Inner Magnetosphere Modeling with RAM-SCB

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**Aims:**
Develop a comprehensive model of the inner magnetosphere that will include:

- A kinetic ring current /radiation belt model coupled with a 3-D force balance model that calculates self-consistently the magnetic field and inductive electric field
- An MHD model coupled to an ionospheric model that calculates self-consistently the convection electric field
- Simulate stormtime ring current dynamics and assess the effect of non-dipolar magnetic field and the feedback of **self-consistently computed magnetic field**

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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 E-field (empirical)
- Updated to general B field
- Coupled with a plasmasphere model

3D equilibrium code [Cheng, 1995; Zaharia et al., 2004]

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

- Euler potentials (flux coordinates)
- Empirical B-field BCs
Model Development: Self-Consistent Magnetic Field (RAM-SCB)

- Gradient-curvature and electric drift velocities:
  \[
  \langle \tilde{V}_{GC} \rangle = \frac{2p}{q \tau_B B_0} \nabla_o I \times \tilde{e}_o, \quad I = \int_s^s' \sqrt{1 - \frac{B(s)}{B_m}} ds; \quad \langle \tilde{V}_{conv} \rangle = \frac{E_o \times \tilde{B}_o}{B_o^2}
  \]

- Hydrogen Density:
  \[
  \langle H_{DENS} \rangle = \frac{1}{4 R_0 h(\mu_0)} \oint \frac{N_H(s)}{\sqrt{1 - \frac{B(s)}{B_m}}} ds, \quad \text{where} \quad h(\mu_0) = \frac{1}{2 R_0} \int_s^s' \frac{1}{\sqrt{1 - \frac{B(s)}{B_m}}} ds
  \]

- Self-consistently calculated magnetic field in force balance with anisotropic plasma pressures from RAM:
  \[
  \nabla \cdot \left[ (\nabla \alpha)^2 \nabla \beta - (\nabla \alpha \cdot \nabla \beta) \nabla \alpha \right] = -\frac{(B \times \nabla \alpha)}{\sigma B^2} \cdot \left[ \nabla P_\perp + (1 - \sigma) \nabla \left( \frac{B^2}{2} \right) \right]
  \]
  \[
  \nabla \cdot \left[ (\nabla \alpha \cdot \nabla \beta) \nabla \beta - (\nabla \beta)^2 \nabla \alpha \right] = -\frac{(B \times \nabla \beta)}{\sigma B^2} \cdot \left[ \nabla P_\perp + (1 - \sigma) \nabla \left( \frac{B^2}{2} \right) \right]
  \]

where \( B = \nabla \alpha \times \nabla \beta \), \( \sigma = 1 + (P_\perp - P_\parallel)/B^2 \) and \( \alpha \) and \( \beta \) are the Euler potentials.
November 2002 Storm:
IP Conditions, Geomagnetic Indices & Electric Potential

- Double-dip geomagnetic storm with $Dst \approx -85$ nT at hour 21 and $Dst \approx -130$ nT at hour 35
- Strong enhancement of convection potentials during storm main phase
Rates in the dipole, SCB, and T04 magnetic field in the SM equatorial plane for E=100 keV and PA=45° ions

The bounce-averaged radial & azimuthal velocities, energy & pitch angle rates increase at $L>4$ on the dusk-midnight side in the non-dipole case

Lead to faster westward ion drifts, larger acceleration, and drift shell-splitting in a non-dipolar B field
Ring Current H⁺ Flux: Main Phase

- Initial ring current injection from midnight proceeding towards dayside as the storm develops
- Largest fluxes are obtained with dipole B field; weakest with T04S model
- The drift shell splitting is seen when non-dipole B-field is used
• Considering only charge exchange and loss to atmosphere, no wave-particle interactions

• Initially positive anisotropy occurs at lower L~5 shells on the dayside

• During the main phase large positive anisotropy develops at L>6 on the dayside or near the plasmapause using non-dipolar B field; negative anisotropy on the nightside

• The positive anisotropy causes the excitation of intense EMIC waves in the non-dipolar case
The calculated **ring current injection & Dst** using T04 or self-consistent B field is **smaller** reflecting the big stretching of the magnetic field during disturbed times.
Large magnetic field depressions occur on the nightside during disturbed times when self-consistent B field and T04S models are used.
• RAM-SCB - magnetically self-consistent
• RAM - fixed grid - **E-fields induced by B changes** need to be considered
• Calculating E-fields in 3-D code (SCB) - Euler potential formulation
  - total field (e.g. Schindler and Birn, [1978]; Hesse et al., [1997]):
    \[ E = -\frac{\partial \alpha}{\partial t} \nabla \beta + \frac{\partial \beta}{\partial t} \nabla \alpha - \nabla \psi \]
  - ionospheric potential \( \psi \equiv \Phi \) (neglecting \( E_\parallel \) and assuming no ionospheric “field slippage” on time scale of significant B value change)
  - much easier than integrating Faraday’s law in Cartesian coordinates: B-field in “integrated” form (Euler potentials)
• Are the storm-time induced E-fields important? (vs. convective fields)
Largest pressure at dusk-premidnight in storm main phase
Self-consistent (SC) pressure is lower vs. RAM dipolar run (30 nPa max. vs. 60 nPa)
Fine SC structure: local gradients, double peaks; larger pressure farther away
Main phase $\Rightarrow$ field line stretching $=$ flux decrease on night side

- Dusk sector - (weakly) oppose convection field
- $E_{\text{ind}}$ depends on magnetic flux boundary change ($Kp_{38} = 5.2; Kp_{39} = 5.7$)
- $E_{\text{ind}} \times B$ will drive particles away from Earth - adiabatic effect

Recovery phase $\Rightarrow$ less stretching $=$ flux increase on night side

- $Kp_{41} = 6; Kp_{42} = 5.5$
- Field compression $\Rightarrow E_{\text{ind}} \times B$ will drive particles Earthward
Neglect radial $E_{\text{ind}}$; only azimuthal $E_{\text{ind}}$

Decrease of magnetic flux (main phase) $\Rightarrow$ eastward inductive $E$; **opposite to convective $E$**

Increase of flux (recovery phase) $\Rightarrow$ westward inductive $E$; same direction as convective $E$

Effect: *(slightly) less energization during main phase; more during recovery phase; changed radial transport due to ExB drift*
- Obtained from magnetically SC April 2001 storm simulation (1-hour coupling)
- Comparison with $E_c = \text{Weimer01 (convective)} + \text{corotation fields}$
- Main phase/recovery: small 0.2 mV/m (vs. $E_c \sim 1.5 \text{ mV/m}$) $\sim 1/7 \ E_{cM}$
- Can dominate azimuthal component of $E_c \Rightarrow$ change radial transport $E \times B$

[Zaharia et al., 2008]
Coupling of RAM-SCB with SWMF/BATSRUS Model

Modules in our comprehensive IM model and coupling between them
SWMF/BATSRUS Simulation: 31 August 2005

- No coupling with RAM-SCB

- Large storm selected for study by the LWS TR&T Focus Team on IM plasma storm time redistribution
One-way Coupling of RAM to SWMF/BATSRUS

A) Single Fluid (No PWOM)

B) Multi Species & PWOM
Virtual Satellites in RAM-SCB: RBSP
Virtual Satellites in RAM-SCB: Example

Fluxes from RAM-SCB along RBSP orbit

Omnidirectional H⁺ Flux

Omnidirectional O⁺ Flux

Universal Time from 2005-08-31T09:01:00

The HOPE instrument on RBSP

Coincidence Counting Rate - Combined Species

Pixel 0

Pixel 1

Pixel 2

Pixel -1

Pixel -2
Contributions to RBSP science:

- Simulate the global distributions of both trapped and precipitating ring current ion and electron fluxes
- Simulate inner magnetospheric magnetic and induced electric fields
- Simulate global distributions of EMIC, chorus, and magnetosonic waves
- Investigate how the plasma and fields change during magnetic storms (temporal & spatial evolution)
- Study the effect on the radiation belt dynamics
- Study the relation to ground-based observations
- ...