The Space Weather Modeling Framework as a Predictor of the Plasma Environment

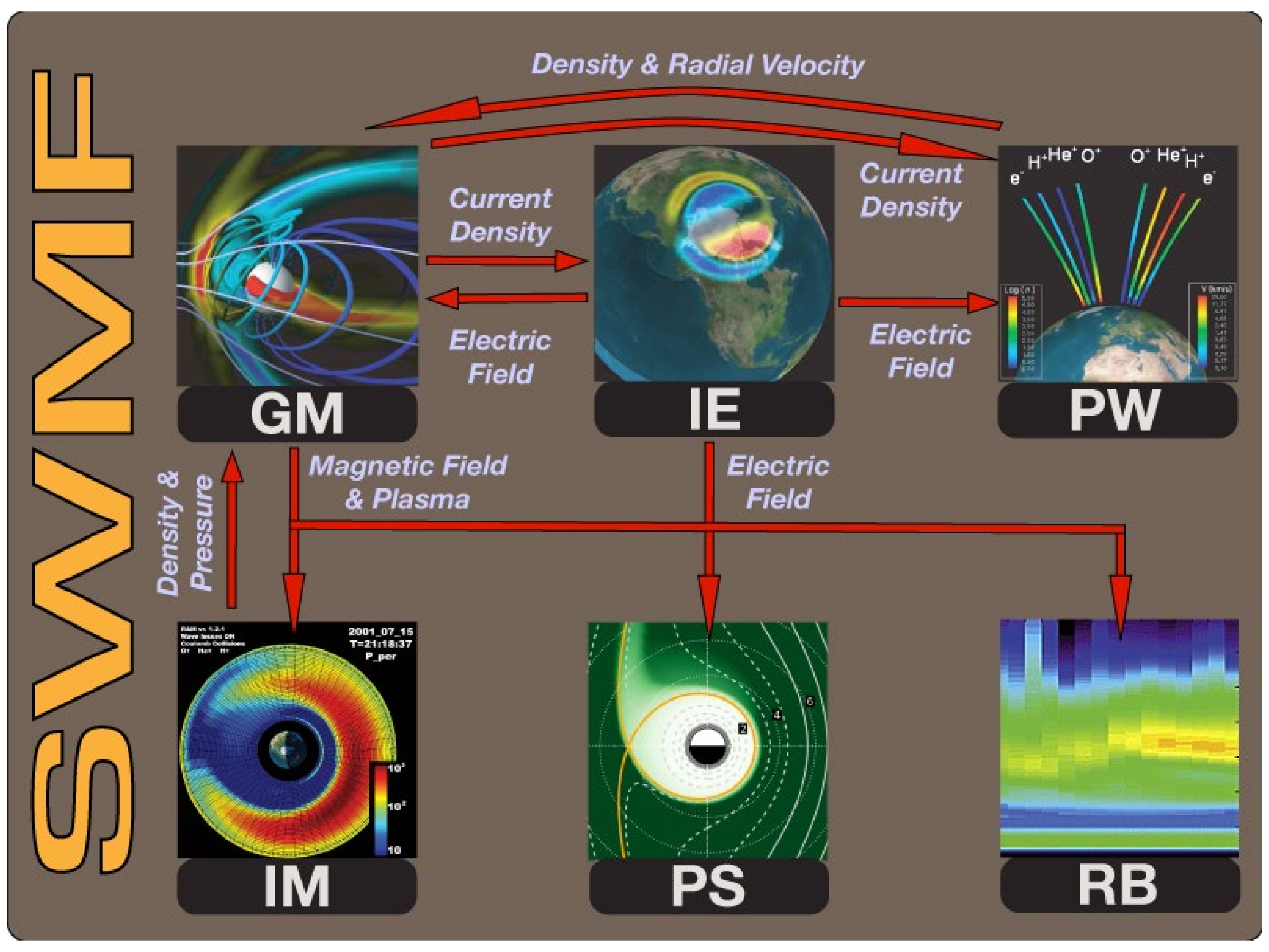
D. T. Welling[1], M. W. Liemohn[1], G. Toth[1],
T. I. Gombosi[1], A. Glocer[2]
[1]University of Michigan Atmospheric, Oceanic, and Space Sciences
[2]NASA Goddard Space Flight Center

Contact Info

Poster & References

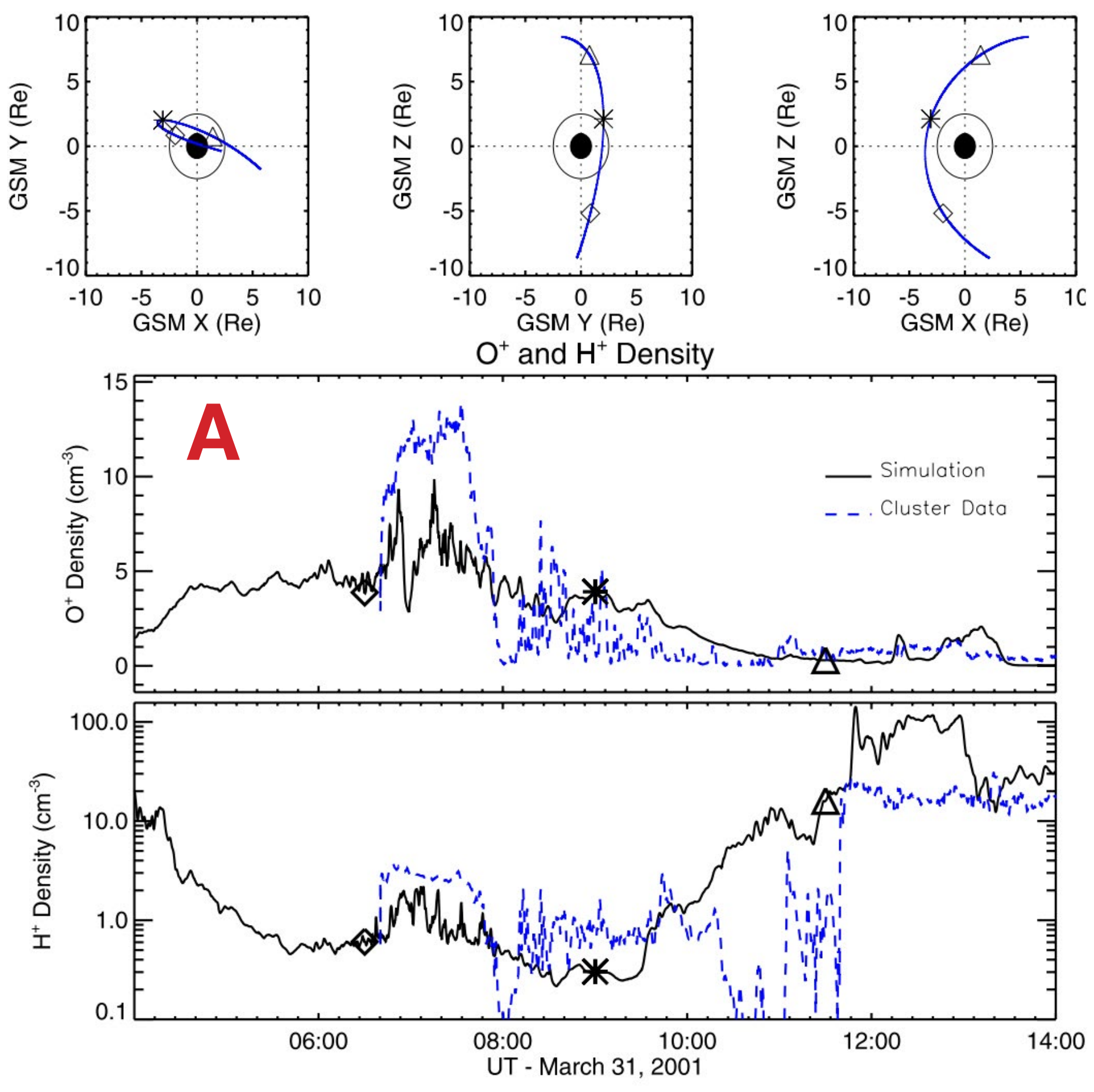
- The Space Weather Modeling Framework is a flexible software framework for executing, synchronizing, and coupling many independent models of the space environment.
- Previous work has demonstrated the SWMF's ability to reproduce in-situ magnetic field, ground-based field perturbations, and activity indices.
- The SWMF is currently being transitioned into operational use at the NOAA Space Weather Prediction Center.

This presentation highlights the SWMF's capabilities to reproduce the complicated magnetospheric plasma environment.



	Model Name	Model Type	Couplings	Plasma Output
GM	**BATS-R-US**	Magnetohydrodynamic: Ideal, Hall/anomalous resistive, anisotropic, multi-species/ fluid.	Provides B-field and plasma to other models.	Fluid moment data over entire MHD domain.
IE	Ridley Ionosphere Model (**RIM**)	Height-integrated ionospheric electrodynamics solver.	Receives FACs from GM, yields electric field to all other models	None.
IM	Rice Convection Model (**RCM**)	Isotropic adiabatic drift.	Receives electric and magnetic fields from IE/GM. Plasma initial and outer boundary conditions from GM. Returns density/pressure to GM.	Isotropic electron & ion distribution.
	RAM-SCB	Bounce-averaged drift with force-balanced magnetic field.		Full pitch-angle resolved phase space density for ions and electrons. Energies up to hundreds of keV.
	Comprehensive Ring Current Model (**CRCM**)	Bounce-averaged drift with self-consistent electric field.		
	Hot Electron Ion Drift Integrator (**HEIDI**)	Bounce averaged drift.		
RB	Radiation Belt Environment (**RBE**)	Bounce averaged drift with energy & pitch angle diffusion.	Receives magnetic field from GM.	e^- distribution, 10keV-6MeV
PS	Dynamic Global Core Plasma Model (**DGCPM**)	2D continuity/E×B drift in equatorial plane.	Receives magnetic/electric field from GM.	Cold plasma density, velocity.
PW	Polar Wind Outflow Model (**PWOM**)	Collection of 1-D fluid flux tubes.	Receives FACs from GM, returns outflowing plasma.	Ion and electron fluid moments

Outer Magnetosphere



BATS-R-US Plasma Composition (A)

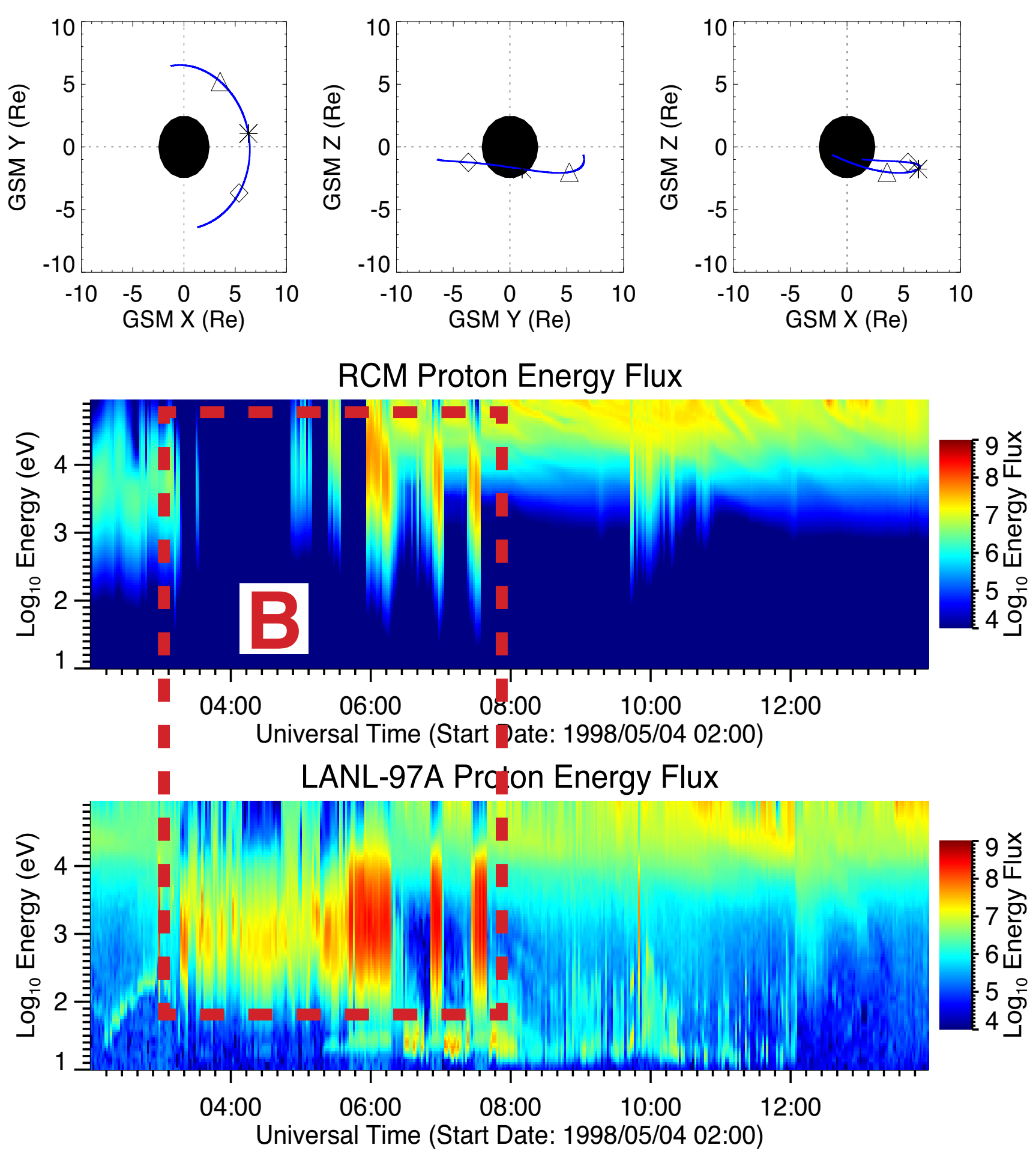
- Multi-species and multi-fluid MHD have been used extensively to investigate how the inclusion of ionospheric outflow affects model results.
- The March 31, 2001 storm was simulated with BATS-R-US, RCM, RIM, and PWOM [*Glocer et al.,* 2009].
- Comparisons with Cluster show good species-specific density agreement, especially in the lobes.

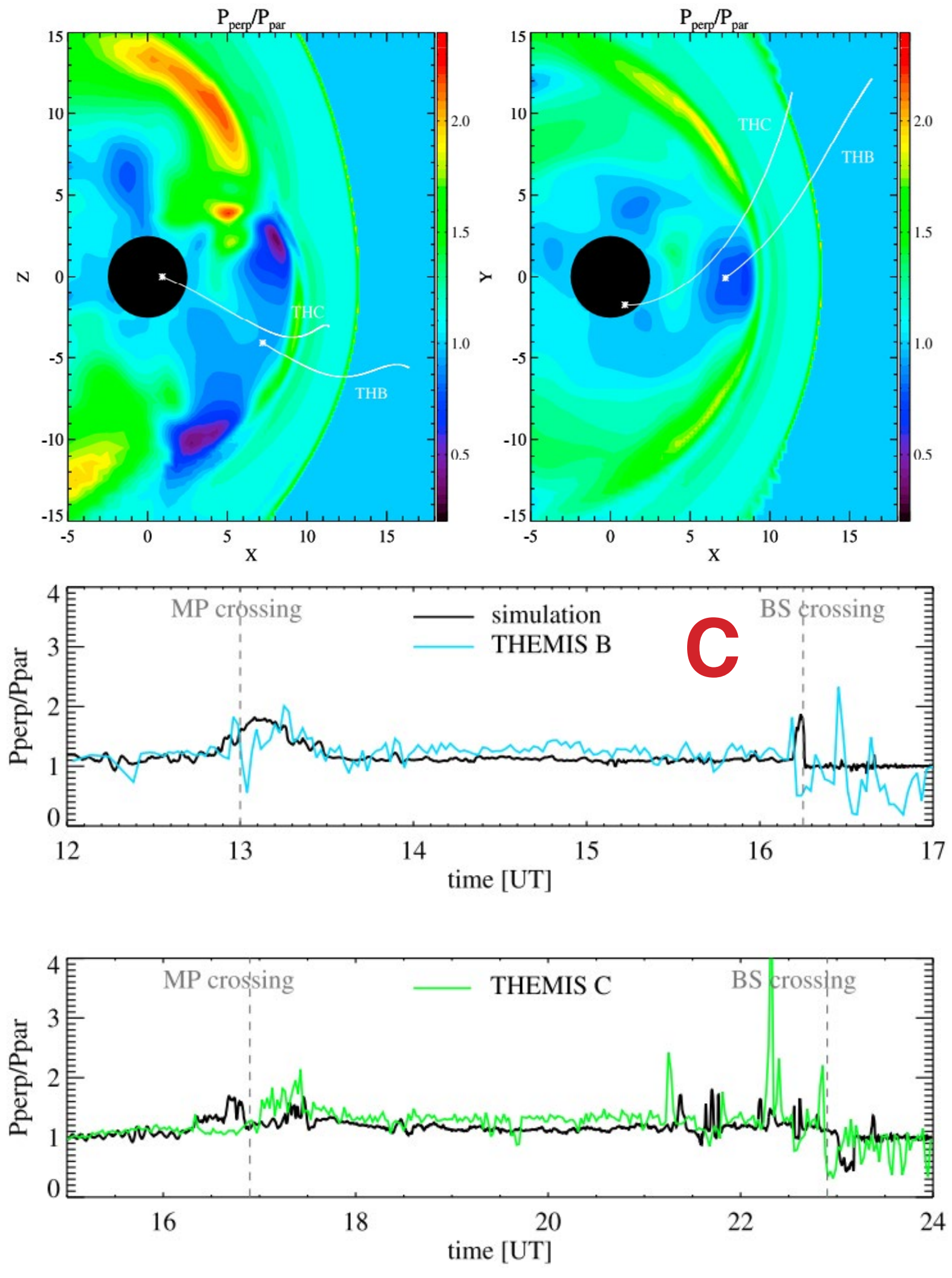
RCM Magnetopause Crossings (B)

- BATS-R-US, RIM, and RCM were used to simulate the May 4, 1998 strong storm.
- Four separate magnetopause crossings by the LANL-97A were all predicted by the MHD/ring current model combination [*Welling & Ridley*, 2010].
- Extensive validation of magnetopause crossings at geosynchronous demonstrated strong predictive skill for the combined models.

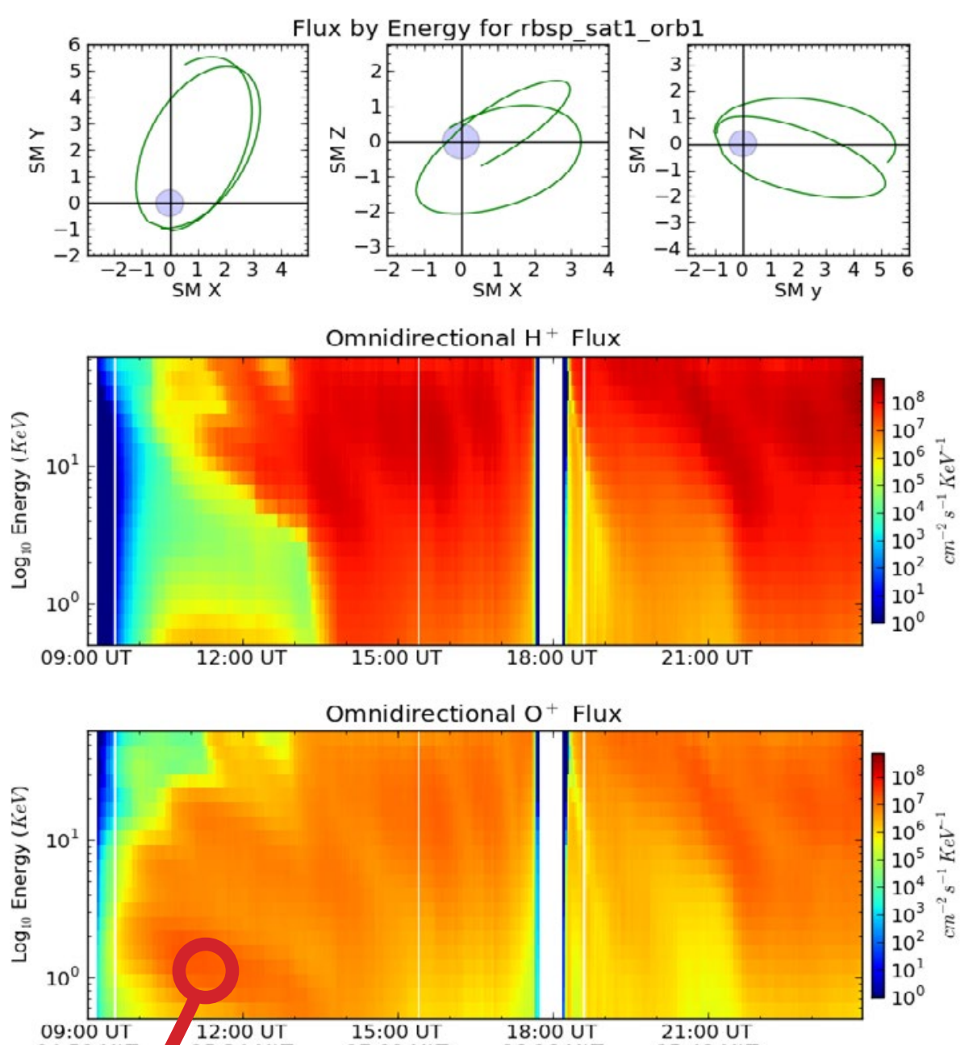
BATS-R-US Plasma Anisotropy (C)

- Anisotropic BATS-R-US and RIM were used to simulate the magnetospheric conditions during June 16, 2008.
- Plasma anisotropy compares favorably to observations from the THEMIS constellation [*Meng et al.,* 2012].
- Similar comparisons demonstrate that anisotropic MHD improves plasma velocity and pressure in the magnetotail, especially when combined with an IM code [*Meng et al.*, 2013].



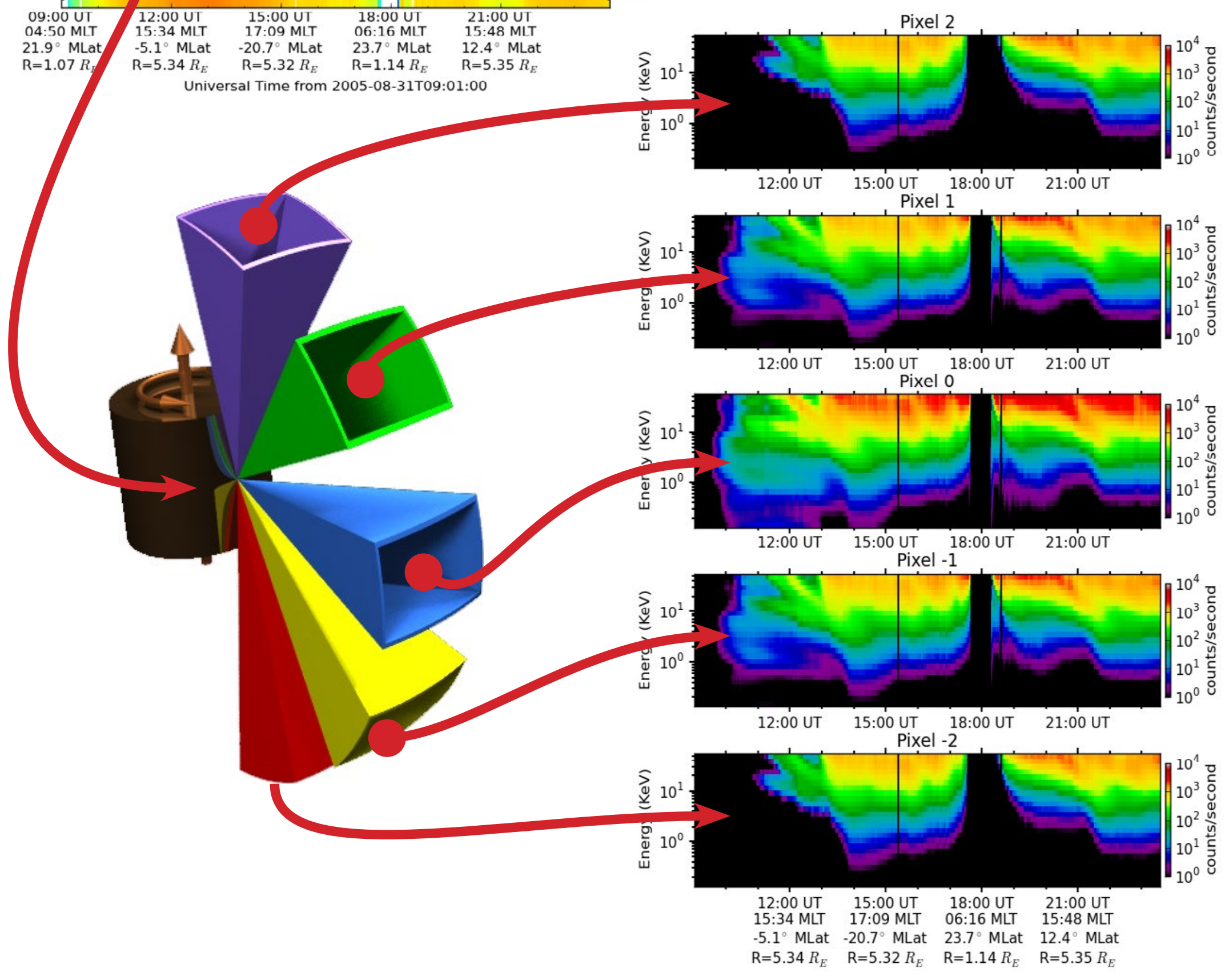


Ring Current



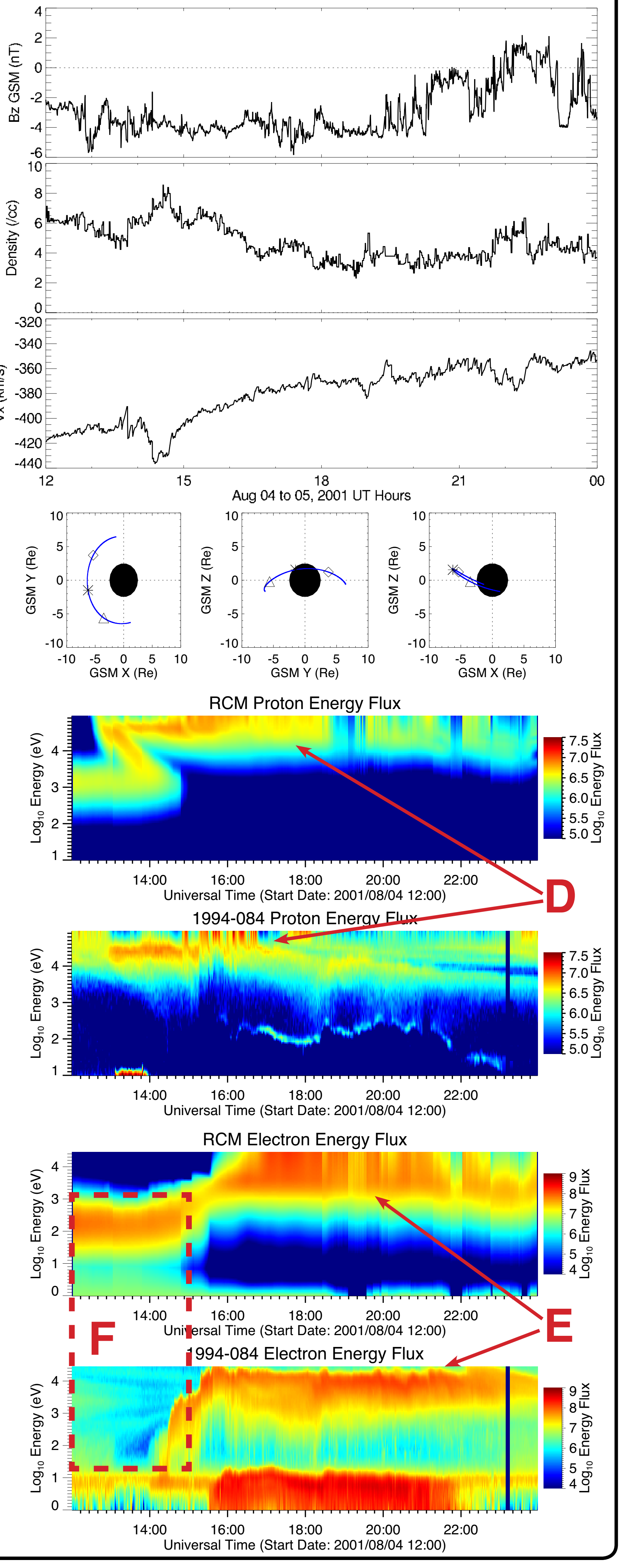
Pre-Launch RBSP-HOPE Predictions with RAM-SCB

- Aug. 31st, 2005 storm simulated with BATS-R-US, PWOM, RIM, and RAM-SCB.
- RAM-SCB distribution function mapped to hypothetical RBSP locations [*Welling et al.*, 2010].
- Fluxes convolved with RBSP-HOPE response function to yield coincidence count rates.
- Study demonstrated modeling capabilities and predicted RBSP ring current measurements before mission launch.



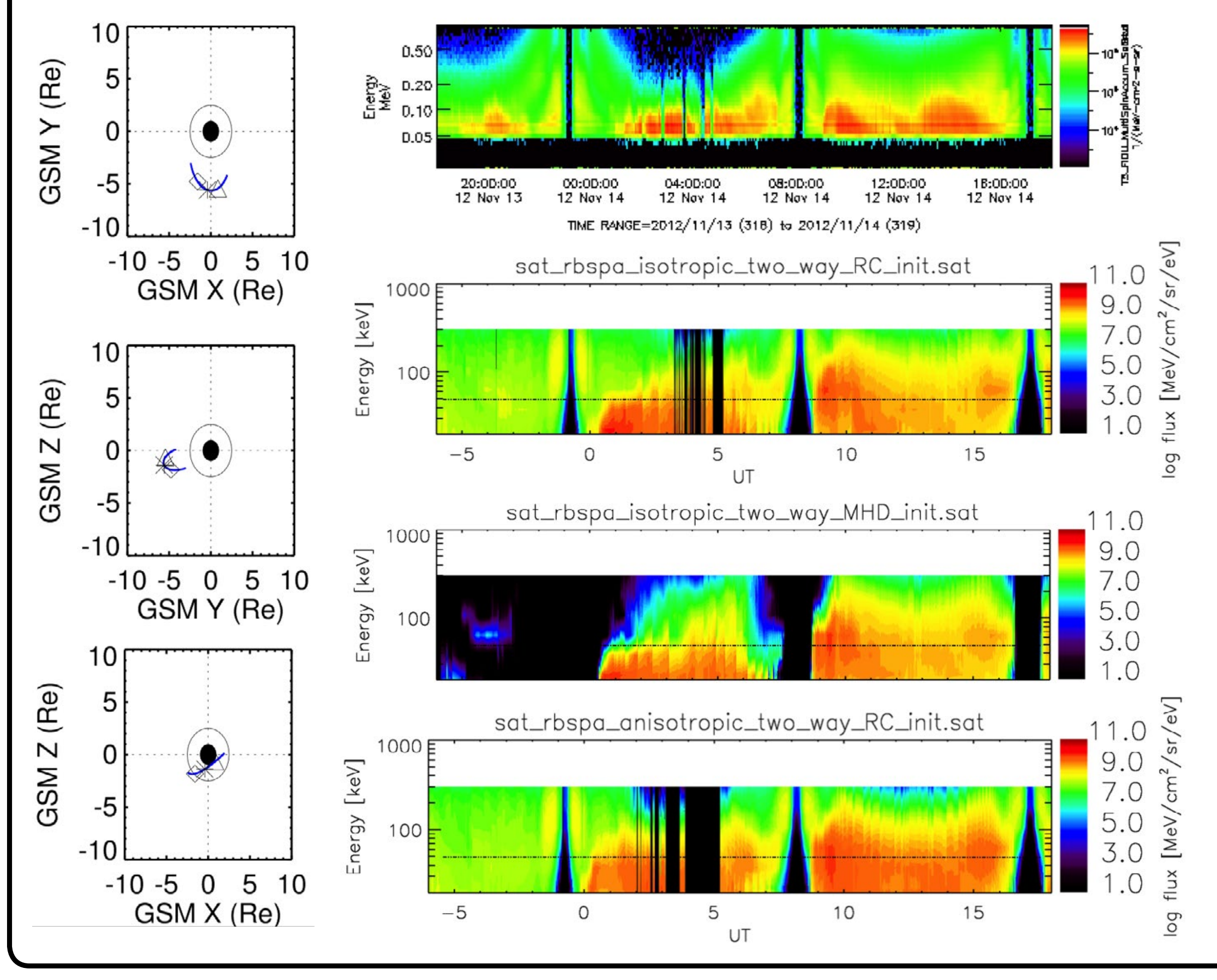
RCM Validation at Geosynchronous

- Ten events simulated with BATS-R-US, RIM, and RCM to validate SWMF predictions [*Welling & Ridley,* 2010].
- Model results were compared to LANL Geosynchronous MPA observations.
- For constant, moderate southward B_z, RCM is able to accurately reproduce the build-up of warm/hot ion (D) and electron (E) distributions.
- MHD-based initial conditions for the ring current are generally a poor representation of real quiet-time distribution (F).
- Comparisons of distribution temperature and density moments show reasonable agreement.



CRCM Comparisons to RBSP-RBSPICE

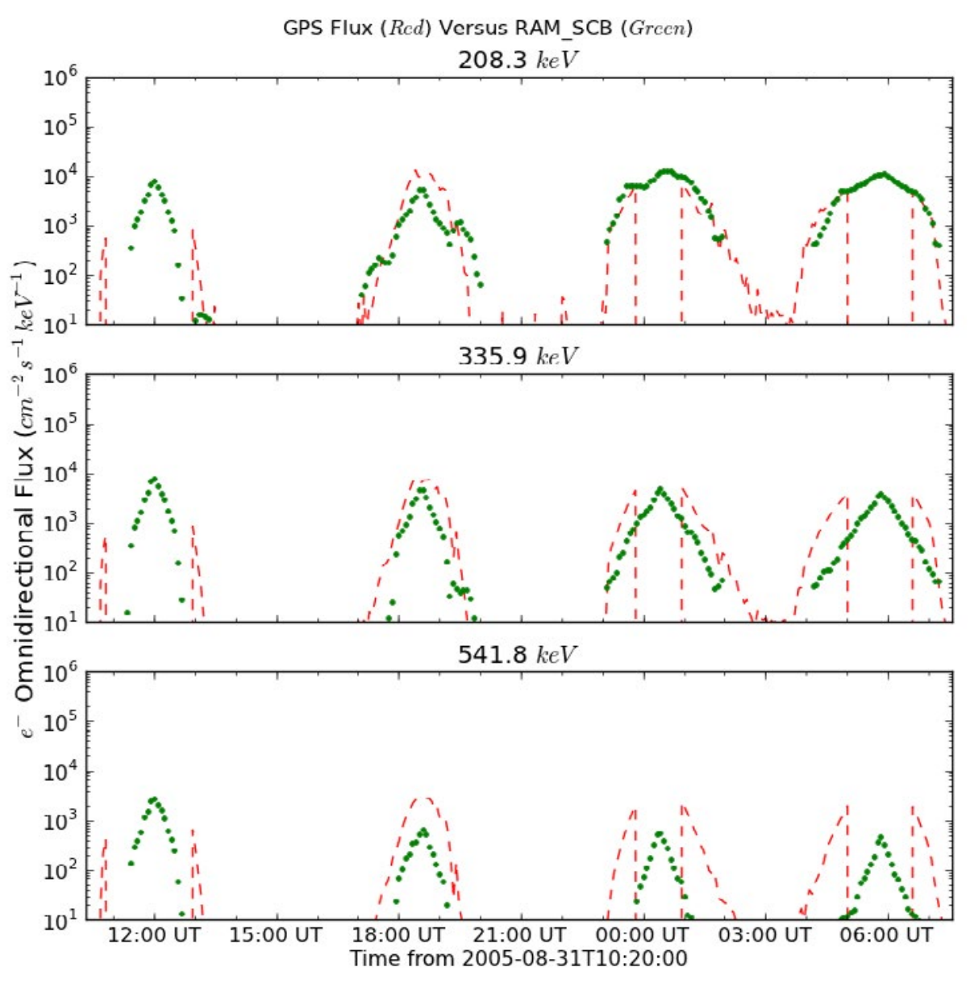
- CRCM, BATS-R-US, RBE and RIM were used to model the Nov. 14, 2012 storm.
- Both isotropic and anisotropic MHD versions were used.
- The coupled models found that observed flux dropouts were correlated to times when the spacecraft came very near or crossed the magnetopause [*Glocer et al.*, 2013].
- Proper initial conditions for the ring current were critical for obtaining realistic results.

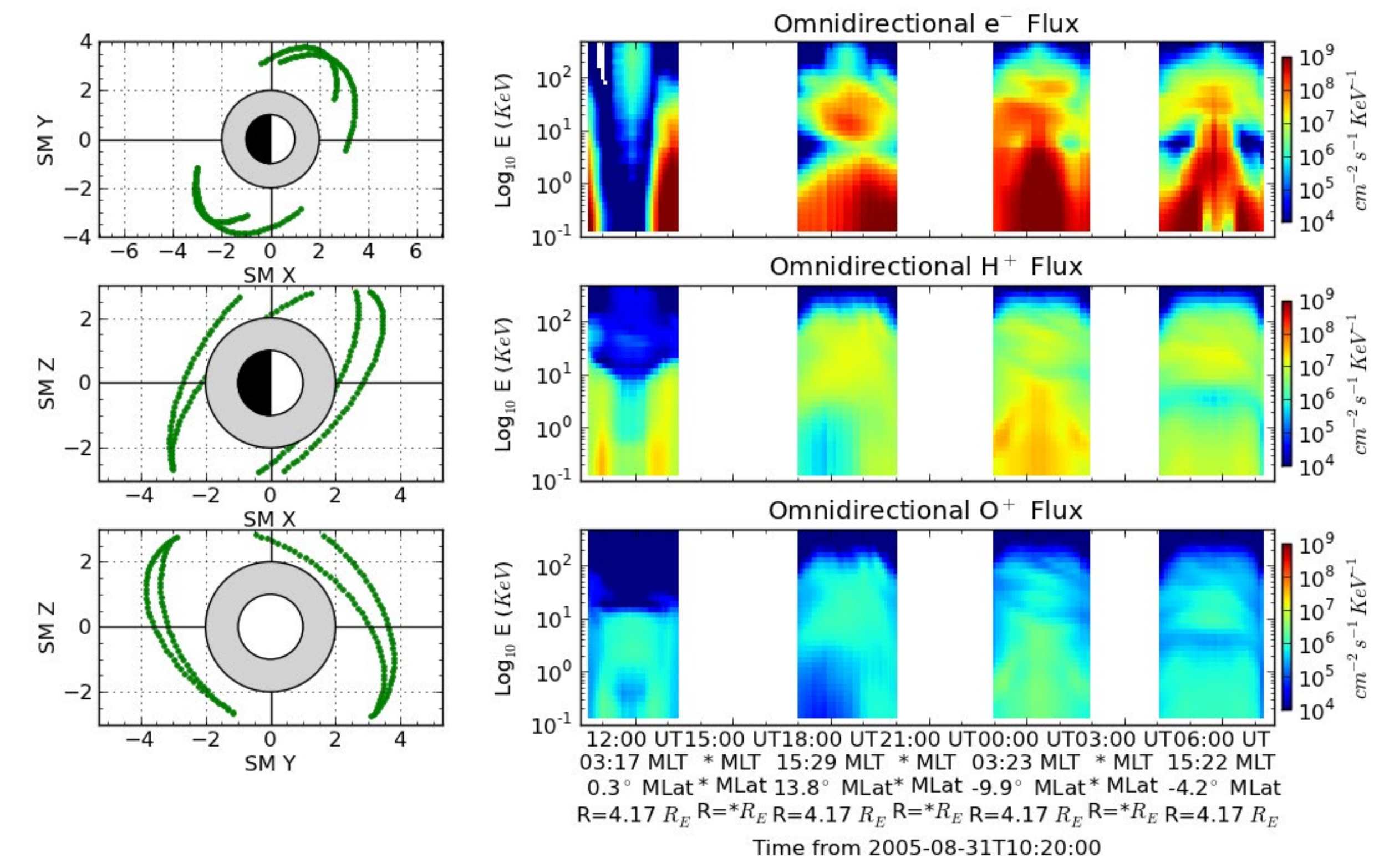


Radiation Belts

RAM-SCB Comparisons to GPS

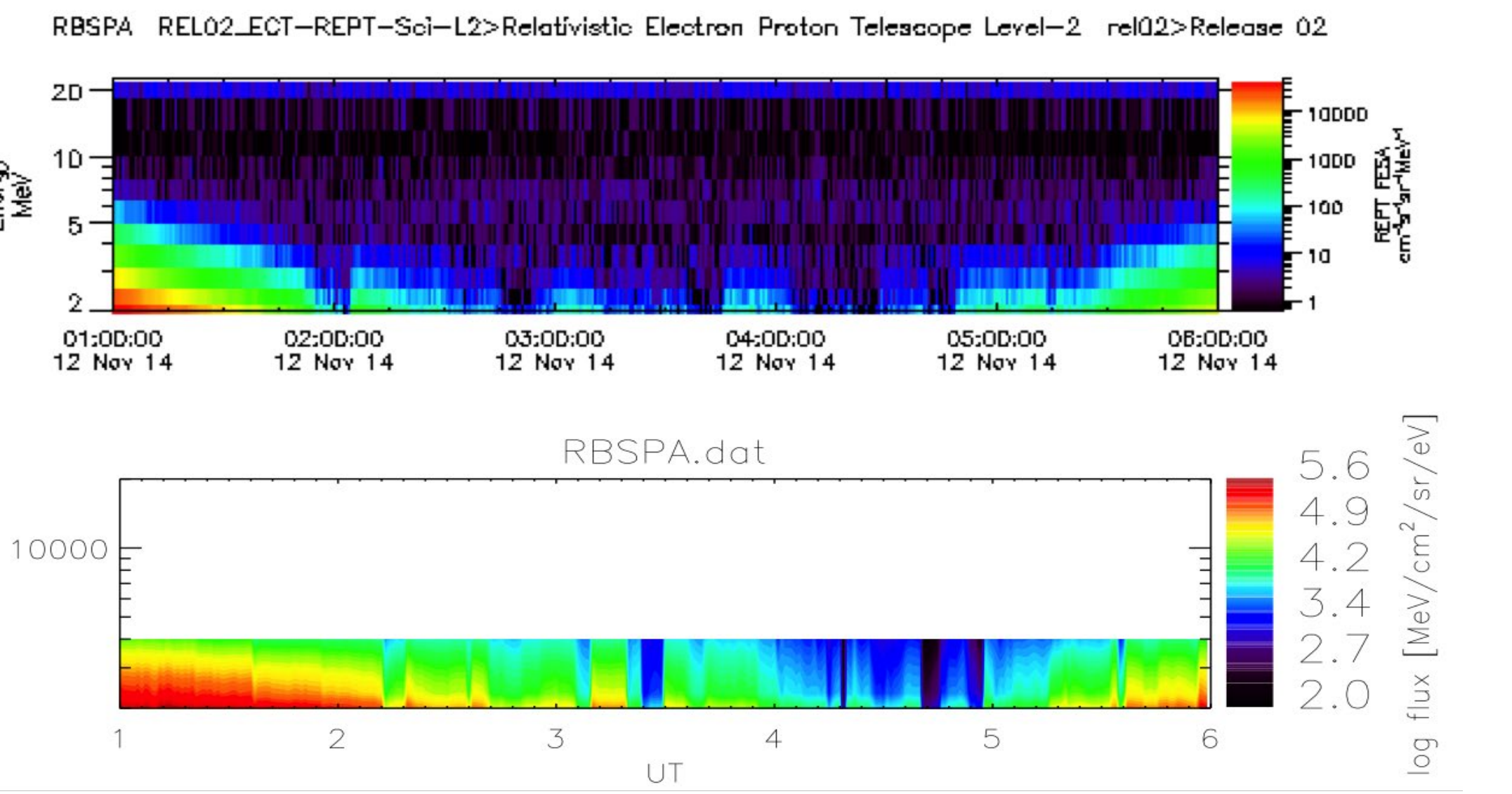
- RAM-SCB was used to model the Aug. 31, 2005 storm. Virtual satellites were placed at GPS locations [*Welling et al.*, 2011].
- RAM-SCB distribution function was integrated in order to make comparisons to GPS omni-directional dosimeter values.
- Electron omni-directional flux dynamics for lower energy channels captured very well (magnitudes scaled down).
- Inclusion of force-balanced magnetic field calculation improved results drastically over simulation using dipole magnetic field.





RBE Comparisons to RBSP-REPT

- CRCM, BATS-R-US, RBE and RIM were used to model the Nov. 14, 2012 storm.
- Both isotropic and anisotropic MHD versions were used [*Glocer et al.*, 2013].
- The coupled models reproduced the observed fluxes and the associated drop outs.



Conclusions

- The Space Weather Modeling Framework has immense, high-fidelity plasma simulation capabilities.
- Inter-model coupling through the SWMF enables virtual satellite tracing and consistently improves results.
- Virtual plasma distributions from the SWMF have been used extensively in the scientific literature.
- SWMF virtual satellites are robust and reaching the maturity required for operational use.