Global Simulations of Ring Current Development

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Challenges to develop a comprehensive model of the ring current with **predictive capabilities**:

- **thorough understanding** of the mechanisms involved in the transport, acceleration, trapping, and loss of energetic particles
- develop **a self-consistent treatment** of the plasma and the fields
- need to consider **multi-scale coupling** across spatial, temporal, and energy scales

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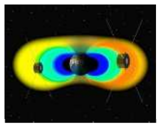
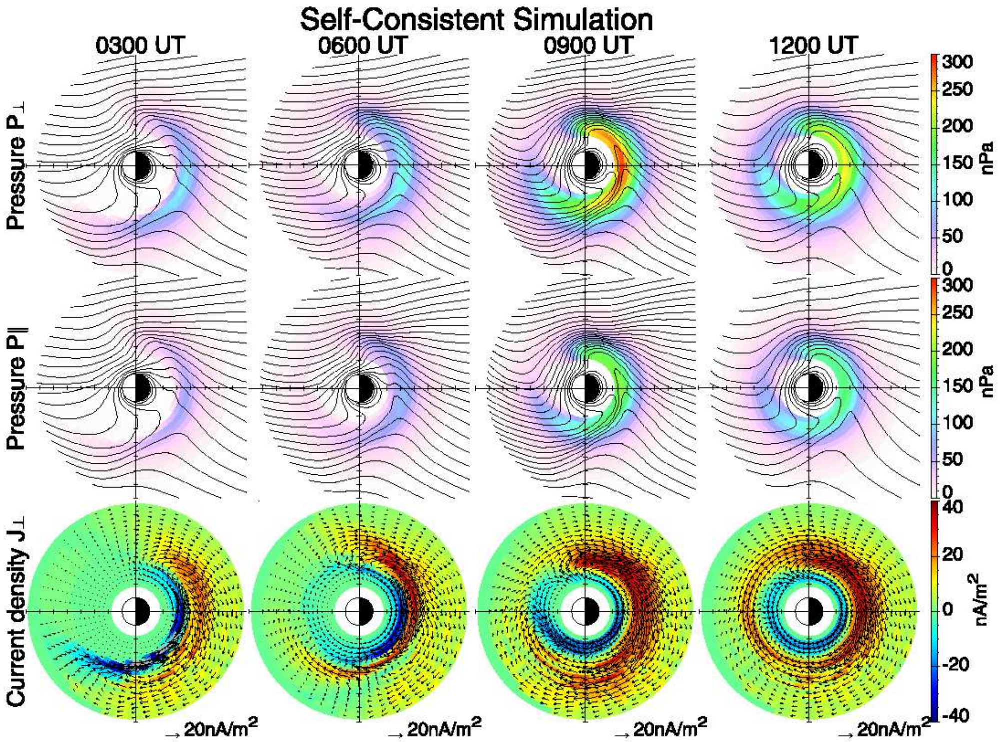


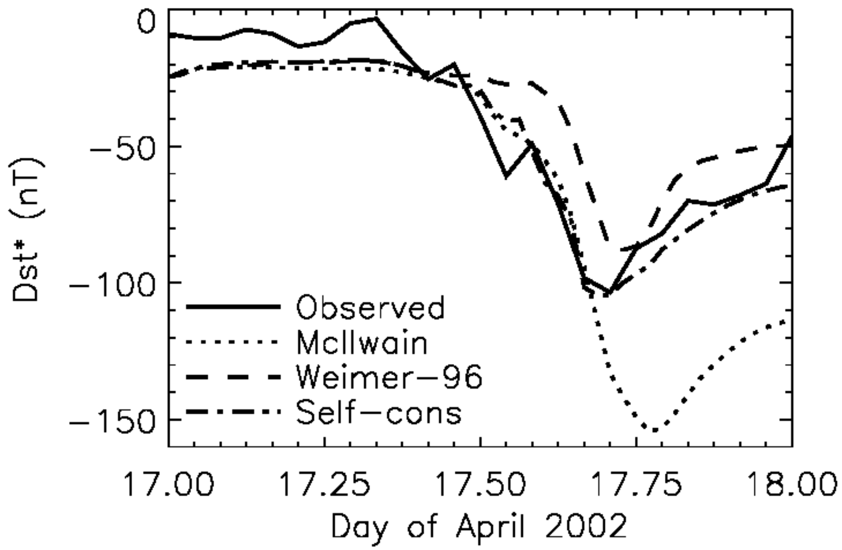
RBSP/EMFISIS

RBSP/ECT

GEM-CEDAR Workshop, Boulder, 23 June, 2013

Electrically Self-consistent Models





Ring current parameters during the 12 August 2000 storm [Ebihara et al., 2004] using the CRCM, which couples the Fok et al. [2001] ring current model with the Rice Convection Model [Wolf et al., 1982]

Dst* from MI-RAM using three electric field descriptions: modified McIlwain, Weimer 96 model, and a self-consistent Poisson equation solution [Liemohn et al., 2004]

Magnetically Self-consistent Models (RAM-SCB)

Ring current-atmosphere interactions model (RAM)

[Jordanova et al., 1994, 2006]

- Bounce-avg. Boltzmann equation for H^+, O^+, and He^+ ions and electrons
- Including all major loss processes & radial diffusion
- Convection/corotation electric field
- Updated to general B field
- Coupled with a plasmasphere model

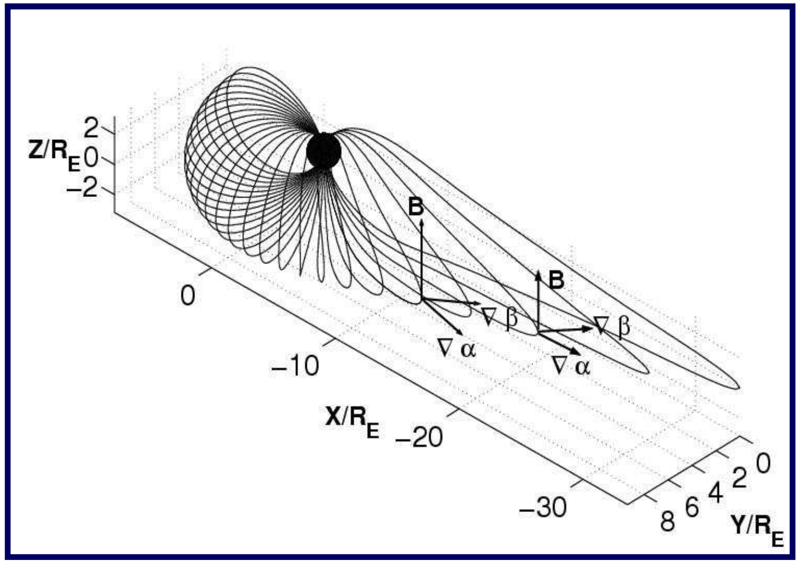
Pressure →

← B-field

3D equilibrium code

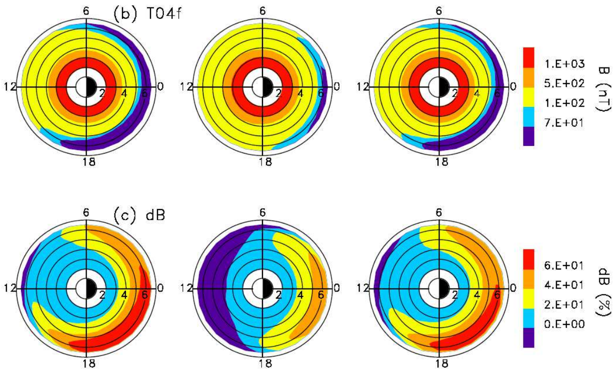
[Cheng, 1995; Zaharia et al., 2006]

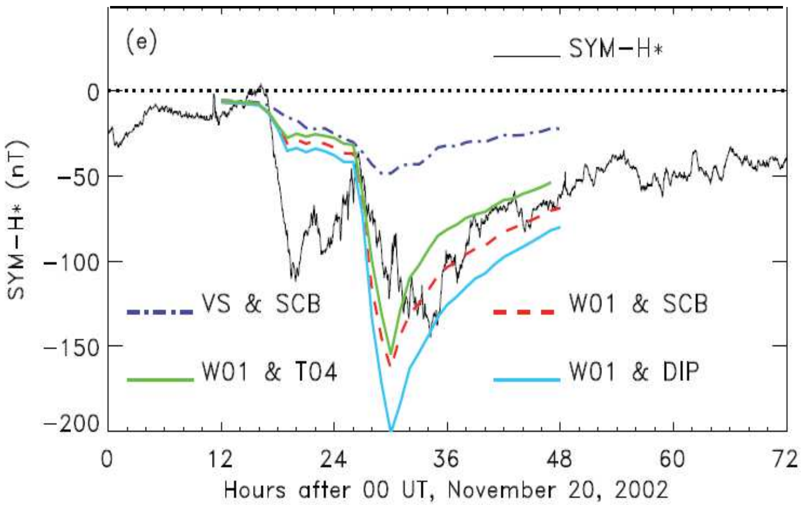
$$\mathbf{J} \times \mathbf{B} - \nabla \cdot \mathbf{P} = 0$$



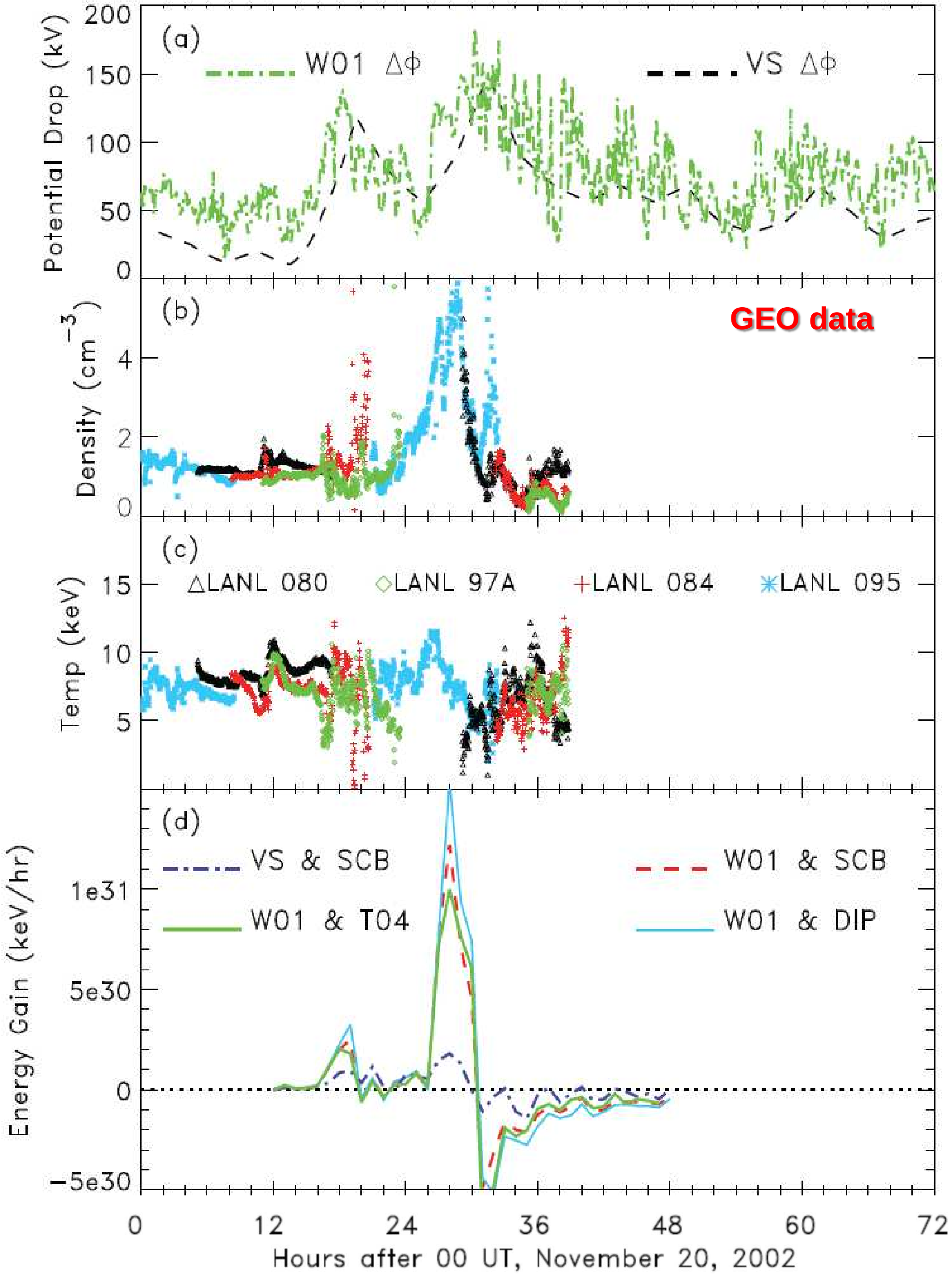
- Euler potentials (flux coordinates)
- Empirical B-field BCs

Ring Current Development and Dst Index

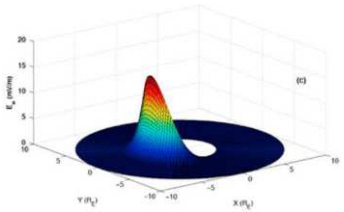




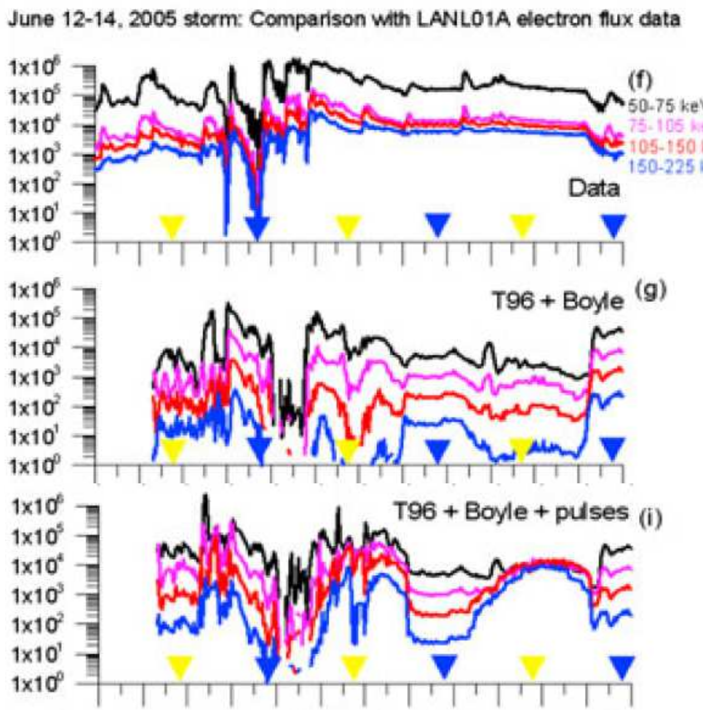
The calculated **ring current injection & Dst** using **T04 or self-consistent B field is smaller** reflecting the depression of the magnetic field on the nightside during disturbed times [Jordanova et al., 2010]



Role of Induced Electric Field

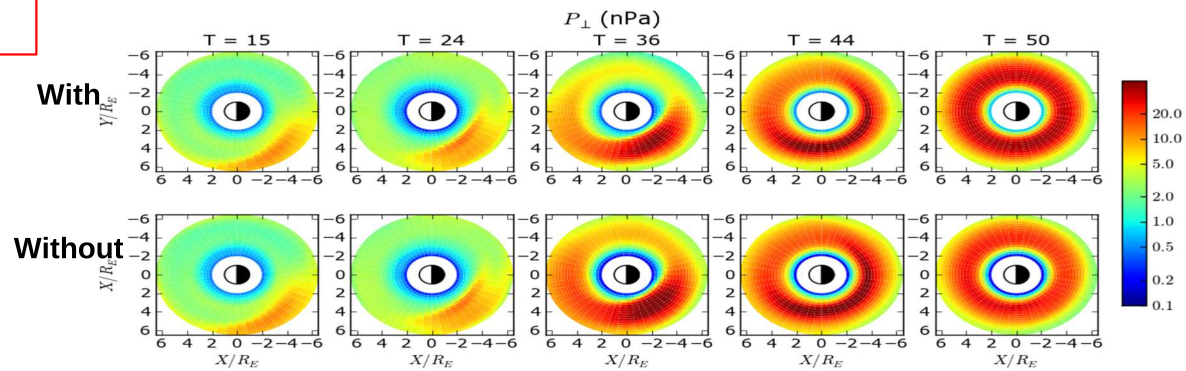


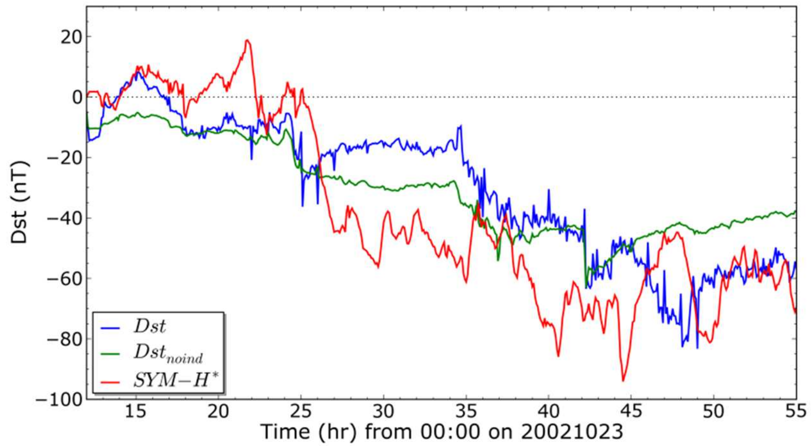
Including an earthward-propagating electromagnetic pulse



Transport of low-E (50-250 keV) electrons with IMPTAM model [Ganushkina et al., 2013] from 10 Re to GEO shows **increase in the electron fluxes up to 2 orders of magnitude** when substorm-associated impulsive fields are taken into account

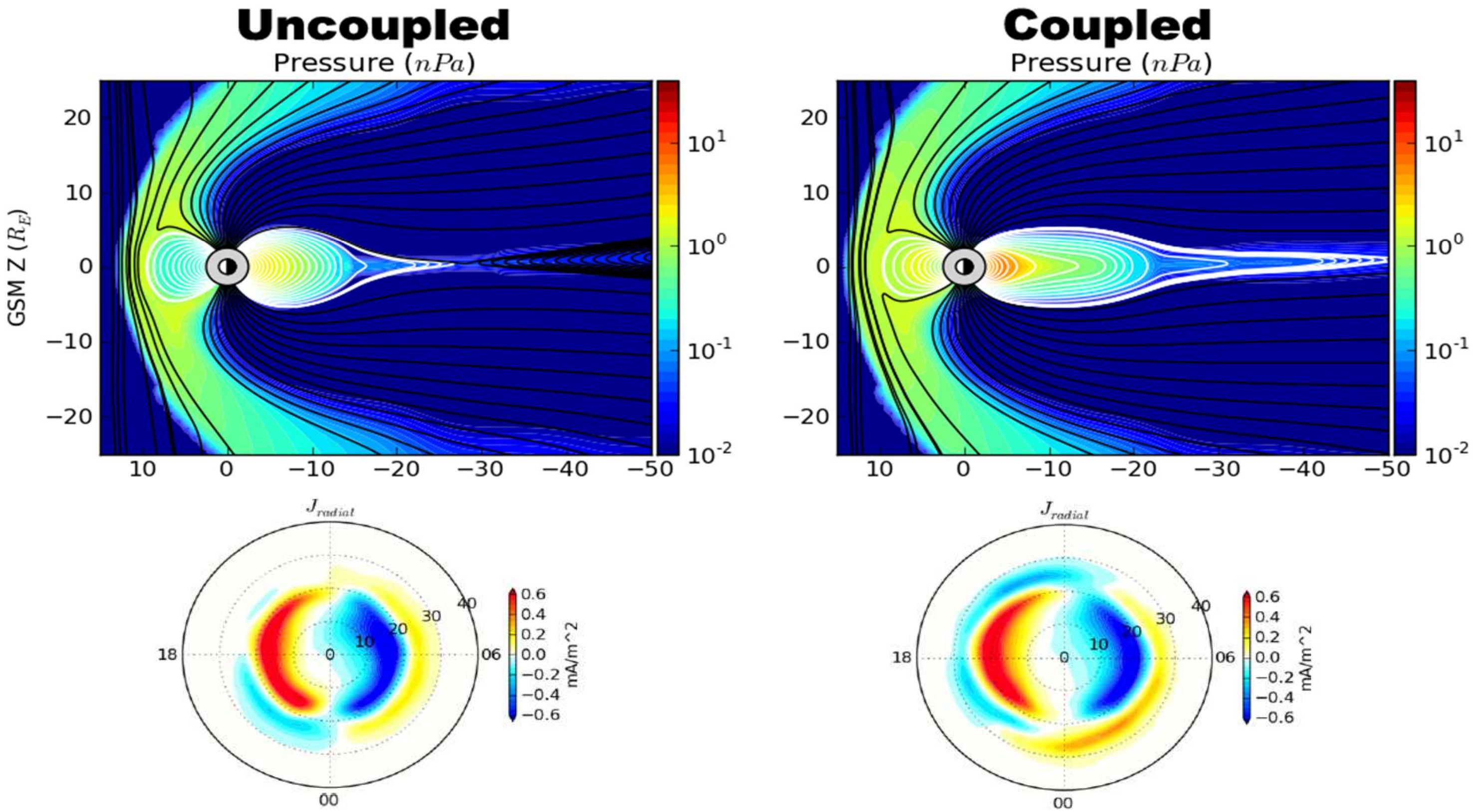
Calculating E-field induced by B-field changes in 3-D code SCB





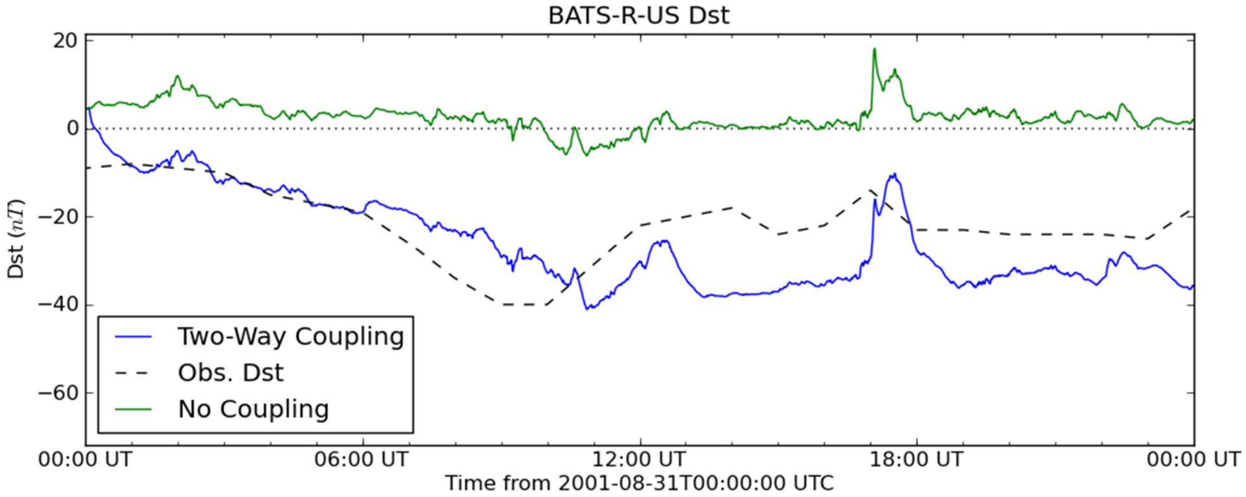
- E_{ind} slightly decreases ring current pressure in main phase but significantly increases ring current pressure in recovery phase
- Effect of induced E-field: weaker main phase ring current, but **stronger at peak (by ~ 50%) and during recovery phase** [Zaharia et al., 2008]

Coupling Global MHD with Ring Current Models

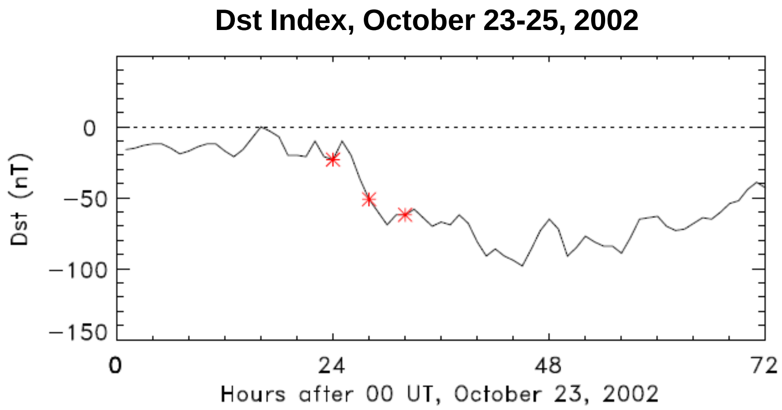


Two-Way Coupling of RAM-SCB with SWMF/BATSRUS:

- increased pressure near Earth, elongated magnetotail
- enhanced region 2 FACs
- modeled Dst from the coupled simulation follows observations far better than the uncoupled simulation



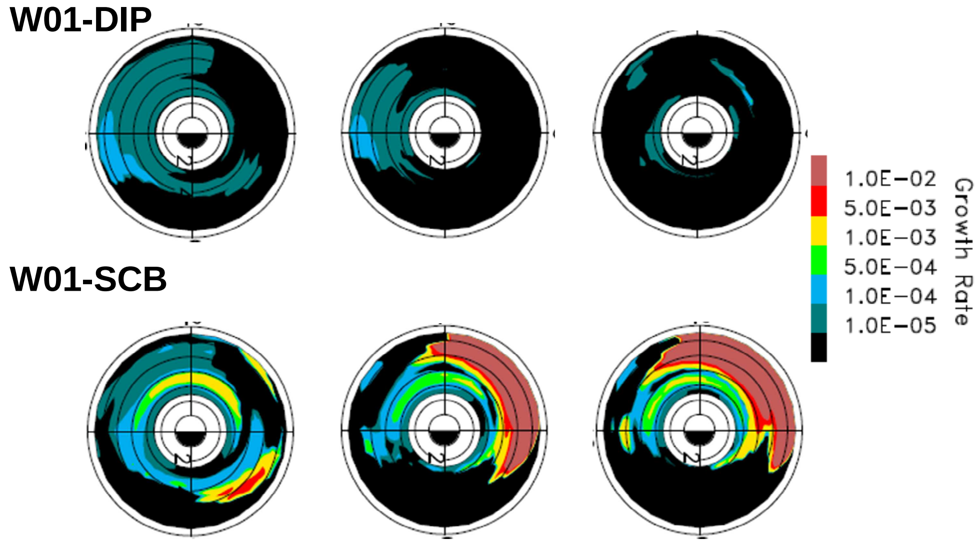
Ring Current Electron Instabilities



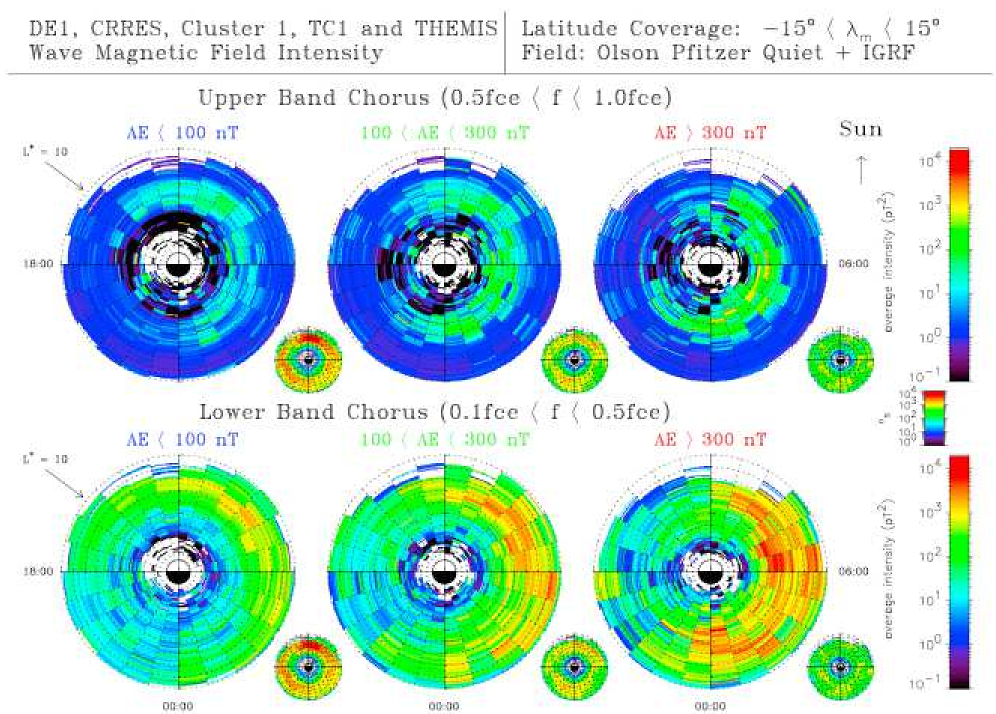
- The ring current **anisotropy** increases at larger L shells on the dawnside in the self-consistent B field simulations
- The **chorus** wave growth maximizes in the **dawnside** MLT sector outside the plasmasphere
- The convective growth rates are larger in **non-dipolar** B field simulations

⇒ These simulation results are consistent with a combined survey of the equatorial wave intensity for chorus waves using multiple spacecraft data from CRRES, THEMIS, Double Star, Cluster and DE1

Chorus Wave Simulations [Jordanova et al., 2012]

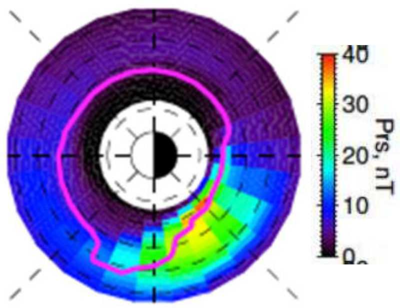


Chorus Wave Observations [Meredith et al., 2012]

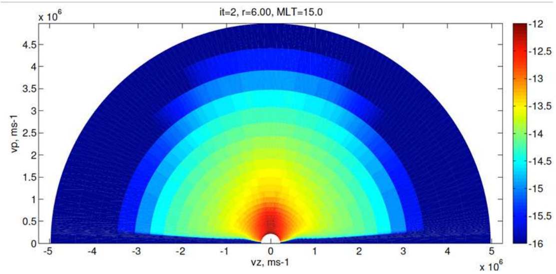


Ring Current Ion Instabilities

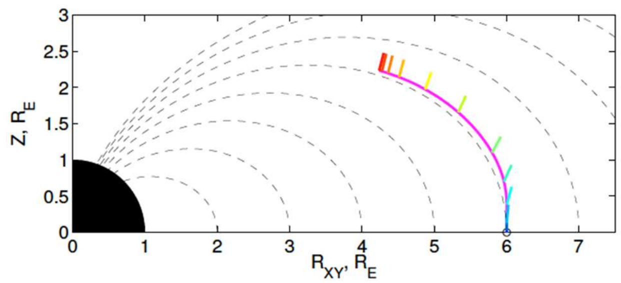
H+ pressure

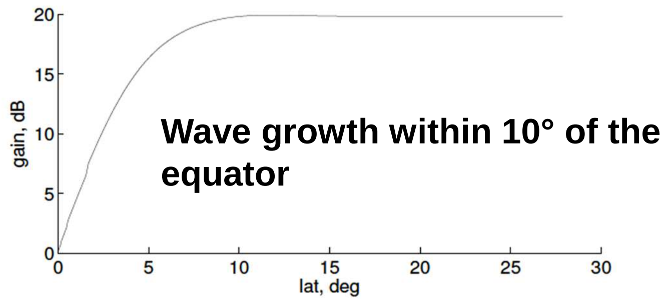


Anisotropic H+ ion distribution

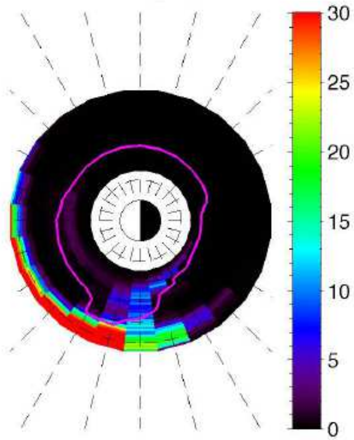


HOTRAY: He+ band is most unstable

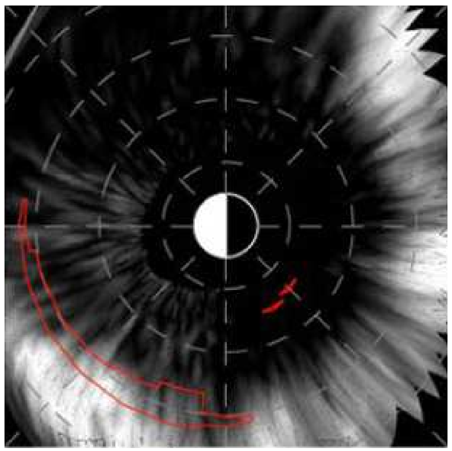




EMIC Wave Gain

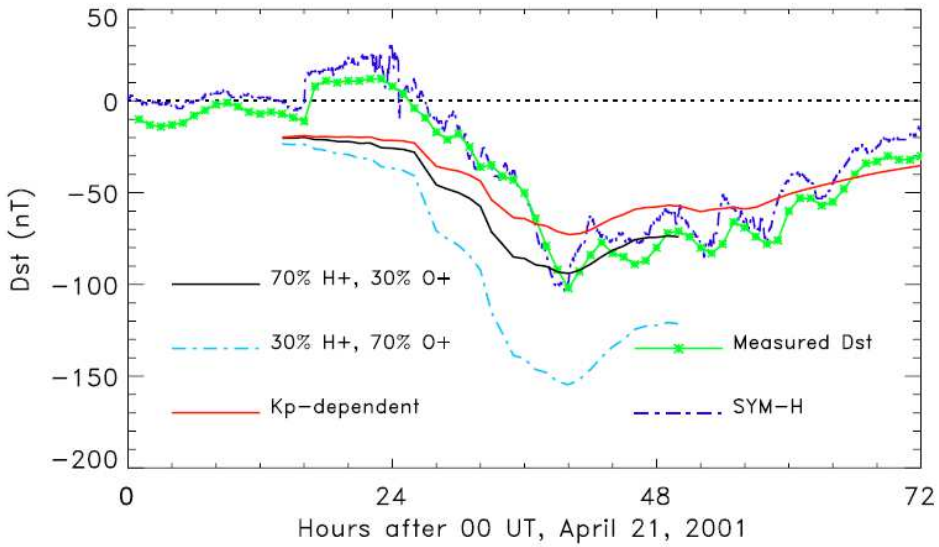


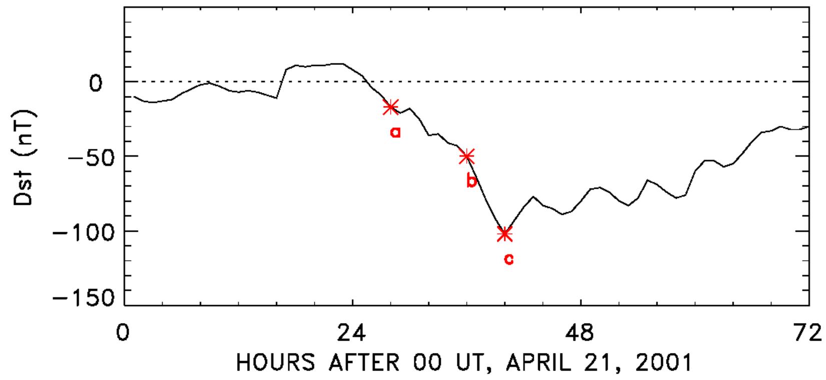
- The **RAM-SCB** code is used to follow the development of the ring current in the inner magnetosphere and to calculate anisotropic ion fluxes
- The **HOTRAY** code is used to obtain the path-integrated gain of EMIC waves from RAM distributions
- The region of strong wave gain (> 20 dB, red contour) agrees with region of strong proton precipitation observed with **IMAGE/FUV**

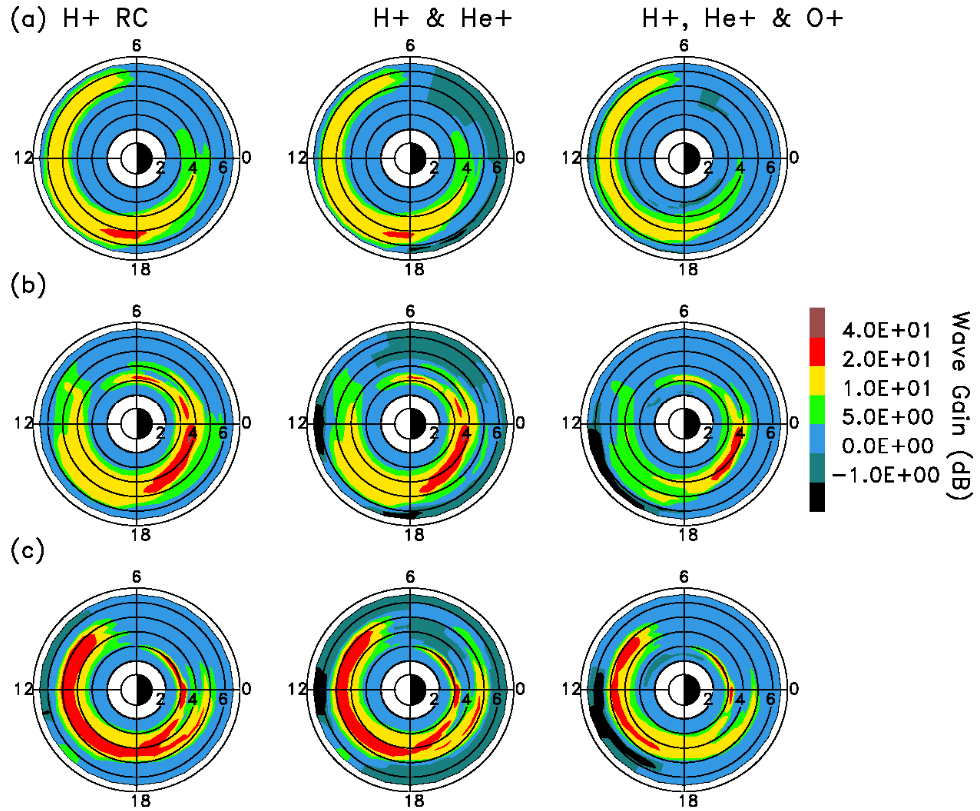


IMAGE/FUV proton aurora
19:00 UT, 09 Jun 2001

Effects of Ring Current Ion Composition







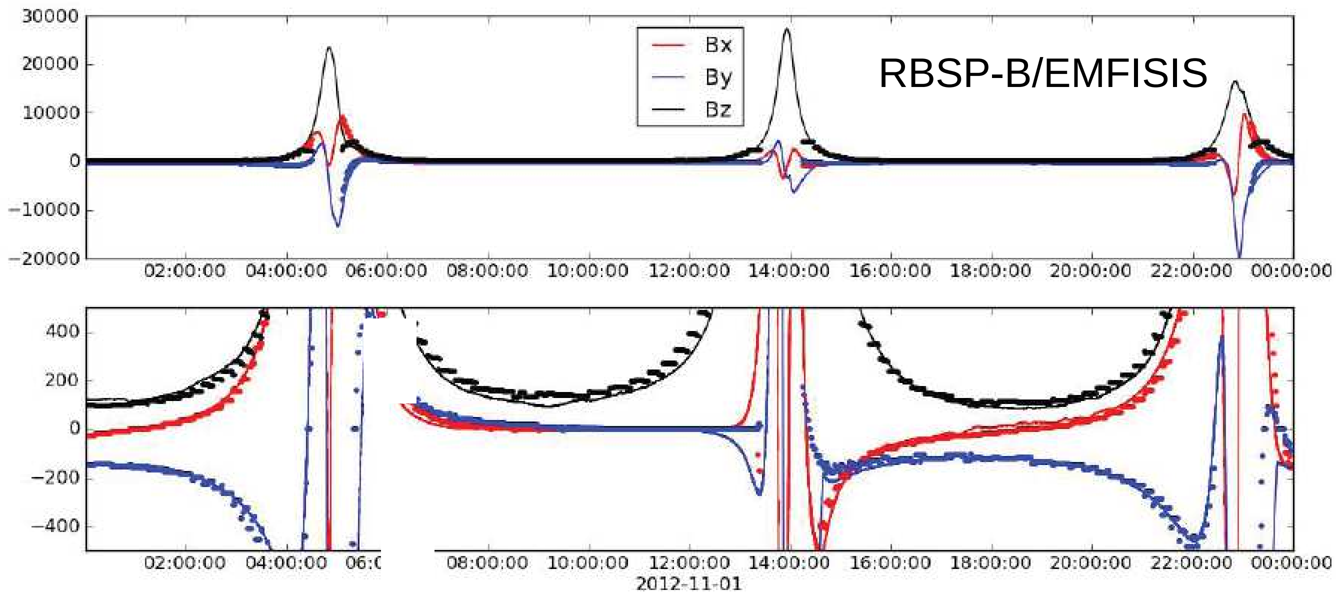
- The total ion **energy density** increases as **O^+** contribution to the ring current increases
- The presence of heavy ring current ions (**O^+** and **He^+**) reduces the wave growth

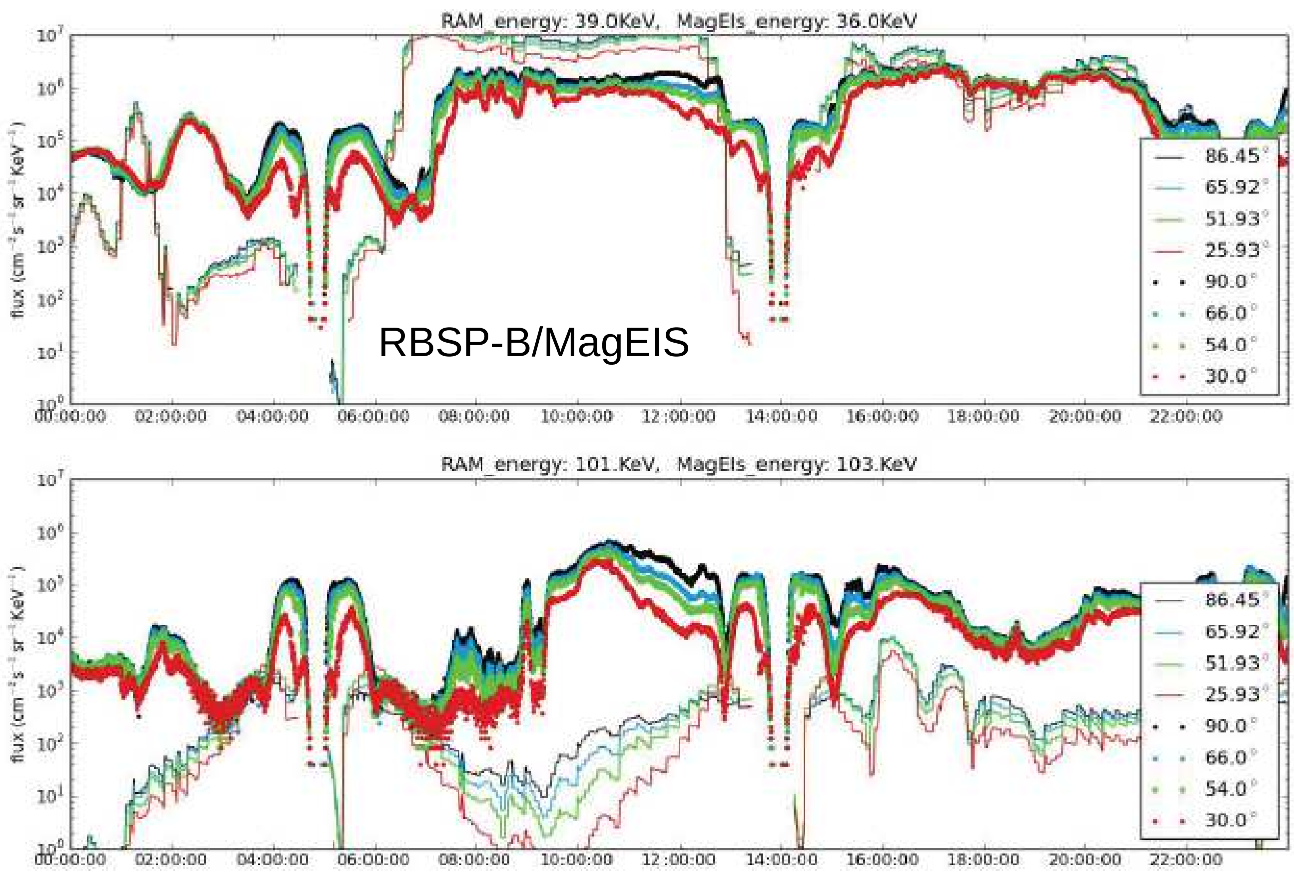
⇒ How does this affect the self-consistently calculated **electric** and **magnetic** fields?

⇒ What are the effects on the ring current **asymmetry**, dynamics of low(high)-energy population?

Model Validations: Comparison with S/C Observations

- RAM-SCB simulations of **1 Nov 2012 storm (Dst=-60 nT)** using boundary conditions at 9 Re [Tsyganenko and Mukai, 2003] as functions of incoming solar wind and IMF parameters
- Comparisons with **RBSP/EMFISIS magnetometer** data showed very good agreement with large-scale magnetic field observations
- The low-energy **~40 keV electron fluxes** are in good agreement with MagEIS data during the storm main phase
- The model underestimates the **high-energy (100 keV) MagEIS** electron fluxes





Summary and Conclusions

The **ring current** is a very dynamic region that couples the magnetosphere and the ionosphere during geomagnetic storms

New results emerging from recent simulation studies:

- the role of **self-consistent electric and magnetic fields** in ring current development
- the importance of the stormtime **plasma sheet enhancement** and **dropout** for ring current buildup and decay
- the significant contribution of **wave-particle interactions** to ion and electron precipitation

Future studies needed:

- determine the effects of **substorm-induced electric fields** on ring current dynamics
- the storm-time **ion composition** and its effects on ring current and plasma wave dynamics
- develop a **dynamic plasma wave model** of chorus, EMIC, magnetosonic waves
- the contribution of ion and electron precipitation to **ionospheric conductances**
- …