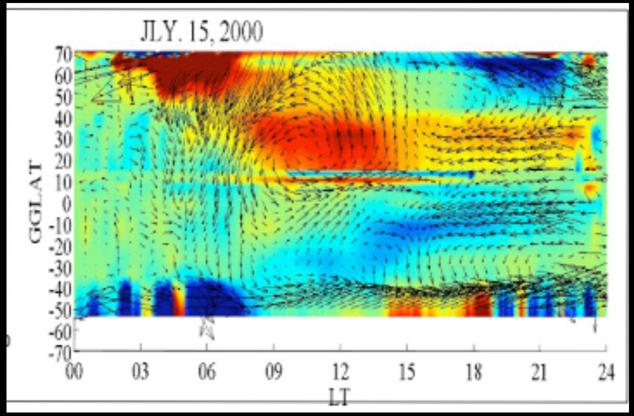


STORM E_{EAST} [mV/m]



Reverse Sq Φ [kV]

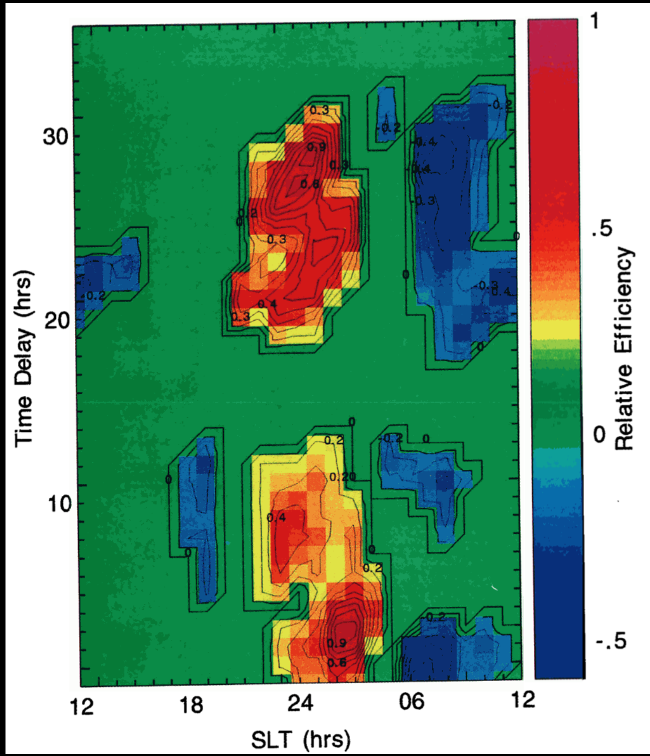




[Kohta et al., 2005]

Equatorial DD Drift Empirical Model

Drift Disturbance vs. Time Delay from Energy Deposition

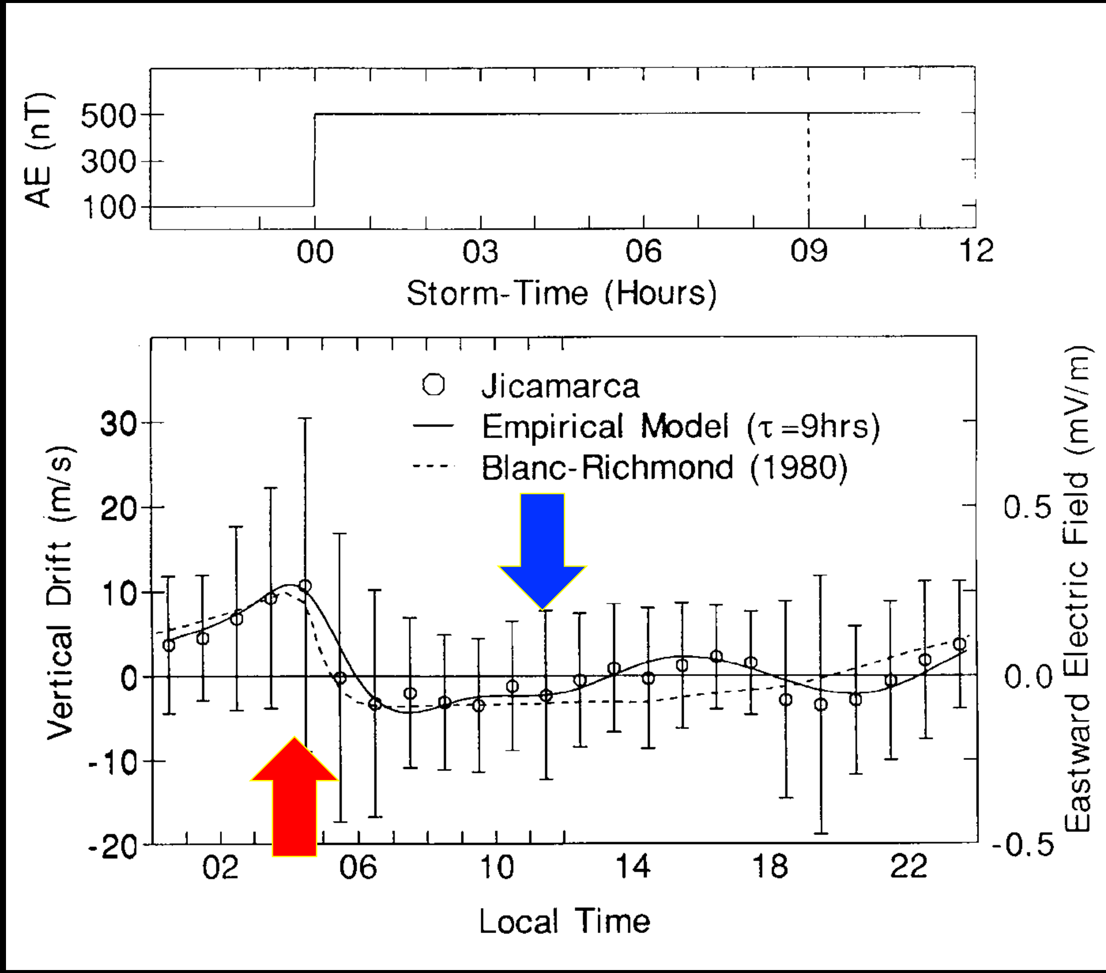


1) 2-3h: dynamo action of fast traveling equatorward wind surges [e.g., Fuller-Rowell et al., 2002];

2) 3-12h: electro-dynamic action of storm-enhanced high latitude equatorward winds [Blanc and Richmond, 1980];

3) One day after: combined effects of storm-driven equatorward winds and conductivity variations (composition changes) [Scherliess and Fejer., 1997]

Equatorial DD Vertical Drift Model as a function of AE

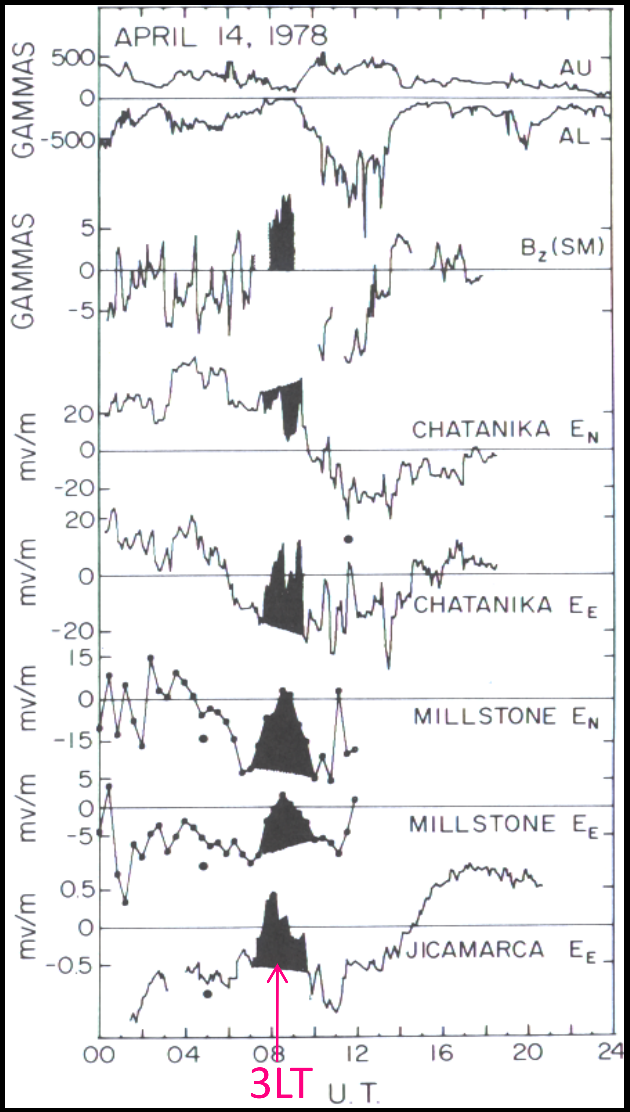


- 9 Normalized Cubic B-Splines
- Time delay(τ) from energy deposition(AE) is considered

[Scherliess and Fejer, 1997]

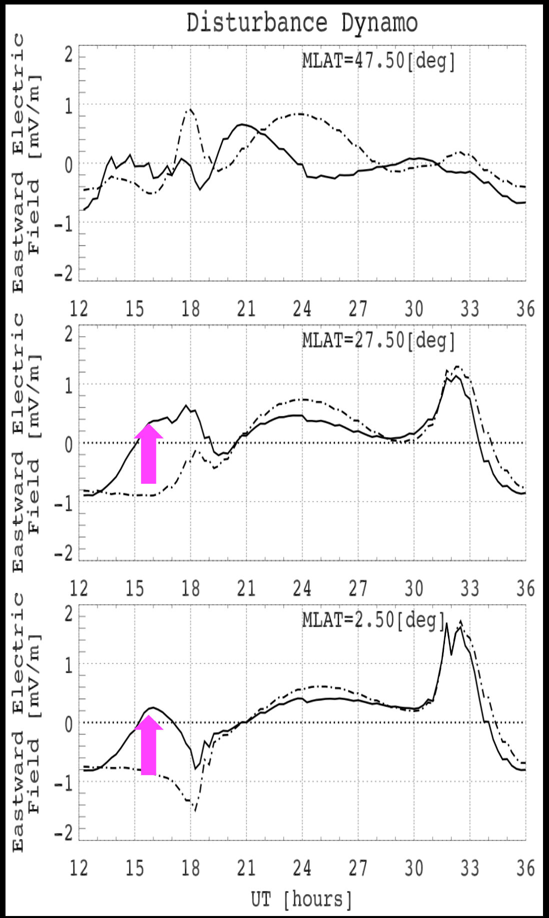
Difficult to distinguish PP vs. DD in observations

Observed PP



[Kelley, 1989]

Rapid DD Response (CTIPe)



[Fuller-Rowell et al., 2008]

- Observed PP from the ISR chains show the instantaneous reversal of the post-midnight drift
- (RHS)Rapid DD response happens globally in ~2.5hrs
- PP & DD have comparable magnitudes at night
- Make separation of the 2 mechanisms more difficult
- Makes obs. Interpretation more difficult

Storm
Quiet

Coupled Thermosphere Ionosphere Plasmasphere self-consistent electrodynamics (CTIPe) *[Fuller-Rowell et al., 1970; Millward et al., 2001]*

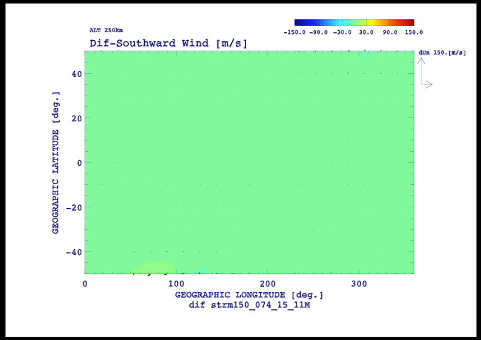
Basic Components:

- ❖ **Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. V_x, V_y, V_z, T_n, O, O_2, N_2, ….**
- ❖ **High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O^+, H^+, O_2^+, NO^+, N_2^+, N^+, V_i, T_i,**
- ❖ **Plasmasphere, and mid and low latitude ionosphere**
- ❖ **Self-consistent electrodynamics (E_{DD} only)**

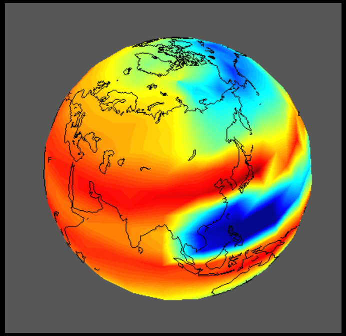
Model Inputs:

- **solar UV/EUV, Tidal forcing**
- **TIROS/NOAA Auroral precipitation**
- **Weimer convection E-field**

Neutral Wind

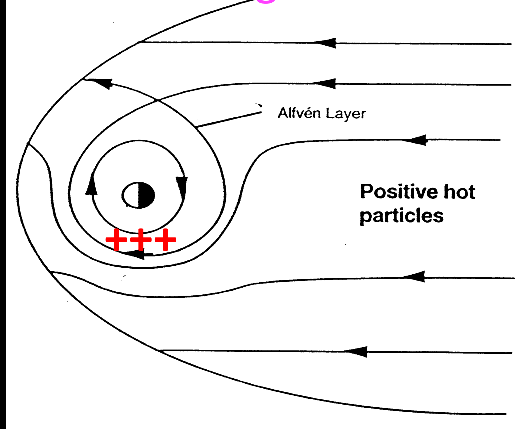


Electron Density

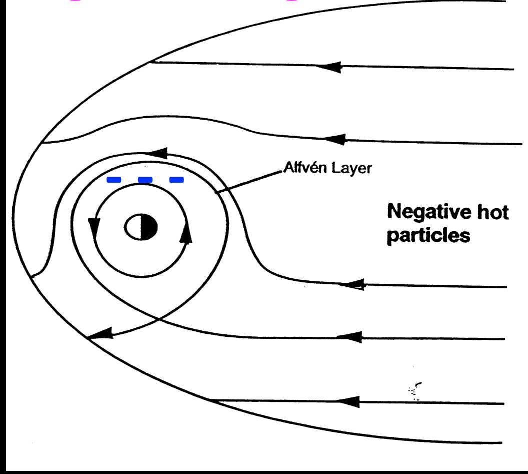


Rice Convection Model (RCM) *[Wolf et al., 1983]*

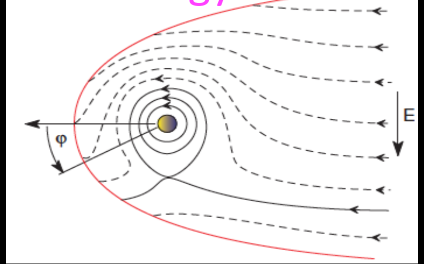
Positive Energetic Particles



Negative Energetic Particles



Low Energy Particles



Conv. + Cor.

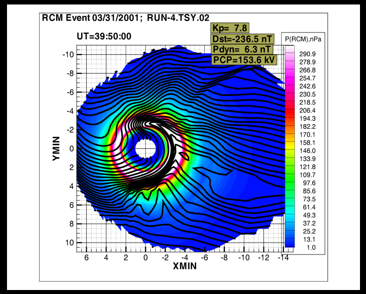
Basic Equations:

- ❖ Adiabatic drift equations in the inner magnetosphere (gradient & curvature drift)
- ❖ pressure gradients ➔ $J_{//}$ (Vasyliunas equation: $J_{//} + J_{PERP} = 0$)
- ❖ Ionospheric current conservation equation: div**J** = 0 (E_{PP} only)

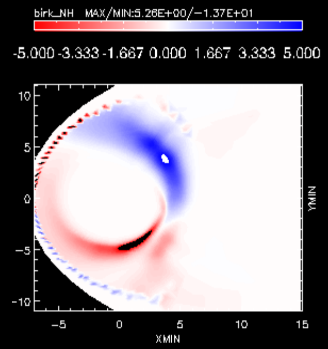
Model Inputs:

- Magnetospheric B-field
- Plasma sheet N and T
- Cross Polar Cap Potential (CPCP)
- Ionospheric Conductance from IRI/MSIS

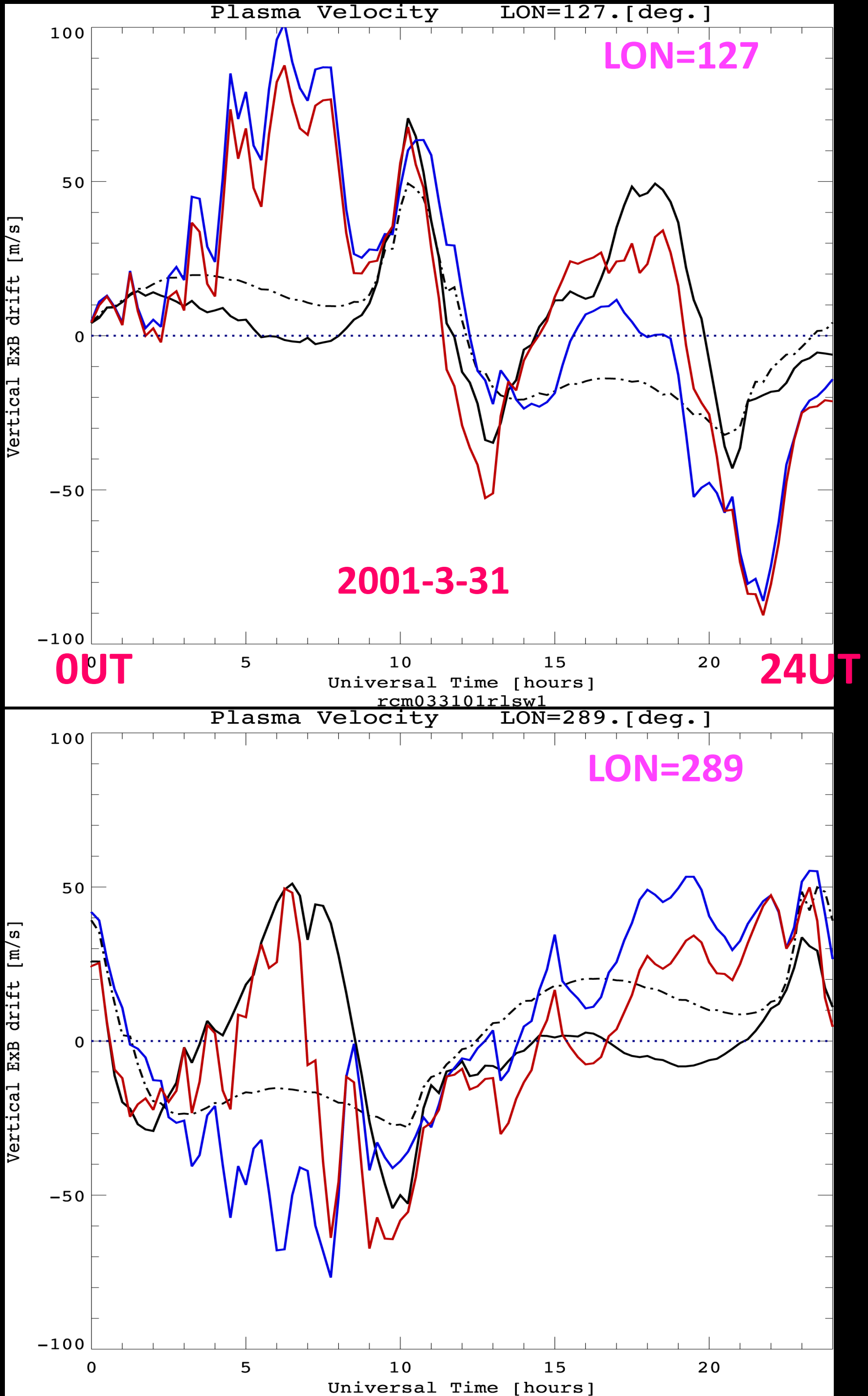
Pressure distribution



Field aligned current ($J_{//}$)



RCM $J_{//}$ provides shielding



Possible Feedback between PP & DD

TotalE = RCM E_{PP} + CTIPe E_{DD}

4 CTIPe Runs:

-----: Quiet time

____: Disturbance Dynamo only (Weimer)

____: Penetration only (RCM)

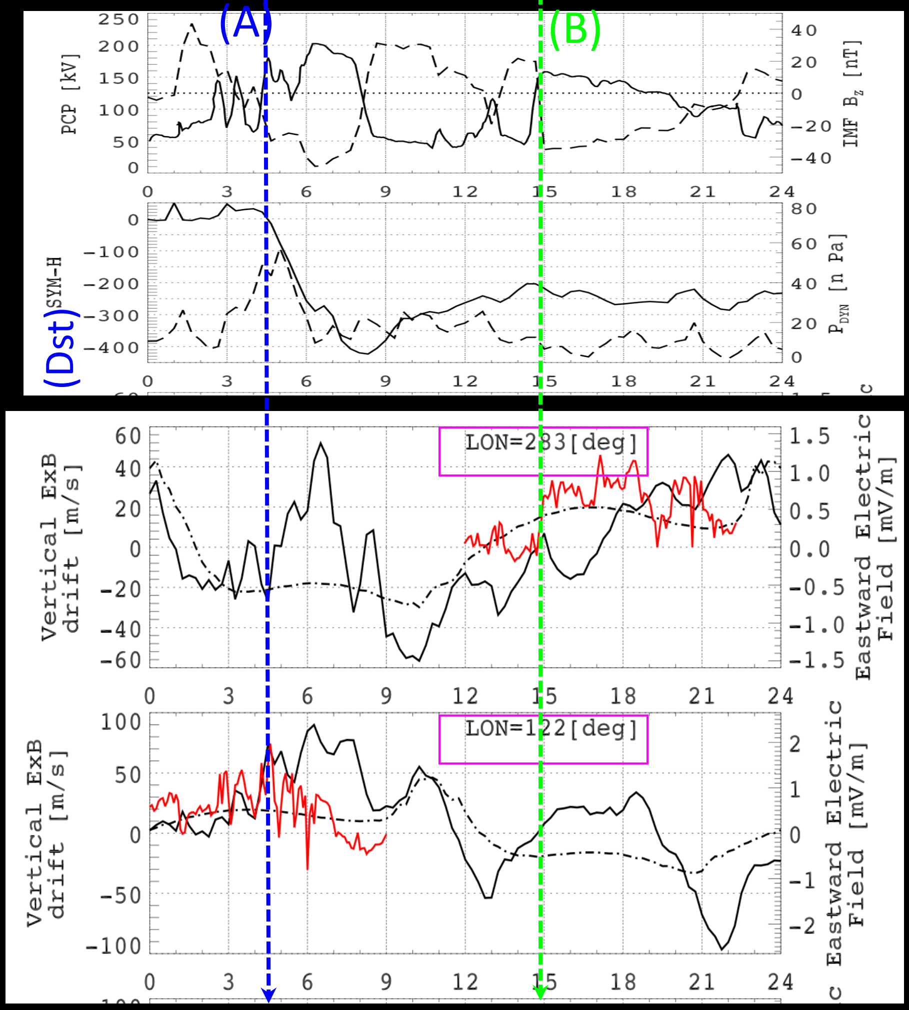
____: both Disturbance Dynamo (Weimer) & Penetration (RCM)

- **Nightside: Both PP and DD effects comparable.**
- **DD + PP /= Total (non-linear effect)**
- **DD modified by including PP through changing Σ & wind.**

[Maruyama et al., 2005]

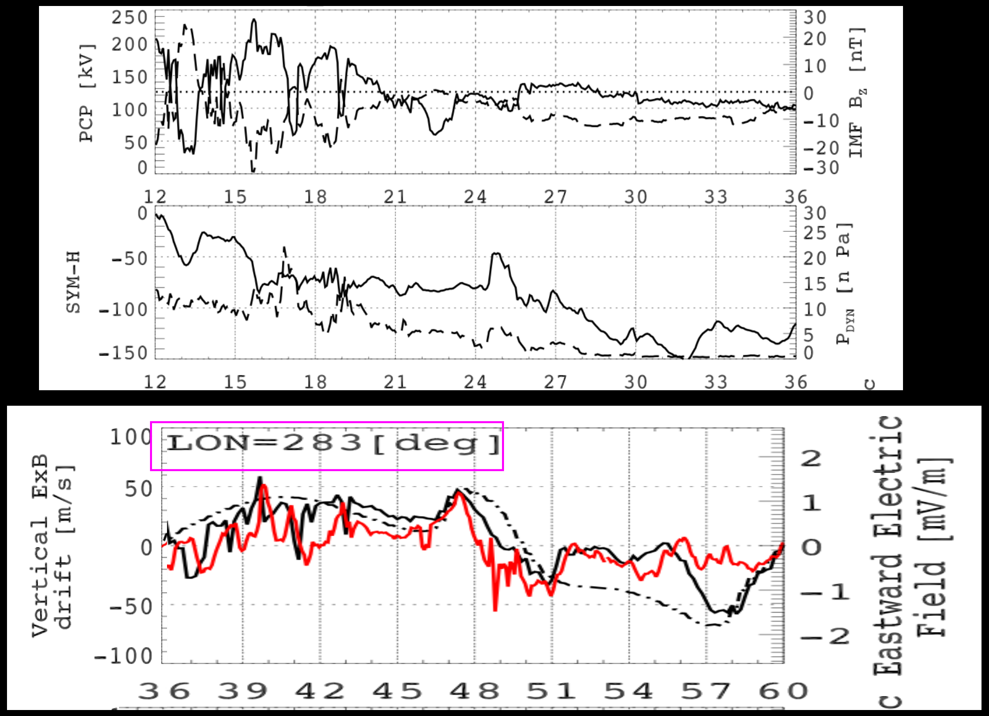
Model can reproduce observed Storm Time Drift (E-fields)

2001-3-31 (Super storm -400nT)



Observations — Storm - · - Quiet

2002-4-17 (Moderate storm -150nT)



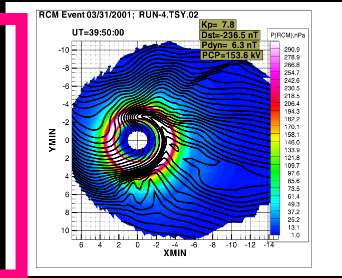
- Reasonable agreement: early phase & moderate storm
- Large discrepancy: super storm later phase
- Possible feedback between PP&DD? (coupling might help?)
- CPCP Comparable: (A)4.5UT=>175kV; (B)15UT=>160kV
- Why smaller drift for (B)15UT?

[*Maruyama et al.*, 2007]

Coupling RCM & CTIPe [Maruyama et al., 2011]

RCM

Auroral Precipitation ← **Hot Plasma transport in E, B fields**

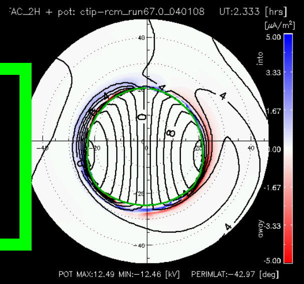


J// (PP + Shielding) ↓

E ↑

Potential (dynamo) Solver

Eq. of J continuity → **E-field**

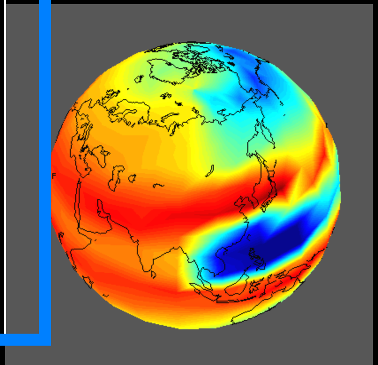


Un ↑ **∑ (DD)**

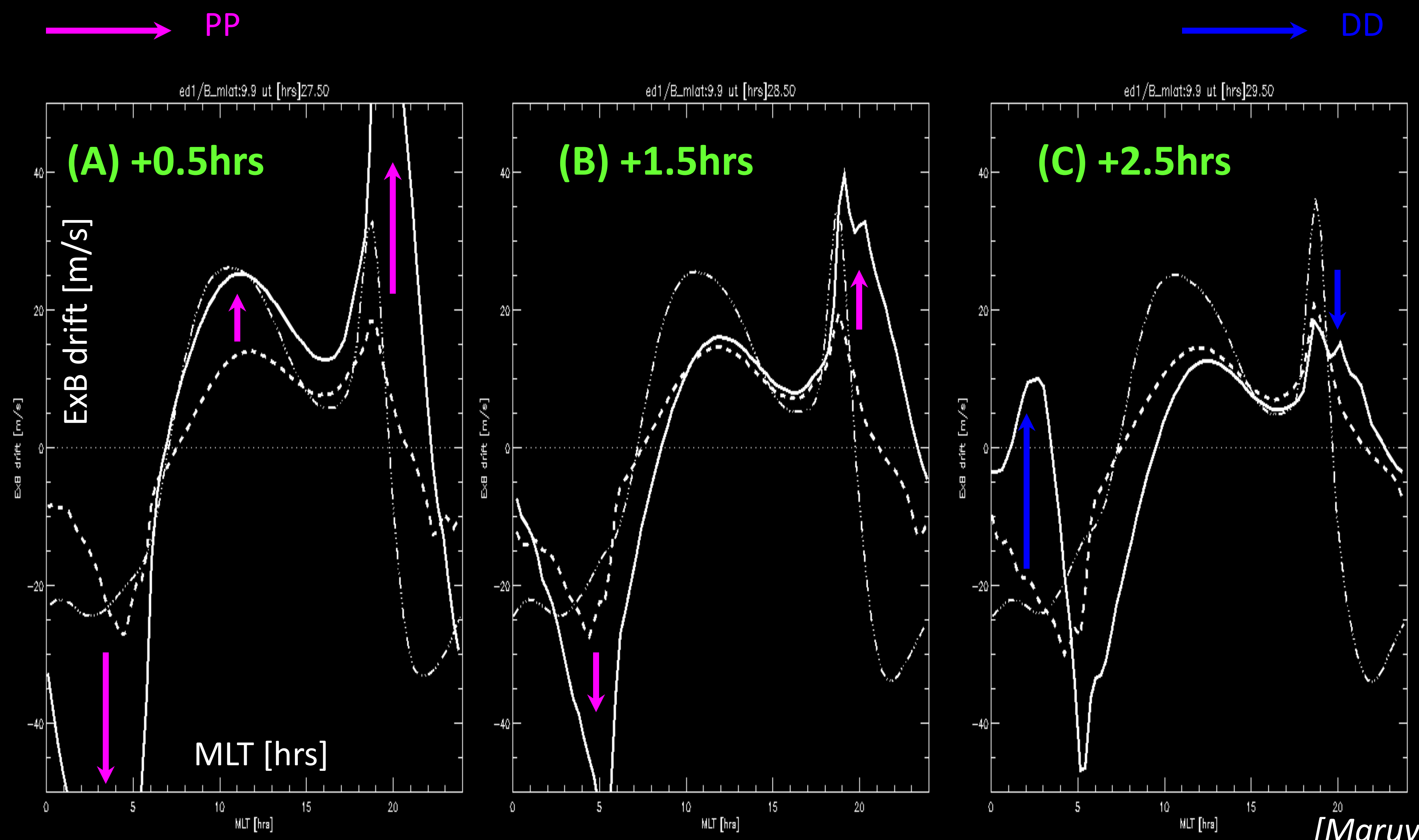
E ↓

CTIP

Thermospheric neutral density, composition wind velocity fields ↔ **Ionospheric Ne, Te Ion Ti, composition Field-aligned Vi Conductance ∑**

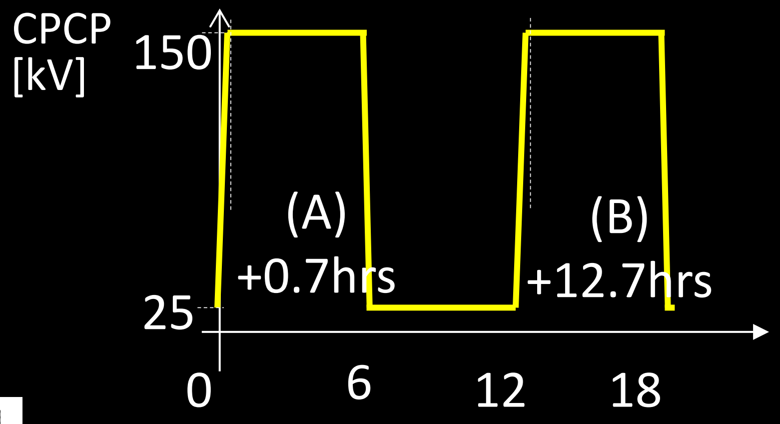


2 sources of Disturbed E-fields Identified: PP & DD

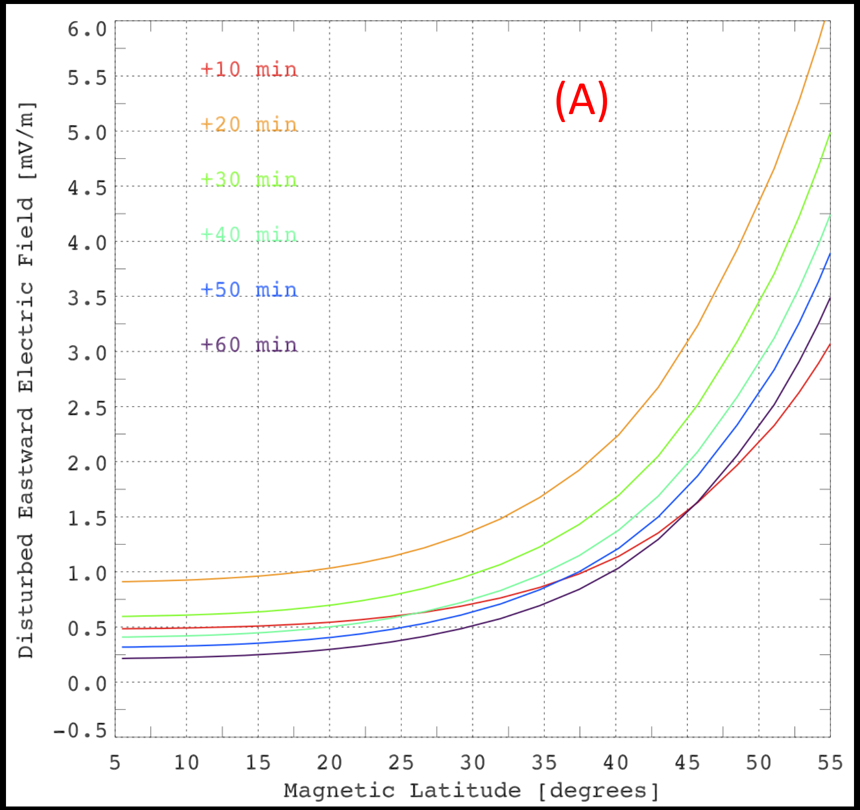


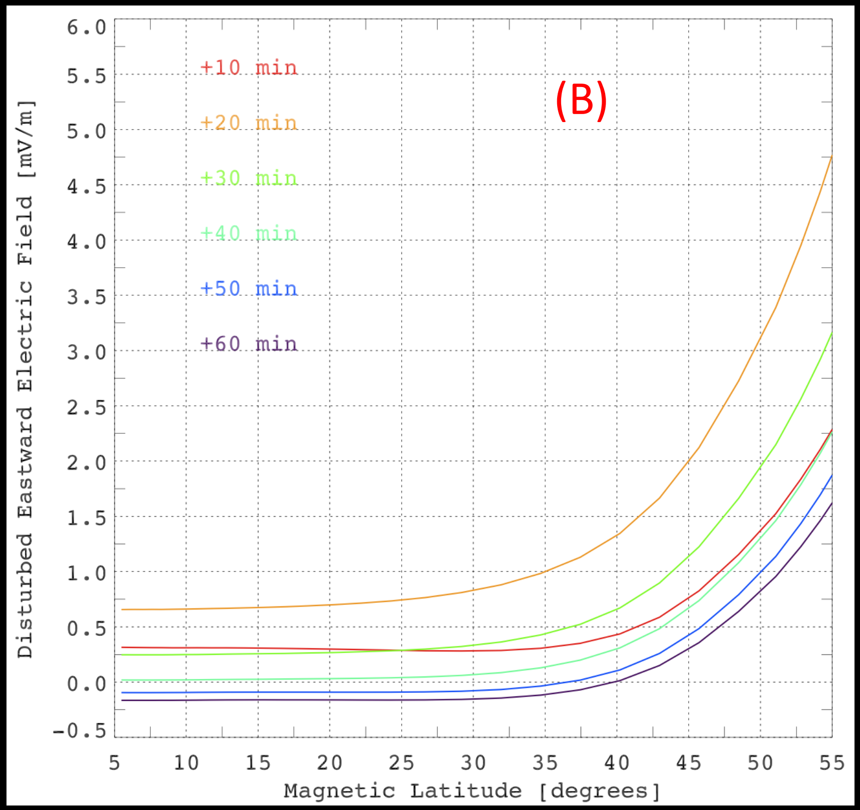
[Maruyama et al., 2011]

Disturbed I-T feedbacks to E-field



Disturbed Eastward E-fields Temporal Evolution





- Magnitude of the Disturbed E-field is much smaller at (B), becoming even negative as early as ~+45 min.
- Latitude profile is modified at (B)
- because of DD effect (disturbed I-T) [Huang et al., 2005] in addition to stronger magnetospheric shielding.

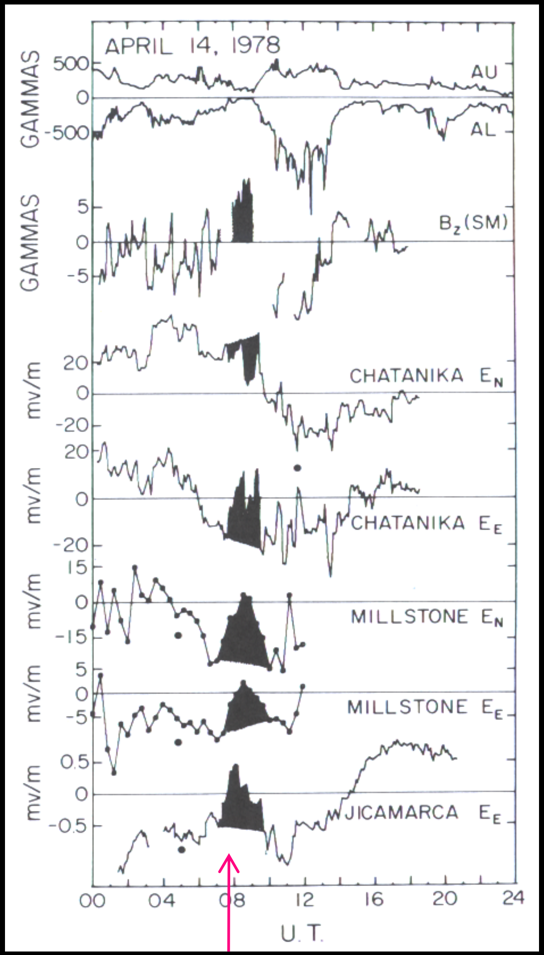
[Maruyama et al., 2011]

Unsolved Problems

- Separating out PP and DD under Overshielding
- Midlatitude storm time electric field needs more investigation
- Ground Based magnetometers need to be used more often
- Impact of lower atmospheric forcing on storm time electric field
- CME vs. CIR
- IMF By effect

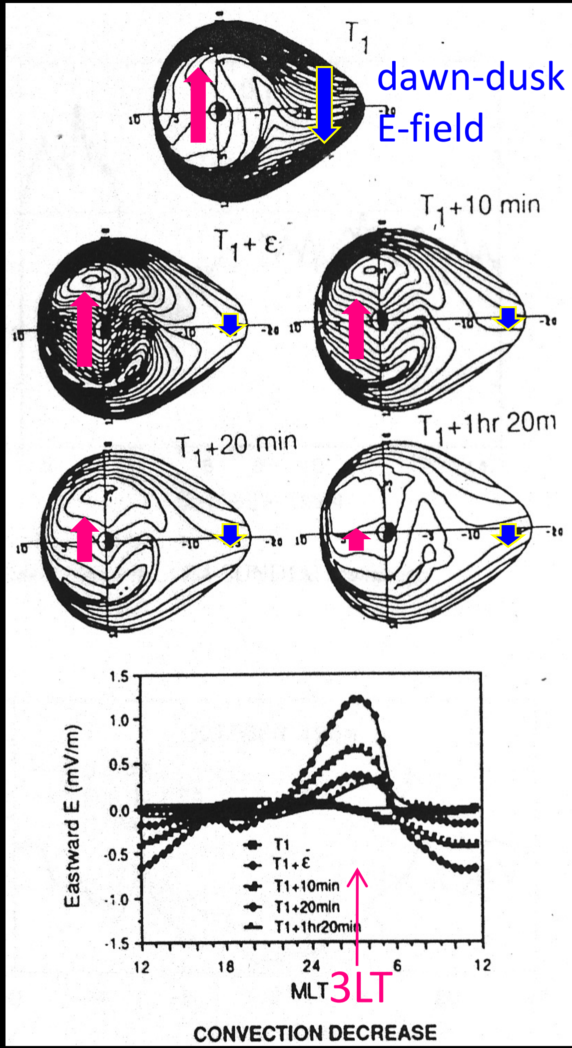
Overshielding Condition: IMF Bz northward turning can confuse DD
[*e.g., Fejer et al*, 1986; Spiro et al., 1988]

Classical PP from ISR obs.



[Kelley, 1989]

Rice Convection Model



[Fejer, 1986]

Reversed convection explained by Overshielding

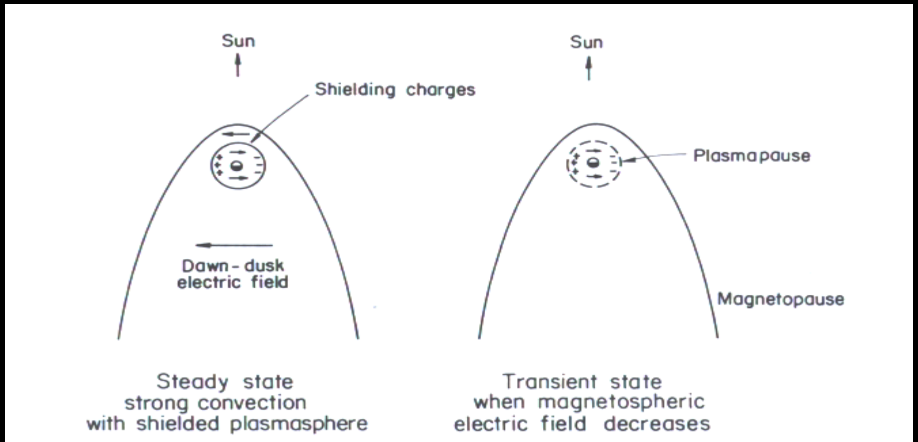
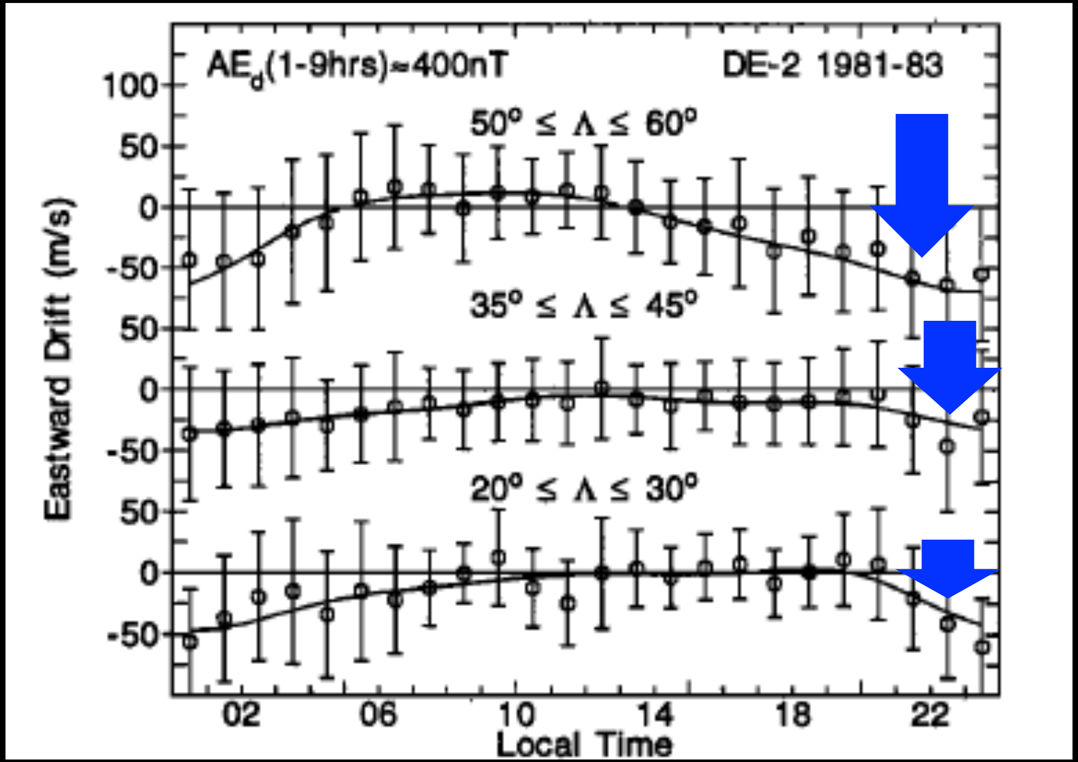


Fig. 3.23. Schematic diagram drawn in the equatorial plane showing how a rapid decrease in magnetospheric convection could create electric field changes inside the plasmasphere.

[Kelley, 1989]

Midlatitude Storm Time Disturbance Needs Investigation: Why Westward Drift Dominates?

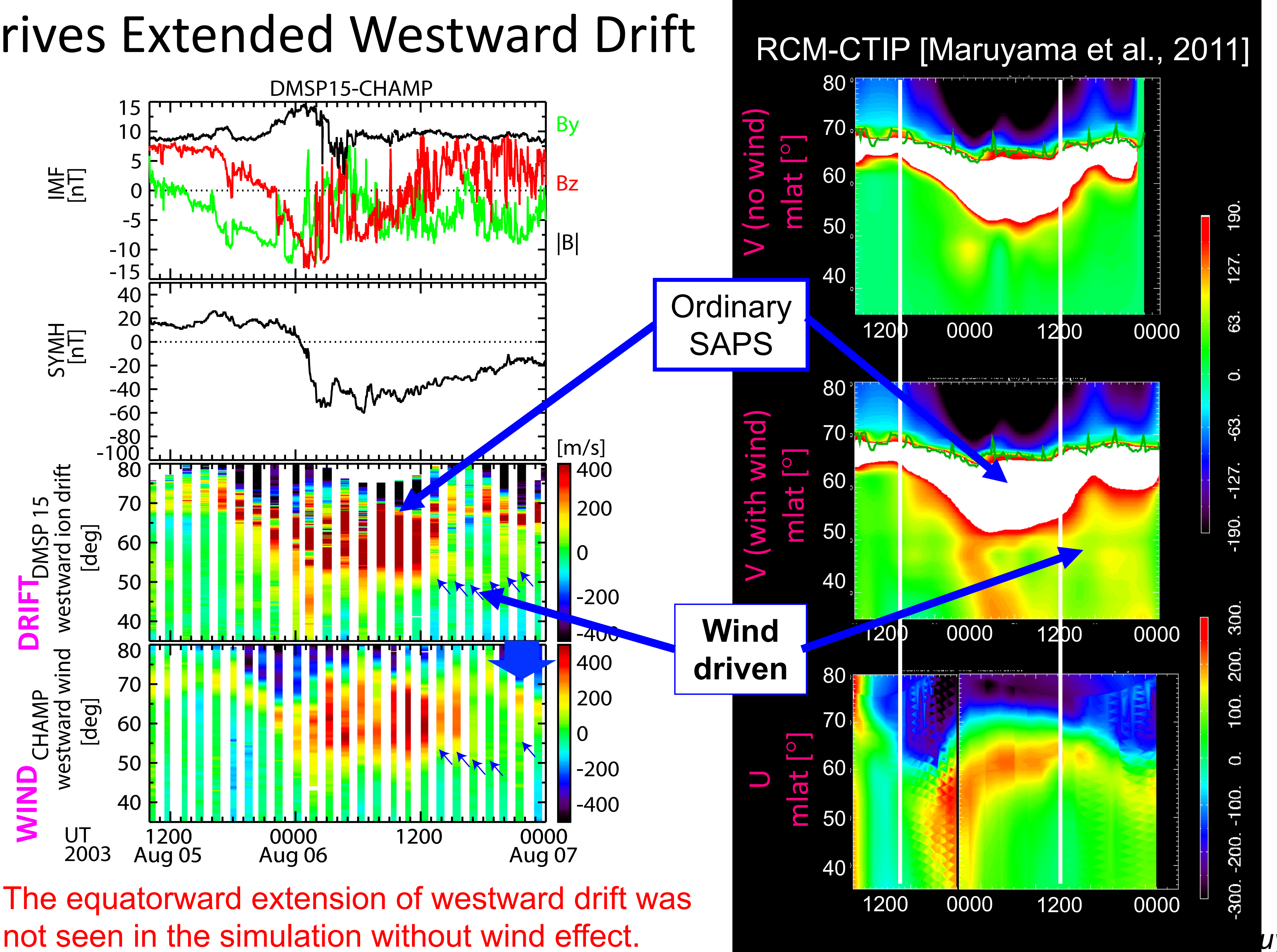
Midlatitude DD Zonal Drifts



[Scherliess and Fejer, 1998]

- Seasonal/longitudinal dependence of midlatitude DD E-fields and currents has not been determined.
- PP and steady state leakage of high latitude E- fields makes the identification of DD E- fields difficult even during quiet time
- IMF By effects cause large changes in the perturbation electric fields.
- Why westward drift dominates?

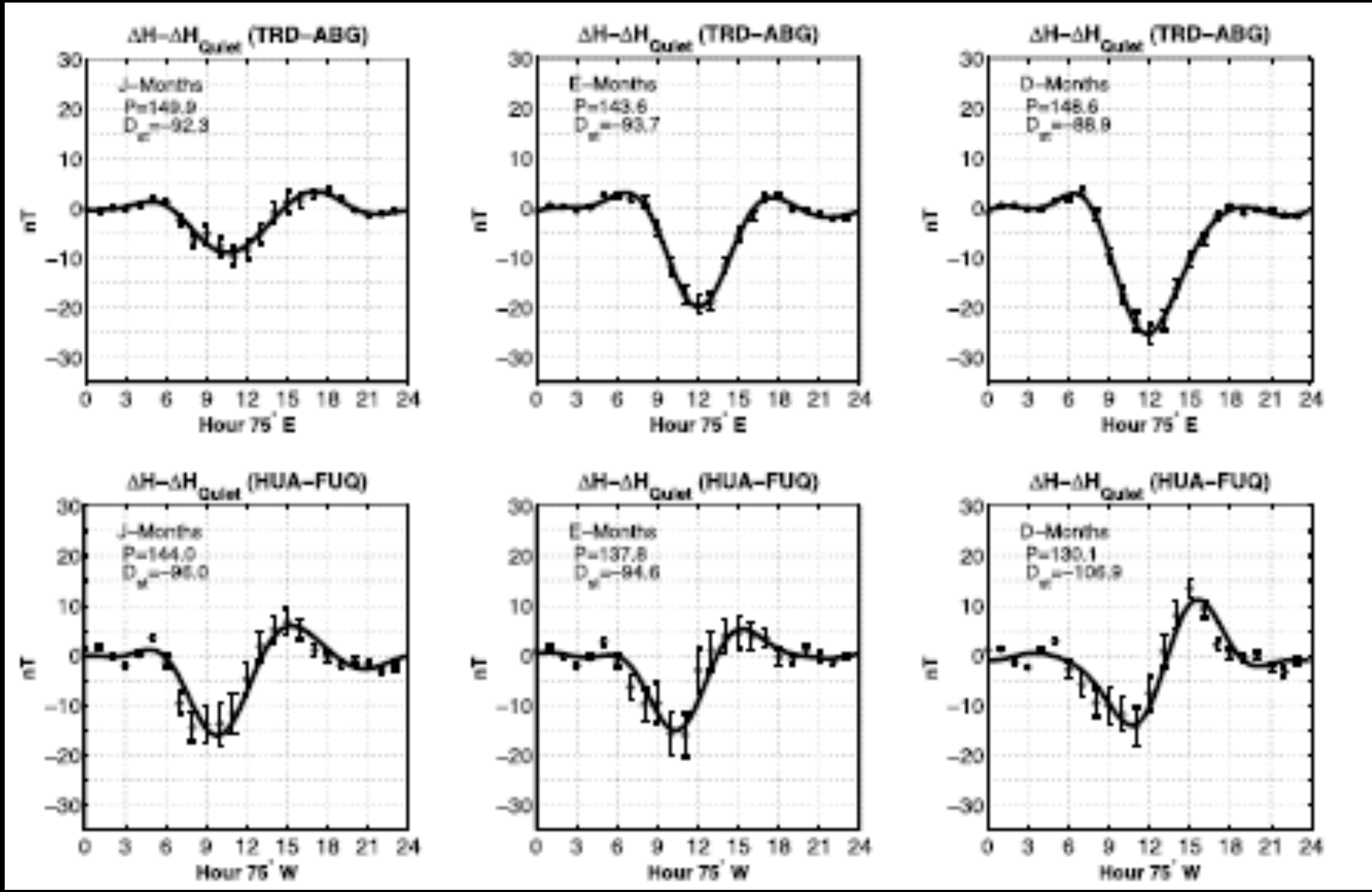
Wind Drives Extended Westward Drift



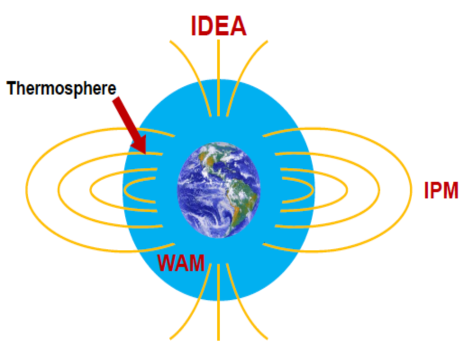
The equatorward extension of westward drift was not seen in the simulation without wind effect.

[...uyama et al 2013]

DD Seasonal dependence From Magnetometers

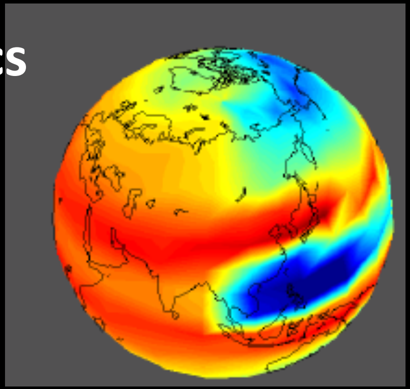


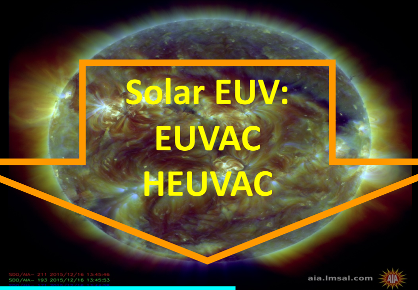
[Yamasaki and Kosch, 2014]

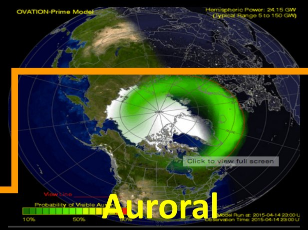


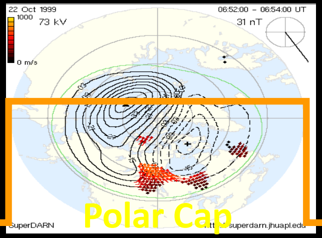
Ionosphere Plasmasphere Electrodynamics (IPE) Model

[Maruyama et al., 2015; Sun et al., 2015]









Solar EUV:
EUVAC
HEUVAC

Auroral Precipitation

Polar Cap Potential: Weimer

Whole Atmosphere Model

MSIS/ HWM

T,U,N

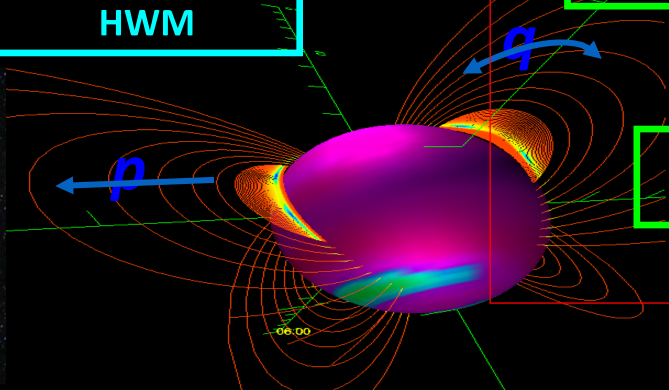
IPE

80 X 170 = 13,600 flux tubes
~3.5 Million grid points

Ionosphere/Plasmasphere (FLIP 1D) [Richards et al]
Ne, Ni, Te, Ti, Vi

Ionospheric Potential [Richmond et al, 1992]
Φ, E, J

IGRF: APEX coordinates [Richmond 1995]



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