Storm Time Ring Current - Atmosphere Interactions: Observations and Modeling

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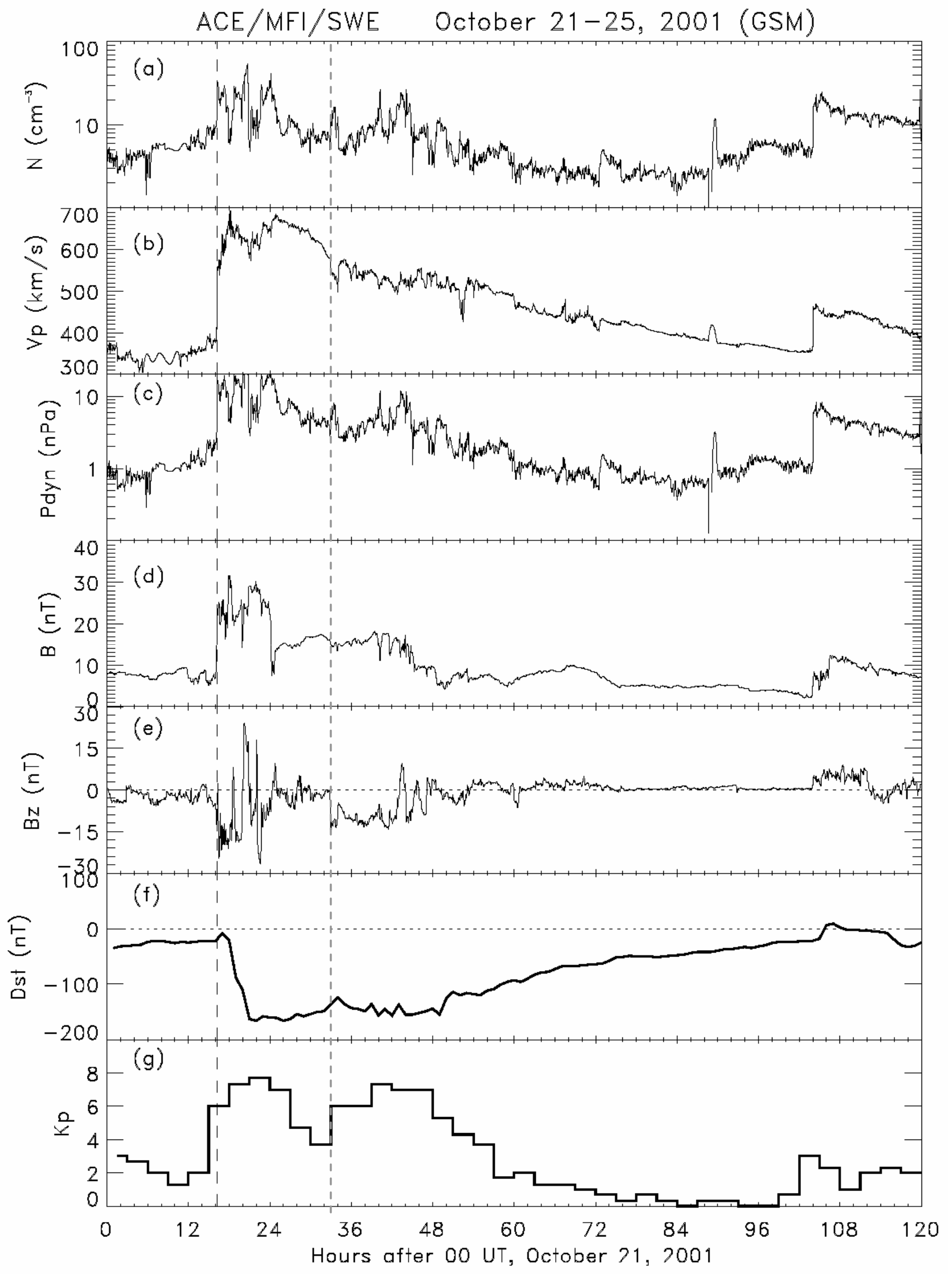
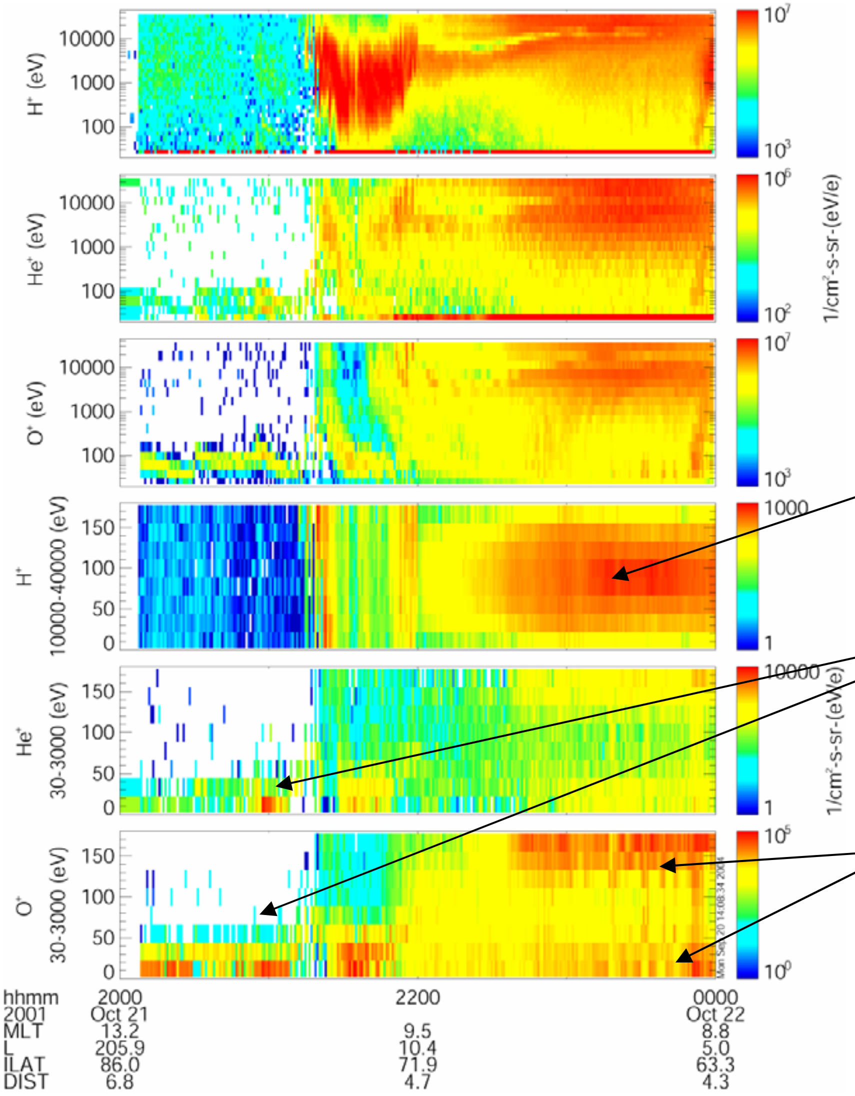
- Simulate the ring current-atmosphere interactions during the large geomagnetic storm of **October 21 - 25, 2001** using data from the **MPA** and **SOPA** instruments on **LANL** spacecraft
- Investigate the relative role of a) the convection electric field, b) radial diffusion, and c) wave-particle interactions on the dynamics of energetic particles
- Obtain **H^+**, **He^+**, and **O^+** ion and **electron** fluxes and study ring current dawn-dusk **asymmetry**; obtain global images of **EMIC** wave growth and ion precipitation
- Compare model results with **Cluster, NOAA, and Polar** observations & ***Dst*** index
- Acquire knowledge needed for the development of an equatorial convection electric field model

Interplanetary Observations: October 21-25, 2001

- An interplanetary shock was observed at ~16 UT on October 21
- IMF Bz~-20 nT & solar wind speed v~700km/s; a 2nd negative Bz~-15 nT excursion at hour~33
- Triggered a large geomagnetic storm with *Dst*~-190 nT; strong geomagnetic activity lasting for about a day with 2nd minimum in *Dst*~-165 nT
- Two enhancements of $Kp=8^-$ and $Kp=7^+$ occurred at hour~22 and hour~40



Cluster/CODIF Data: October 21, 2001



- Energy spectra and pitch angle spectra for H⁺, He⁺ and O⁺ in the prenoon sector as the S/C goes toward perigee (4.0 Re)
- The energy spectra clearly show the deep minimum at about 10 keV in all species

At high energies H⁺ peak @ 90 degrees

Low energy O⁺ and He⁺ outflow

In the inner magnetosphere field aligned low energy O⁺ from both hemispheres

NOAA-15 MEPED Ion Data

- The Medium Energy Proton and Electron Detector (**MEPED**) is an instrument that has been flown on the **NOAA** series of polar orbiting meteorological satellites
- Fluxes of locally mirroring ions

  (a),(b) - 30-80 keV

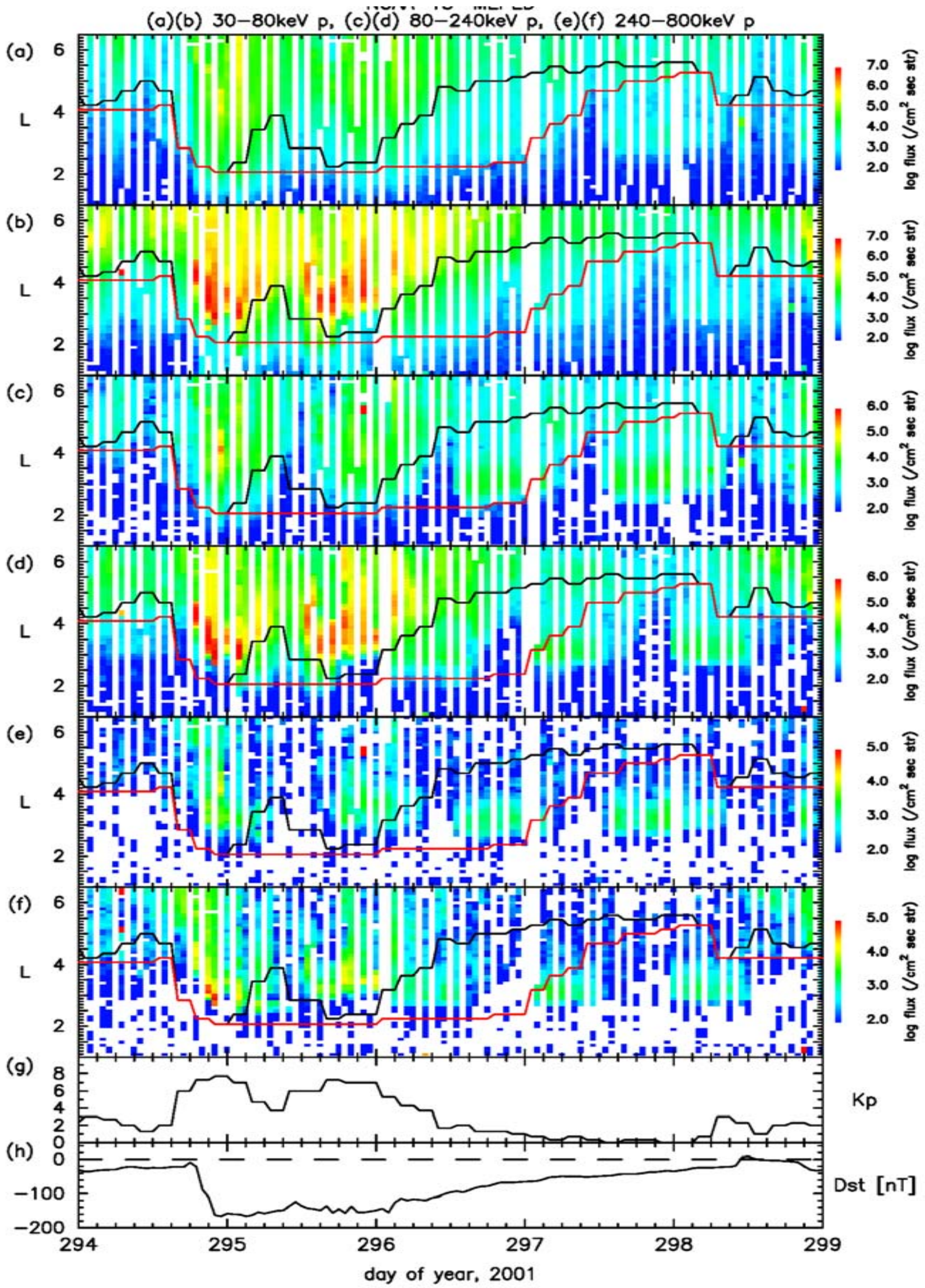
  (c),(d) - 80-240 keV

  (e),(f) - 240-800 keV
- Asymmetric flux enhancement near **dusk** during the main phase

  (a), (c), (e) - dawn, MLT=7

  (b), (d), (f) - dusk, MLT=19

——— plasmapause position



Kinetic Model of the Terrestrial Ring Current

$$\frac{\partial F_t}{\partial t} + \frac{1}{R_o^2}\frac{\partial}{\partial R_0}\left(R_o^2\left\langle\frac{dR_0}{dt}\right\rangle F_t\right) + \frac{\partial}{\partial \varphi}\left(\left\langle\frac{d\varphi}{dt}\right\rangle F_t\right) + \frac{1}{\gamma p}\frac{\partial}{\partial E}\left(\gamma p\left\langle\frac{dE}{dt}\right\rangle F_t\right) +$$

$$\frac{1}{h(\mu_o)\mu_o}\frac{\partial}{\partial \mu_o}\left(h(\mu_o)\mu_o\left\langle\frac{d\mu_o}{dt}\right\rangle F_t\right) =$$

$$\left\langle\left(\frac{\partial F_t}{\partial t}\right)_{rd}\right\rangle + \left\langle\left(\frac{\partial F_t}{\partial t}\right)_{\substack{charge\\ exchange}}\right\rangle + \left\langle\left(\frac{\partial F_t}{\partial t}\right)_{\substack{Coul\\ collis}}\right\rangle + \left\langle\left(\frac{\partial F_t}{\partial t}\right)_{wpi}\right\rangle + \left\langle\left(\frac{\partial F_t}{\partial t}\right)_{atm}\right\rangle$$

where

$$\left\langle\left(\frac{\partial F_t}{\partial t}\right)_{rd}\right\rangle = R_o^2\frac{\partial}{\partial R_0}\left(\frac{1}{R_o^2}\left\langle D_{R_oR_o}\right\rangle\frac{\partial F_t}{\partial R_o}\right) \qquad \text{and} \qquad \gamma = 1 + \frac{E}{m_o c^2}$$

R_o - radial distance in the equatorial plane

φ - azimuthal angle

p - relativistic momentum

$\mu_o = \cos(\alpha_o)$, where α_o is equatorial pitch angle

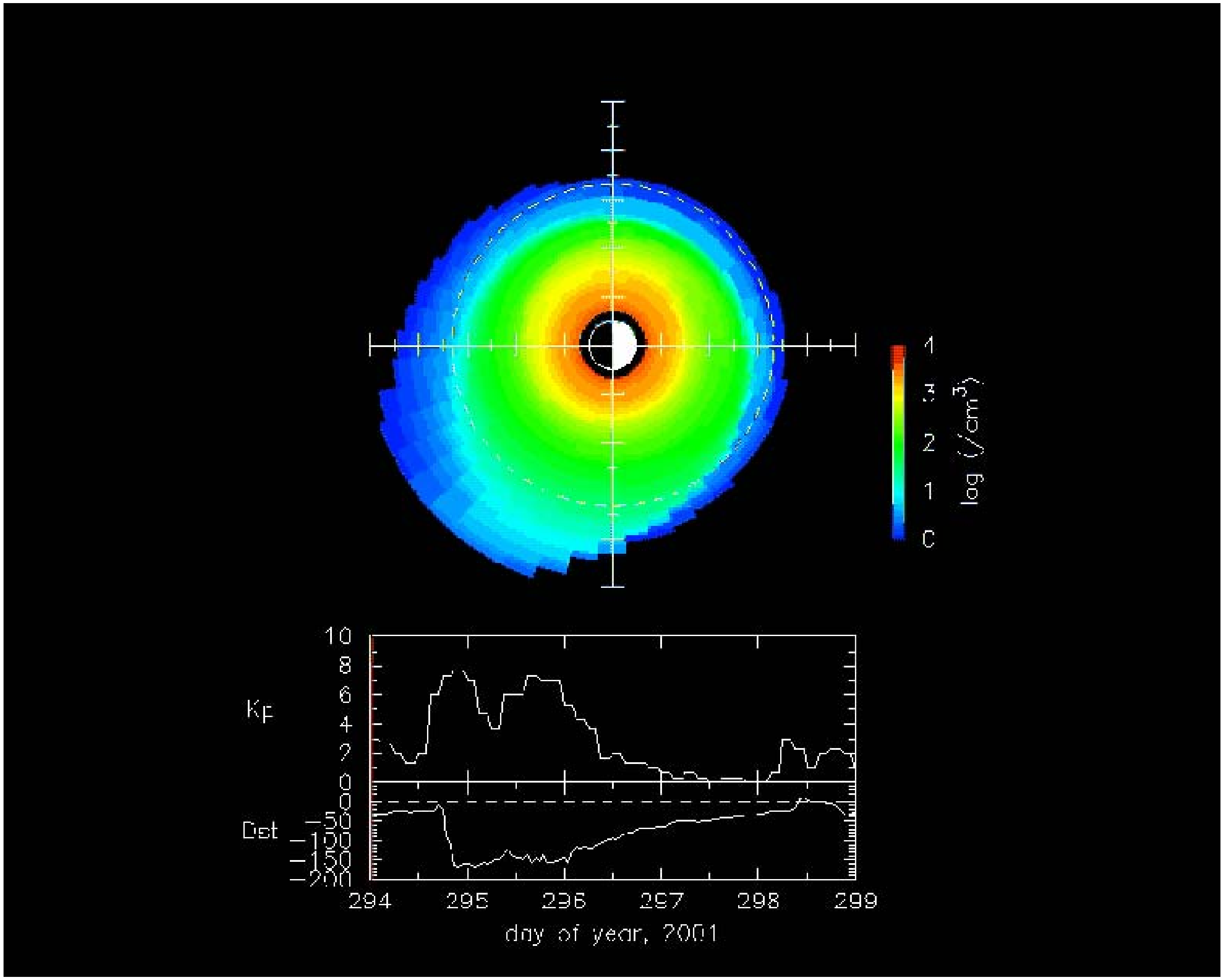
γ - **relativistic factor**, m_o - rest mass,

$D_{R_oR_o}$ - **radial diffusion** coefficients

$$h(\mu_o) = \frac{1}{2R_o}\int_{s_m}^{s_m'}\frac{ds}{\sqrt{1 - B(s)/B_m}}$$

Plasmasphere Model: October 2001

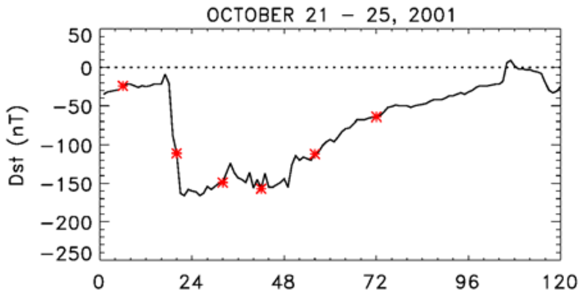
Equatorial plasmaspheric electron density
Ion composition: 77% H^+, 20% He^+, 3% O^+



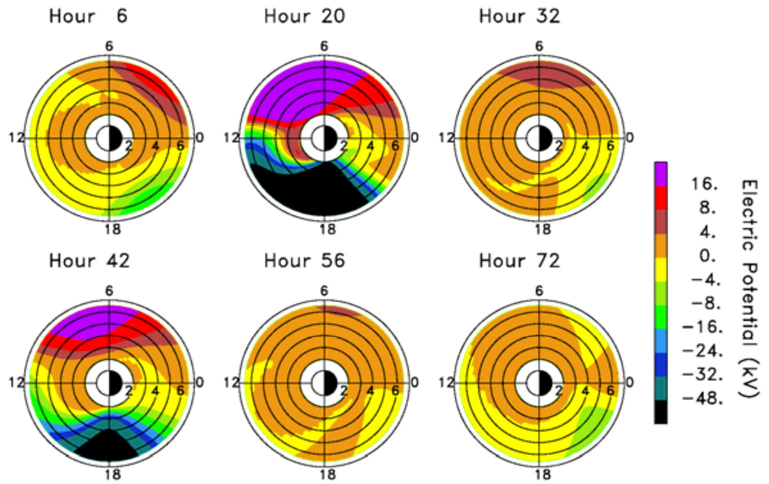
Inner Magnetospheric Convection

Electric potential in the equatorial plane:

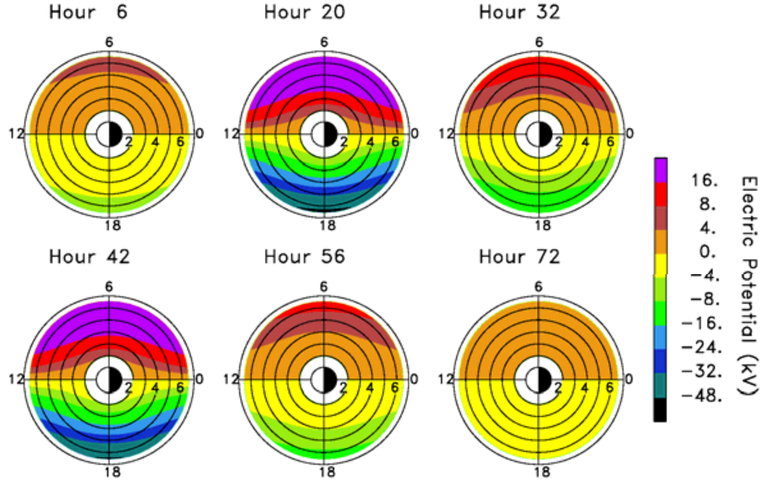
- Both models predict strongest fields during the main phase of the storm
- **Volland-Stern** model is **symmetric** about dawn/dusk by definition
- **Weimer** model is more **complex** and exhibits variable east-west symmetry and penetrates to lower *L* shells during active times



(a) WEIMER MODEL



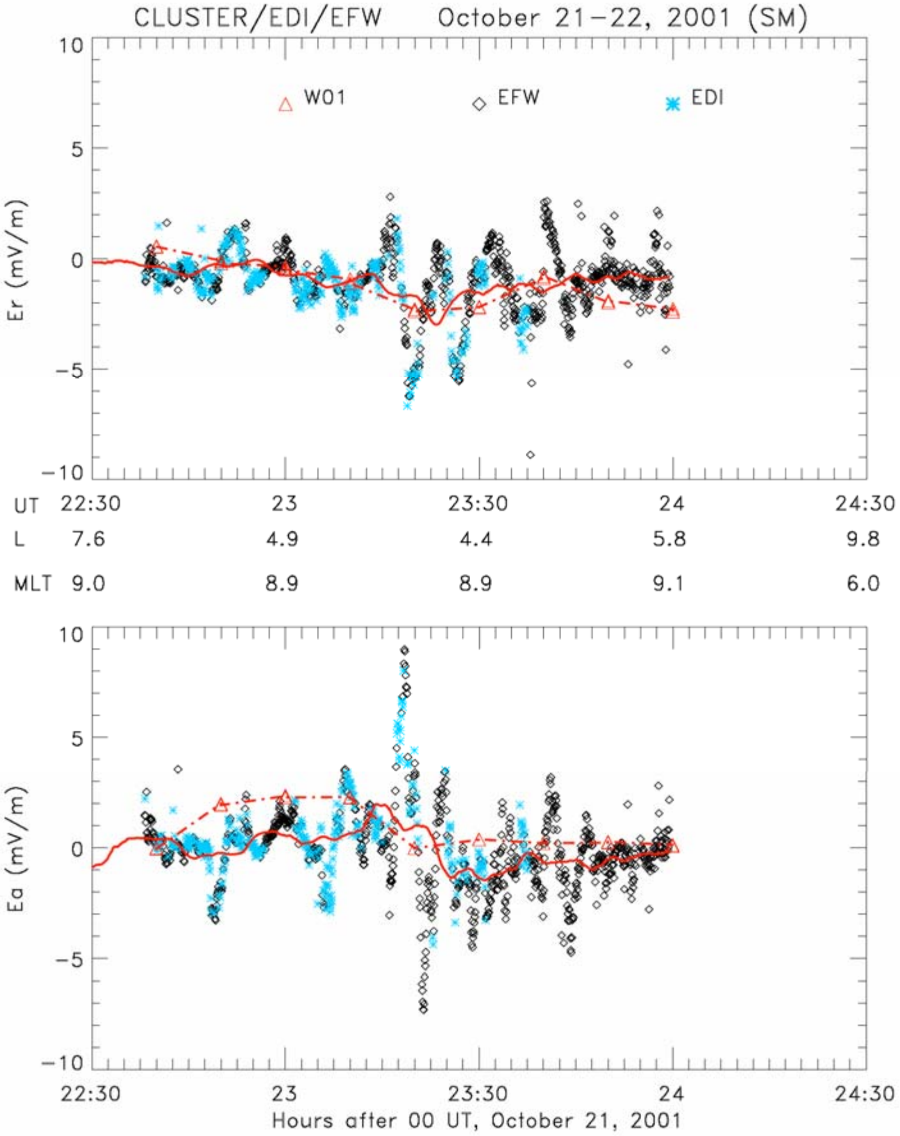
(b) VOLLAND–STERN MODEL



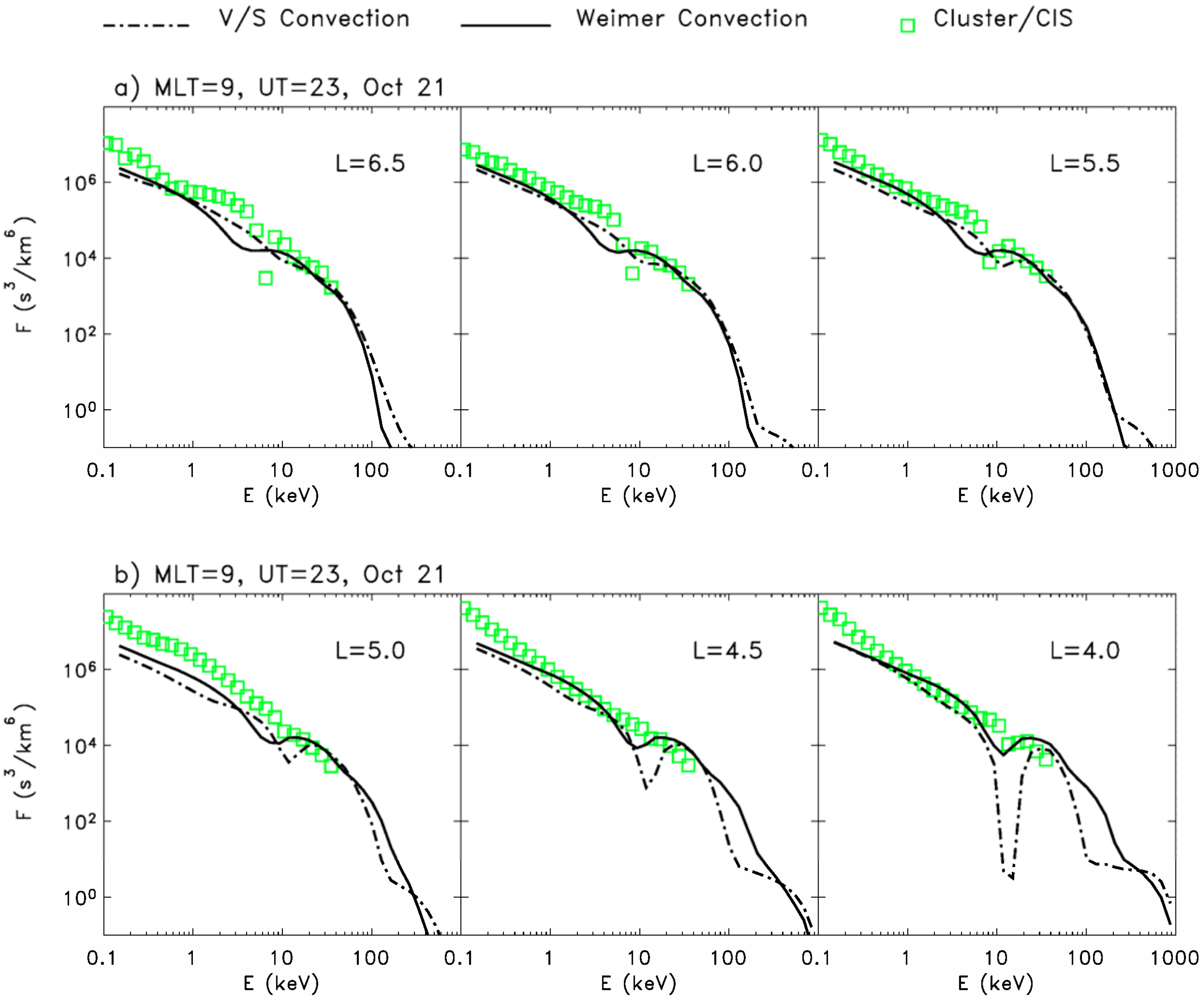
Cluster EDI & EFW Data and Model Comparison

Electric field in the equatorial plane during the storm main phase:

- The fields are mapped to the SM magnetic equator for each 4 s using the Tsyganenko magnetic field model; signatures of ULF (Pc5) waves are seen
- The solid red line indicates 10-min running averages of the data
- **Weimer** model reproduces very well the radial component but not the azimuthal electric field component

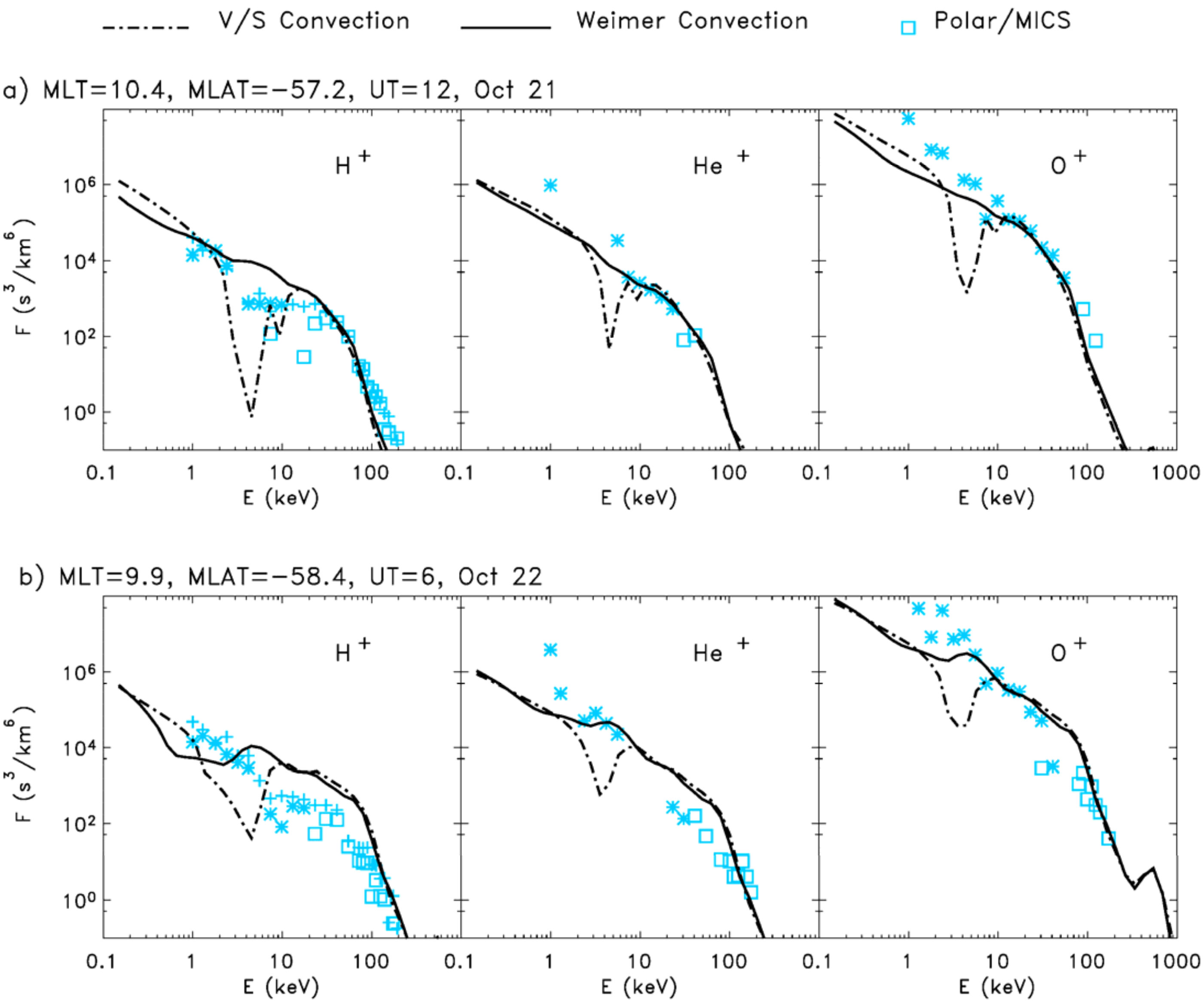


Model H^+ Comparison with CLUSTER/CIS Data

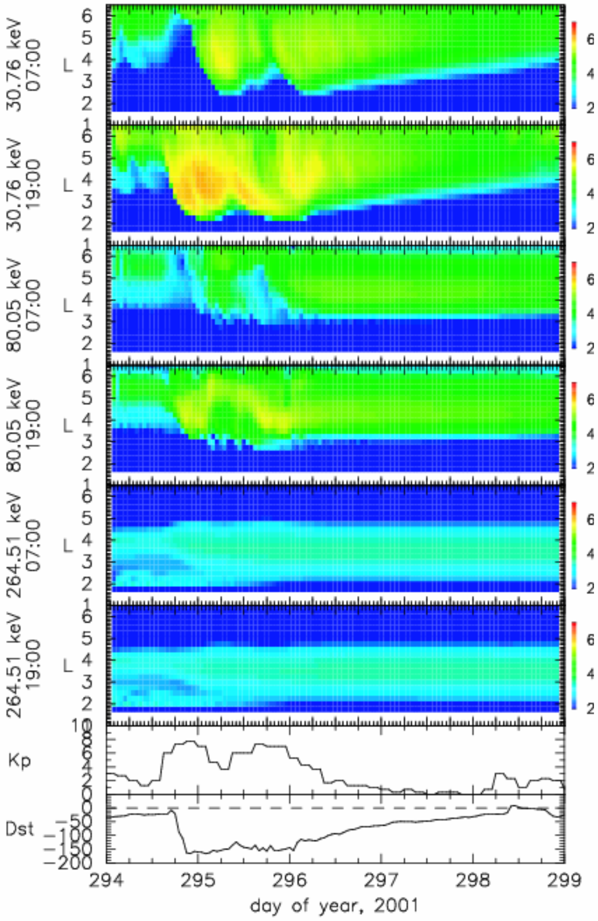


- Volland-Stern model underestimates the distribution within the stagnation dip at low *L*

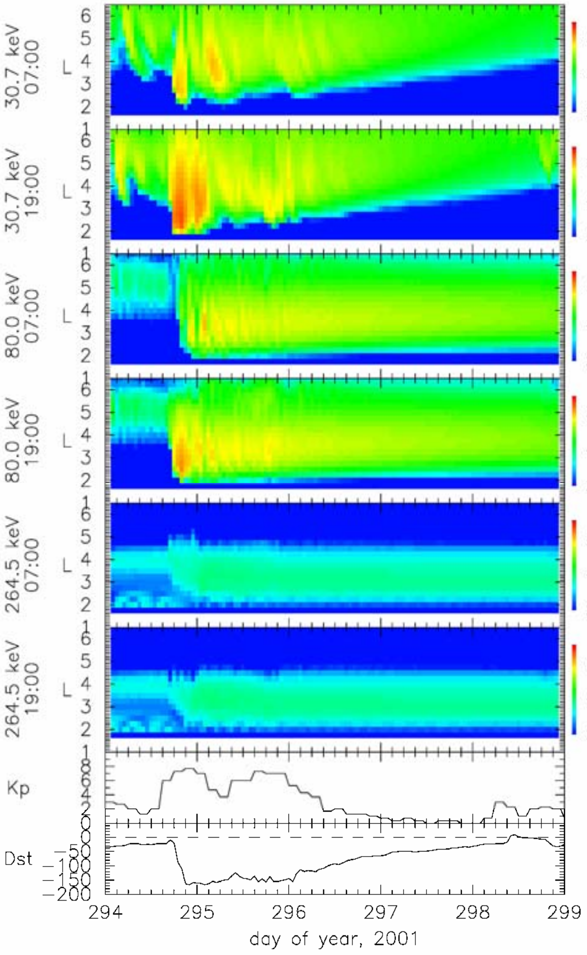
Model Comparison with Polar/MICS Data: Main Phase



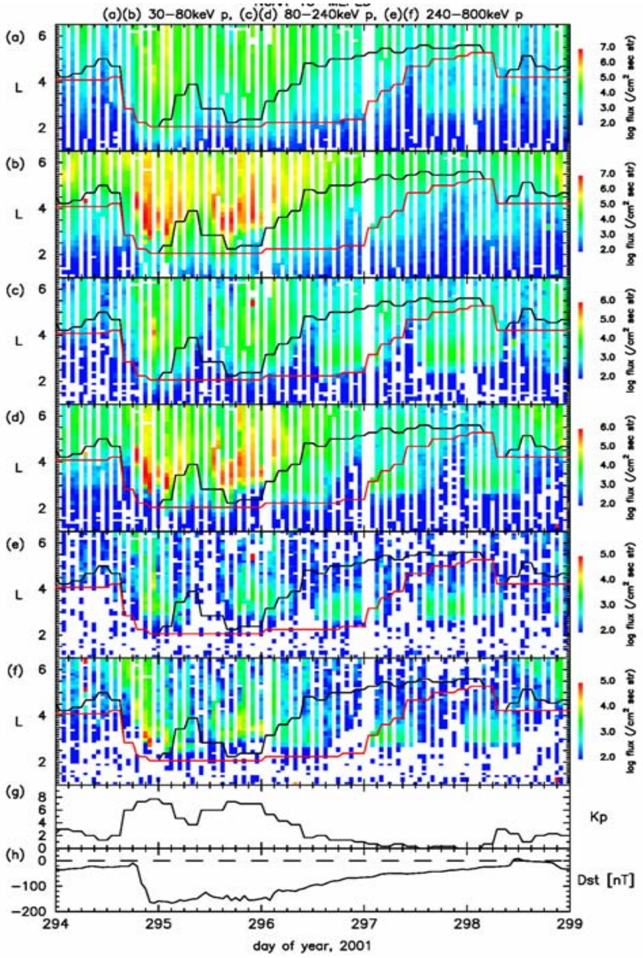
Model Comparison with NOAA Data



H$^+$ Volland-Stern Flux



H$^+$ Weimer Flux



NOAA/MEPED Data

- Good agreement at 30 keV near dusk, Weimer model reproduces better the timing of the enhancement at dawn but overestimates the magnitude

Self-Consistent Wave-Particle Interactions Model

- Convective growth rates of **EMIC** waves are **self-consistently** calculated using the hot plasma dispersion relation:

  $$\frac{\gamma_{\omega}}{V_{g}} = \Psi\left(n_{t}, E_{II}, A_{t}\right)$$

  where n_t, E_{II}, A_t are calculated with our kinetic model for **H^+**, **He^+**, and **O^+** ions

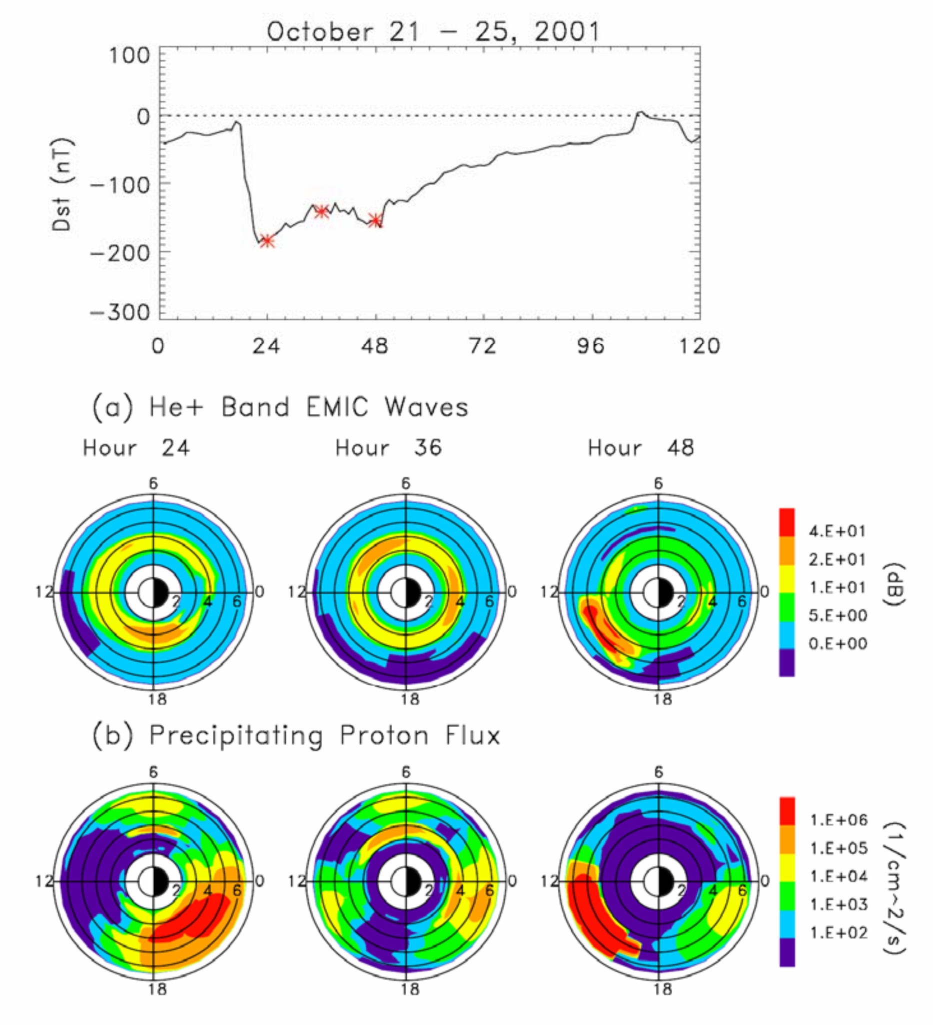
- The local growth rates are integrated along wave paths which are field-aligned and extend over ±5° magnetic latitude (±10° at the plasmapause) to obtain the **wave gain *G* (dB)**

- We calculate the wave amplitude **B_w(nT)** using:
  - $B_w = 10 \times 10^{(G-G_{max})/G_{min}}$ for $G_{min} < G < G_{max}$
  - $B_w = 10$ nT for $G > G_{max}$

  since the amplitudes of EMIC waves reach saturation values of 10 nT in the inner magnetosphere

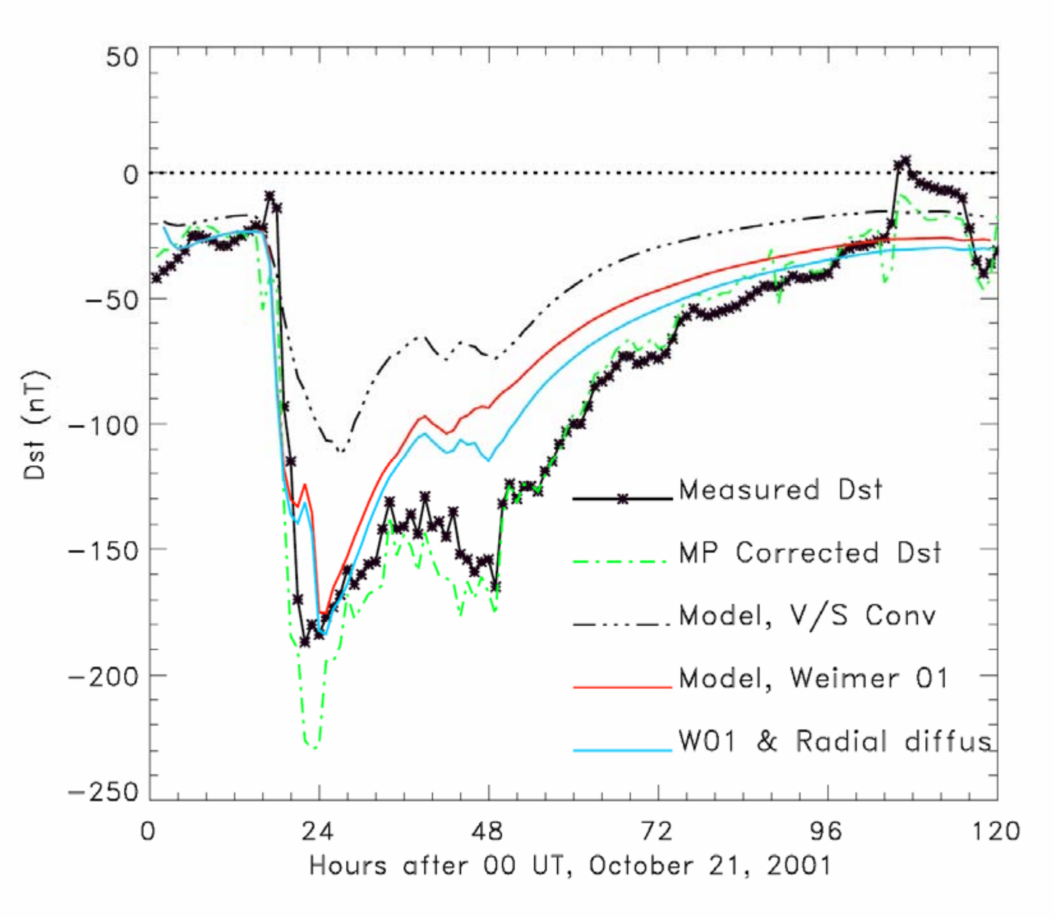
EMIC Waves Excitation and Ion Precipitation

- We calculated the wave growth of EMIC waves from the **He$^+$ band** (between O$^+$ and He$^+$ gyrofrequency)
- Intense EMIC waves are generated near ***Dst* minima** and during the recovery phase
- **Ion precipitation** is significantly enhanced within regions of EMIC wave instability by wave-particle interactions



Ring Current Energization & Dst

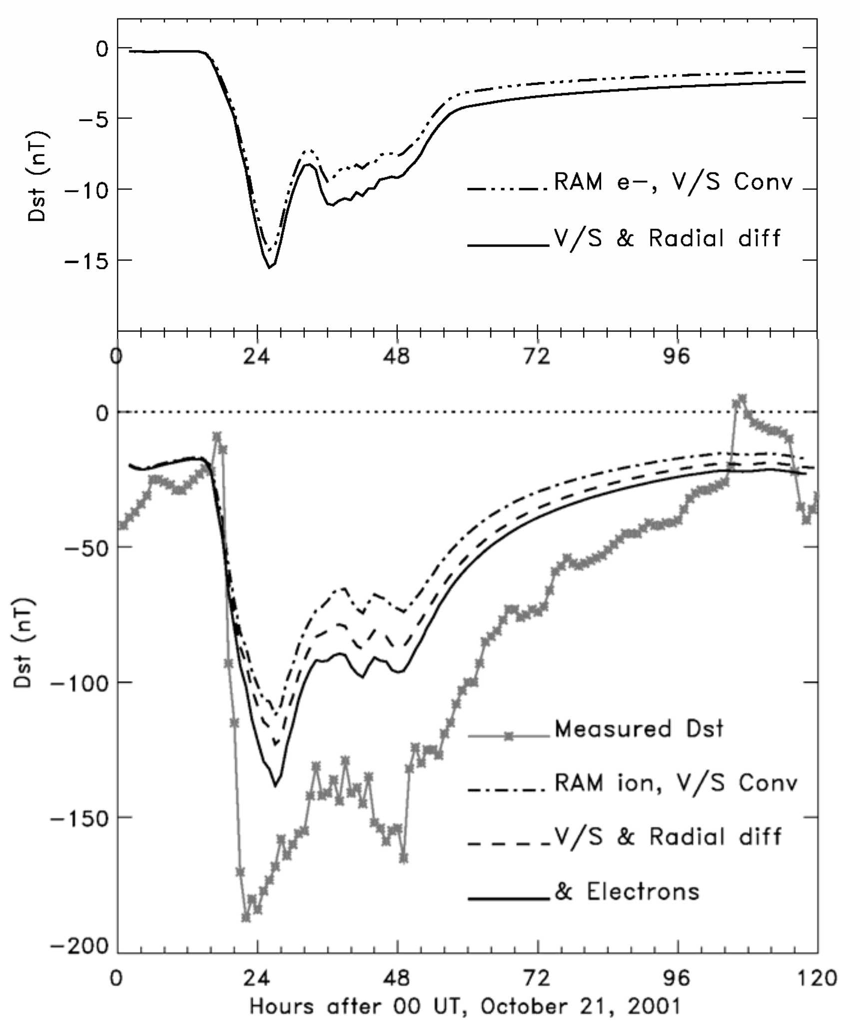
- The *Dst* index is underestimated when the **Volland-Stern** convection model is used
- Ring current energization is increased during the main phase when the **Weimer** model is used
- **Radial diffusion** enhances significantly ring current buildup during the 2nd *Dst* minimum, giving better agreement with observations



Contribution of Ring Current Electrons

- ➢ **Radial diffusion** injects high-energy particles deep into the magnetosphere (*L*<4) and increases the total ring current energy by **~15%** near minimum *Dst*

- ➢ The **electron** contribution is small (~2%) during quiet times and reaches maximum values of **~10%** near *Dst* minima



Conclusions

We simulated ring current (RC) dynamics during the large storm of October 21-25, 2001 and compared results from a) **Volland-Stern**, and b) **Weimer** convection electric field models:

- Both models reproduced the enhancement of ~30-80 keV fluxes near dusk seen in **NOAA** data; the enhancement near dawn was underestimated using a *Volland-Stern* model
- Weimer model reproduced very well the radial component of the merged **Cluster/EDI/EFW** electric field; significant differences were seen in the azimuthal component
- The comparison with **Polar/MICS** and **CLUSTER/CIS** in-situ data showed good overall agreement with both models; Volland-Stern underestimated the fluxes within the stagnation dip
- Intense **EMIC waves** were generated during the main and recovery phases; this caused a significant enhancement of the **ion precipitation** predicted with the model. Scattering by EMIC waves caused about 10% reduction of the total RC energy
- Comparison with ***Dst*** index showed:

  - the *Dst* index was underestimated when the **Volland-Stern** convection model was used; **Weimer** model reproduced faster RC buildup and better agreement with observations

  - radial diffusion did not affect RC buildup during the early main phase but increased significantly the total ring current energy during the recovery phase
- Further extensions of this work will consider constructing an **equatorial convection electric field model** of the inner magnetosphere based on merged EDI and EFW data

Acknowledgments

Many thanks are due to:

- **M. Thomsen and G. Reeves,** Los Alamos National Laboratory, NM
- **Y. Miyoshi,** Solar-Terrestrial Environment Lab, Nagoya University, Japan
- **J. Fennell,** Aerospace Corporation, Los Angeles, CA
- **D. Evans,** SEC/NOAA, Space Environment Lab, Boulder, CO

This work is supported in part by NASA under grants NNG05GG50G and NAG5-13512, and NSF under grant ATM-0309585.

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