Global Simulations of Ring Current Development

Vania K. Jordanova

Space Science and Applications, Los Alamos National Laboratory,
Los Alamos, NM, USA (vania@lanl.gov)

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

Acknowledgments:

Y. Yu and S. Zaharia, Los Alamos National Laboratory, Los Alamos, NM
D. Welling and G. Toth, University of Michigan, Ann Arbor, MI
R. Thorne and L. Chen, University of California, Los Angeles, CA

GEM-CEDAR Workshop, Boulder, 23 June, 2013
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

- **3D equilibrium code** [Cheng, 1995; Zaharia et al., 2006]
  - Euler potentials (flux coordinates)
  - Empirical B-field BCs

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

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.

- $E_{\text{ind}}$ 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].

Including an earthward-propagating electromagnetic pulse

Calculating E-field induced by B-field changes in 3-D code SCB
Two-Way Coupling of RAM-SCB with SWMF/BATSRSU:

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

Coupling Global MHD with Ring Current Models
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.
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**.
Effects of Ring Current Ion Composition

- The total ion **energy density** increases as \( \text{O}^+ \) contribution to the ring current increases.

- The presence of heavy ring current ions (\( \text{O}^+ \) and \( \text{He}^+ \)) 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**
- …