Outline

- Details of the CRCM: Description and Inputs
  - Example ENA studies:
    - CRCM with T96: TWINS mission
    - CRCM with BATSRUS: IMAGE
- Details of RBE: Description and Inputs
  - Example studies:
    - Real-time simulations of GOES observations.
    - SAMPEX and Akebono observations
The Comprehensive Ring Current Model (CRCM)

- FOK Ring Current Model
  - Empirical E Field
  - Full Pitch-Angle Distribution

- Rice Convection Model (RCM)
  - Self-Consistent E Field
  - Isotropic Pitch-Angle Distribution

COMPREHENSIVE RING CURRENT MODEL (CRCM)
- Self-Consistent E Field
- Full Pitch-Angle Distribution
The Comprehensive Ring Current Model (CRCM) Inputs

- Dst, Kp: Kyoto University Geomagnetic Data Service.
- Shifted solar wind, IMF data: ACE or WIND satellite
- Distribution at nightside boundary (8-10R_e)
- Magnetic field model: T96
- Ionospheric potential at polar boundary: Weimer Model
- Conductance: Background + Auroral (Hardy Model)
THE TWINS MISSION

Two Wide-angle Imaging Neutral-atom Spectrometers

FIRST STEREOSCOPIC MAGNETOSPHERIC IMAGING MISSION
TWINS PROPOSED IN 1997, MOO (AO 97-OSS-03)
2 NADIR-VIEWING MOLNIYA-ORBIT SPACECRAFT
7.2 RE APOGEE, 63.4° INCLINATION, 12 HOUR ORBIT
ACTUATOR REPLACED S/C SPINNING

STEREO IMAGING BEGAN IN SUMMER OF 2008
AVAILABLE AT http://twins.swri.edu

TWINS TEAM:
PI: DAVE MCCOMAS (SWRI)
PROJECT SCIENTIST: MEI-CHING FOK (NASA)
PROGRAM SCIENTIST: BARBARA GILES (NASA)
SCIENCE ANALYSIS LEAD: JERRY GOLDSTEIN (SWRI)
September 04 2008, modest storm, end of main phase

DIPOLARIZATION STARTS AT ~ 04:30 (GOES 12, MLT ~ 23:30H)
TWINS-CRCM Data-Model
ENA comparison
Ebihara&Ejiri model and $T=10$ keV ENA / $H^+$ energy = 12 keV

03:30 UT

MAX = 0.5

05:00 UT

MAX = 0.6

CRCM

EQUATORIAL $H^+$ FLUX
CRCM-BATSRUS: One Way Coupling

MHD BATSRUS RUN AT THE CCMC

MHD B-field, n, P
(cdf-files)

KAMELEON
INTERPOLATION LIBRARY

B-FIELD IN THE
CRCM DOMAIN; N,T AT
THE EQUATOR

Electric field potential and conductances
in the ionosphere (ASCII files)

LINEAR
INTERPOLATION:
MHD IONOSPHERE GRID-
CRCM IONOSPHERE
GRID

MHD POTENTIAL
AT THE POLAR CRCM BOUNDARY;
CONDUCTANCES AT THE ENTIRE REGION

Buzulukova et. al. [2010], JGR, IN PRESS
AUGUST 12 2000: POST-MIDNIGHT ENHANCEMENT OF THE RING CURRENT

IMAGE HENA DATA

DATE: 12 Aug 2000 (DOY 225)
TIME (UT): 08:39:00 - 08:32:01
S/C POS (SM): 0.5, 0.8, 5.5 Rs
S/C POS (SM R, LAT, LON): 5.5 Rs, 80.0°, 55.7°
ENERGY: 27 - 39 keV
SPIN SUM:
AUGUST 12 2000: POST-MIDNIGHT ENHANCEMENT OF THE RING CURRENT

IMAGE HENA DATA

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ENERGY: 27 – 39 keV
SPIN SUM:

FOK-BATSRUS

August, 12 2000 8:29

CRCM-BATSRUS

August, 12 2000 8:29
AUGUST 12 2000: POST-MIDNIGHT ENHANCEMENT OF THE RING CURRENT

**IMAGE HENA DATA**

- **DATE:** 12 Aug 2000 (DOY 225)
- **TIME (UT):** 08:30:00 – 08:32:01
- **S/C POS (SM):** 0.5, 0.8, 5.5 Re
- **S/C POS (SM, LAT, LON):** 5.5 Re, 80.0°, 55.7°
- **ENERGY:** 27 – 39 keV
- **SPIN SUM:**

**FOK-BATSRUS**

- **H ENA (0.27–0.39 keV):** 8:30 UT Aug 12/2000 FOK+BATSRUS

**CRCM-BATSRUS**

- **H ENA (0.27–0.39 keV):** 8:30 UT Aug 12/2000 CRCM+BATSRUS
The Radiation Belt Environment (RBE) model

Solar Wind, DST, KP Data

Magnetic Field and Electric Field Models

Plasmasphere Model

Wave Diffusion Model

Plasma Sheet Model

Radiation Belt Model

Energetic Electron Flux (10 KeV – 6 MeV)
Radiation Belt Environment model: Equations

\[
\frac{\partial f_s}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial f_s}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial f_s}{\partial \phi_i} = \frac{1}{G} \frac{\partial}{\partial \alpha_o} \left[ G \left( D_{\alpha_o} \frac{\partial f_s}{\partial \alpha_o} + D_{\alpha_o} E \frac{\partial f_s}{\partial E} \right) \right] + \frac{1}{G} \frac{\partial}{\partial E} \left[ G \left( D_{EE} \frac{\partial f_s}{\partial E} + D_{E\alpha_o} \frac{\partial f_s}{\partial \alpha_o} \right) \right] - \left( \frac{f_s}{0.5 \tau_b} \right)_{\text{loss cone}}
\]

\[
f_s = f_s(t, \lambda_i, \phi_i, M, K)
\]

\(f_s\): phase space density of electrons

\(\lambda_i\): magnetic latitude at the ionosphere

\(\phi_i\): magnetic local time at the ionosphere

\(M\): magnetic moment

\(K\): longitudinal invariant

\(\langle \dot{\lambda}_i \rangle, \langle \dot{\phi}_i \rangle\): drift velocities (convection + magnetic drift + corotation)

\[
G = T(\alpha_o) \sin 2\alpha_o (E + E_o) \sqrt{E(E + 2E_o)},\ E_o = \text{rest mass energy},\ \text{and} \ T(\alpha_o) = \frac{1}{2R_o} \int_{s_m}^{s_m^*} ds \frac{1}{\cos \alpha}
\]

\(\tau_b\): bounce period

Radial diffusion is included implicitly in the time-varying magnetic and electric fields.
Radiation Belt Environment (RBE) Model: Inputs

- Dst, Kp: Kyoto University Geomagnetic Data Service
- Shifted solar wind data: ACE or WIND Satellite
- Magnetic field model: T96 or T04 (updated 5min)
- Electric field model: Weimer Model (updated 3s)
- Plasmasphere model: Ober and Gallagher model
- Diffusion coefficients: Horne’s PADIE code
- Distribution at outer boundary: Kappa distribution
Low initial flux in the RBE simulations are due to quiet-time initial condition.

RBE simulation without wave-particle interactions show little enhancement during storm recovery.
Real-Time Radiation Belt Simulations

Real-time ACE data: Nsw, Vsw, IMF (NOAA)

Real-time Dst (Kyoto U.) and Kp (NOAA)

Radiation Belt Model (RBM)

Real-time GOES-11 (E > 0.6 MeV)

Energetic Electron Flux (updated every 15 minutes)

Real-time GOES-12 (E > 0.6 MeV)
Real Time Example: November 2008

The disagreement between model and data mainly comes from lack of substorm features in the model.
SWMF: Information Exchange

Glocer et al., [2009], Journal of Atmospheric and Solar-Terrestrial Physics, 71, 1653–1663
On September 4, 2008 a moderate geomagnetic event occurred with Kp reaching as high as 6.

Dst reaches a minimum of -55 early on the 4th.

The Akebono spacecraft measures an increase in the >2 MeV electron flux.

The outer belt electron flux reaches higher values after the Dst effect drop out (according to Akebono and GOES data).
Sept. 2008: Dst and Akebono data

Akebono Electrons: >2.0 MEV

Dst For Sept. 2008 Event
Simulated Dst and B-Field from MHD
Magnetic Field Configuration During Flux Increase
MHD+RBE

Log(P) with Magnetic Field-Lines

SEPTEMBER 4, 2008
3-5UT
Conclusions

- The CRCM and RBE models can be used with both empirical fields, and MHD derived fields.

- We have used the CRCM with T96 and with BATSRUS in order to study ENAs observed by TWINS and IMAGE missions.

- We have used the RBE with T04 and BATSRUS to study energetic electron enhancements observed by Akebono and SAMPEX spacecrafts.

Other notes:
- Two way coupled CRCM - OpenGGCM is coming along well.
- The coupled RBE-BATSRUS should be available at CCMC soon.
Extra Slides
CRCM ENAs for three runs (12 keV)

- Tsyganenko&Mukai PS model
  - Temperature $T = 10$ keV, Max = 0.6

- Ebihara&Ejiri density
  - Temperature $T = 10$ keV, Max = 0.6
  - Temperature $T = 3$ keV, Max = 1.2

03:30 UT

05:00 UT
TWINS-CRCM DATA-MODEL COMPARISON DENSITY
Ebihara&Ejiri model and T=10keV ENA / H+ energy = 30 keV

MAX = 0.18
MAX = 0.4

EQUATORIAL H+ FLUX

TWINS
CRCM

03:30 UT

05:00 UT
Sept. 2008: No Waves

- RBE with no waves as compared to Akebono.
- B-Field from T04 using original and modified inputs
- Dipolarization of B-field has a large effect!

**AKEBONO ELECTRONS: >2.0 MEV**

**MODIFIED B: 1.7-5.2 MEV ELECTONS**

**1.7-5.2 MEV ELECTONS**

[Images of graphs showing particle fluxes and other data related to electron interactions and field modifications.]
Dipolarization?
Sept. 2008: RBE with MHD B-Field

- **RBE without waves as compared to Akebono.**
- **B-Field from MHD with updates provided every 10 seconds (See Glocer et al. [2009] for coupling details)**
- The timing of the enhancement is well predicted.
- Dynamic magnetic field model leads to a dynamic radiation belt electron population.