SWMF Geospace

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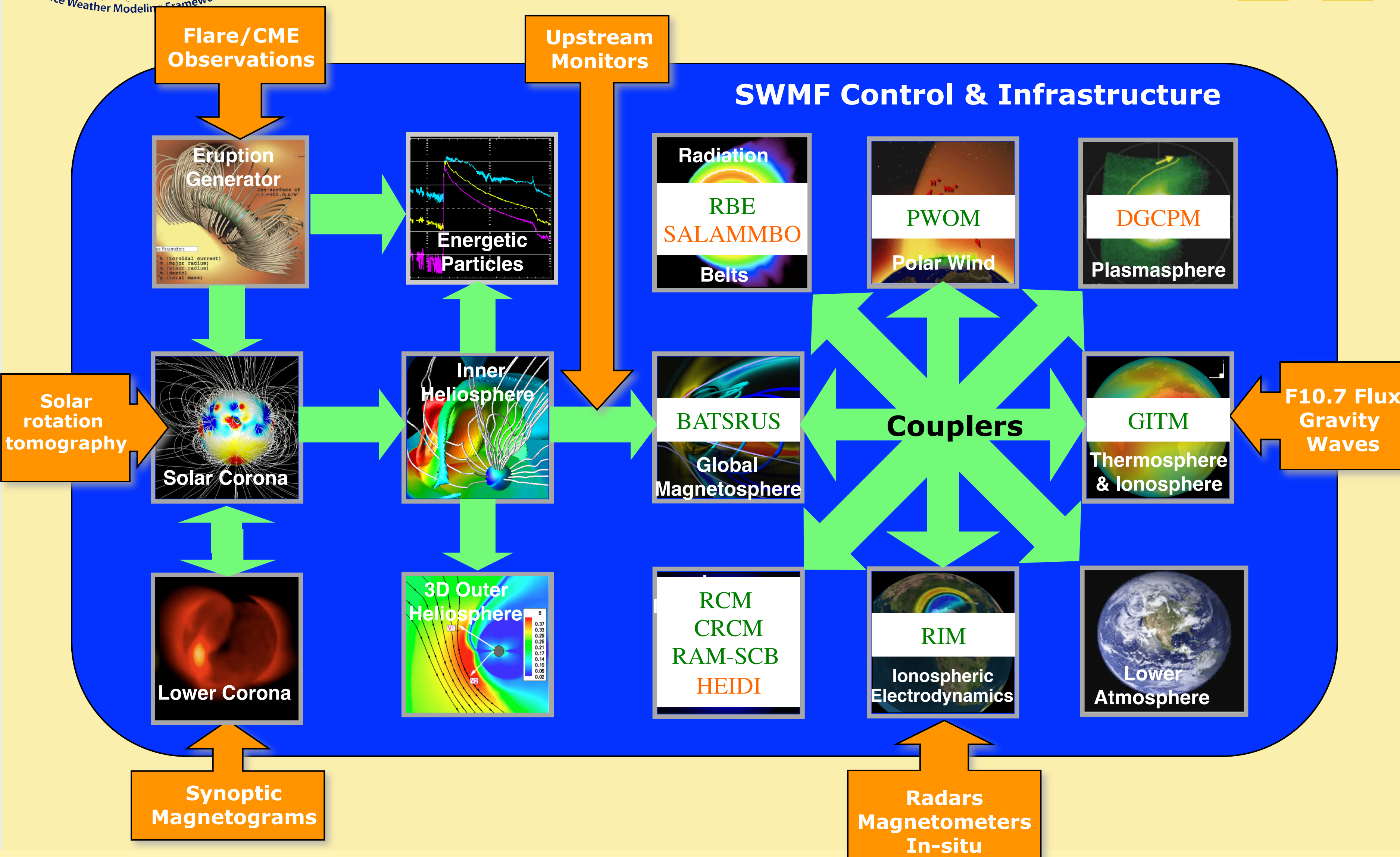
Outline

- New geospace models in the SWMF: HEIDI, RAM-SCB, CRCM
- Improvements in magnetic storm modeling: RCM decay, variable inner boundary, synthetic Kp index and magnetometers
- New Physics in PWOM and BATSRUS
- Coupling anisotropic BATSRUS with CRCM
- Numerical infrastructure: Block Adaptive Tree Library
- Summary

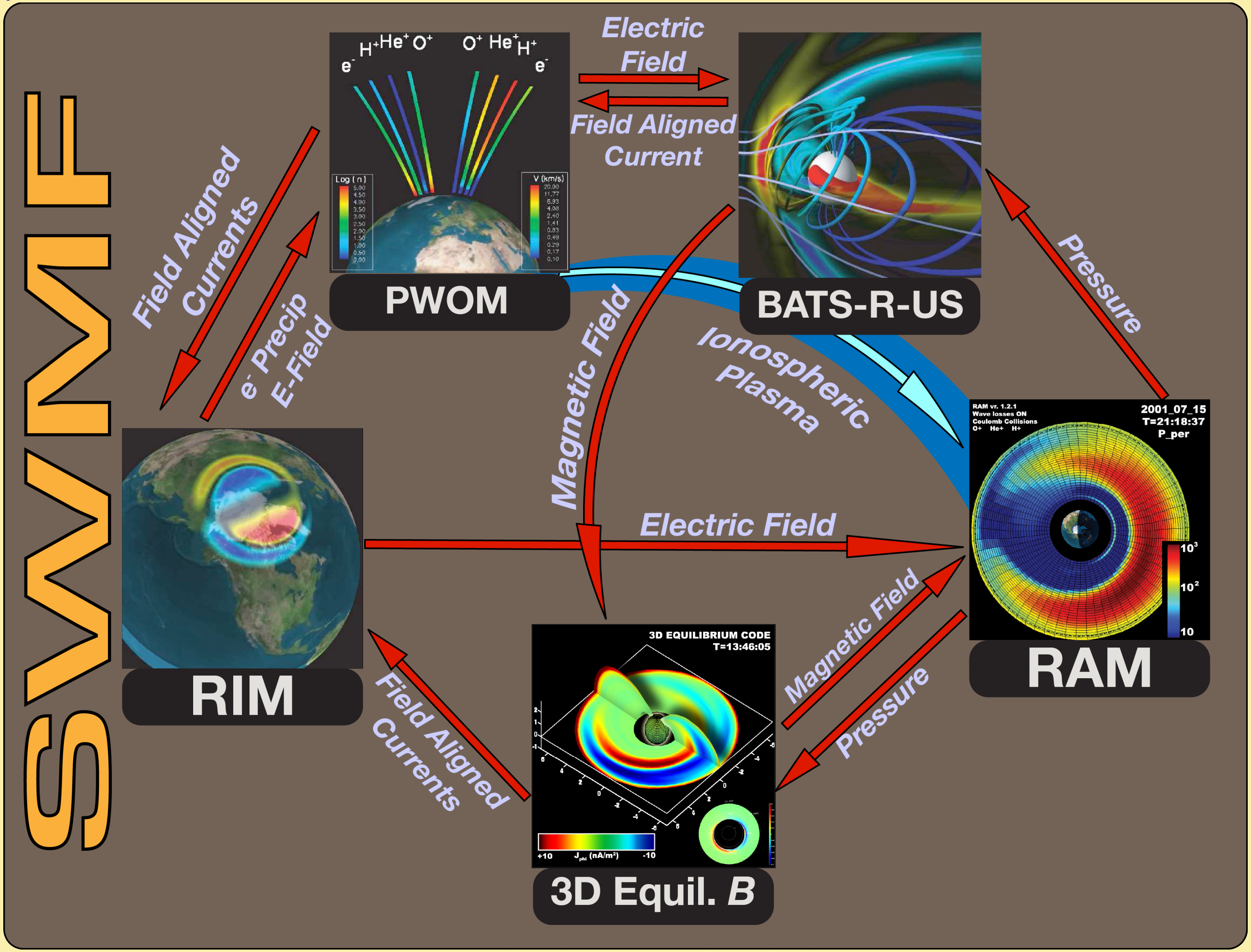
Geospace Components in the SWMF



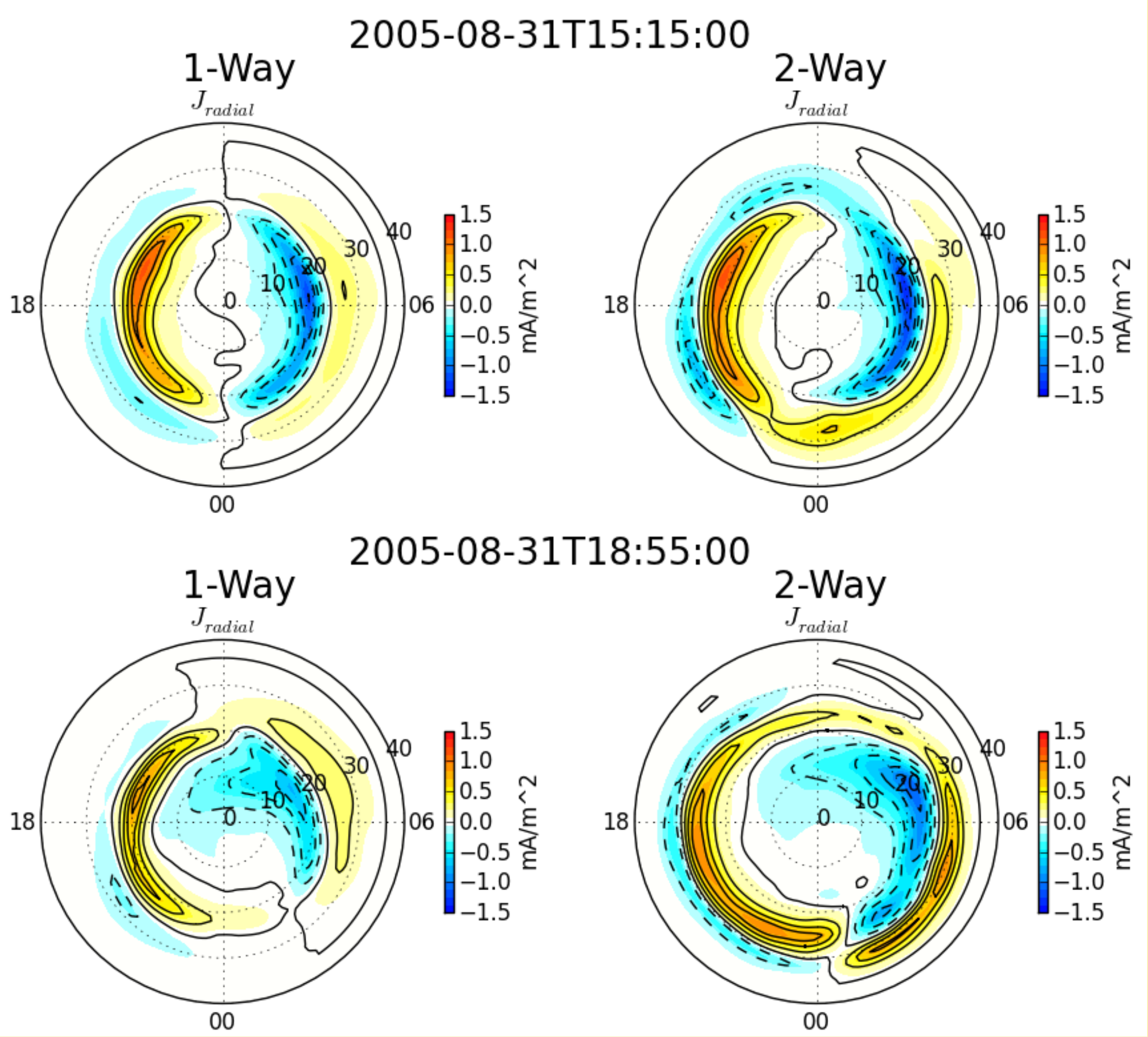
SWMF is freely available at http://csem.engin.umich.edu and via CCMC

RAM-SCB in the SWMF

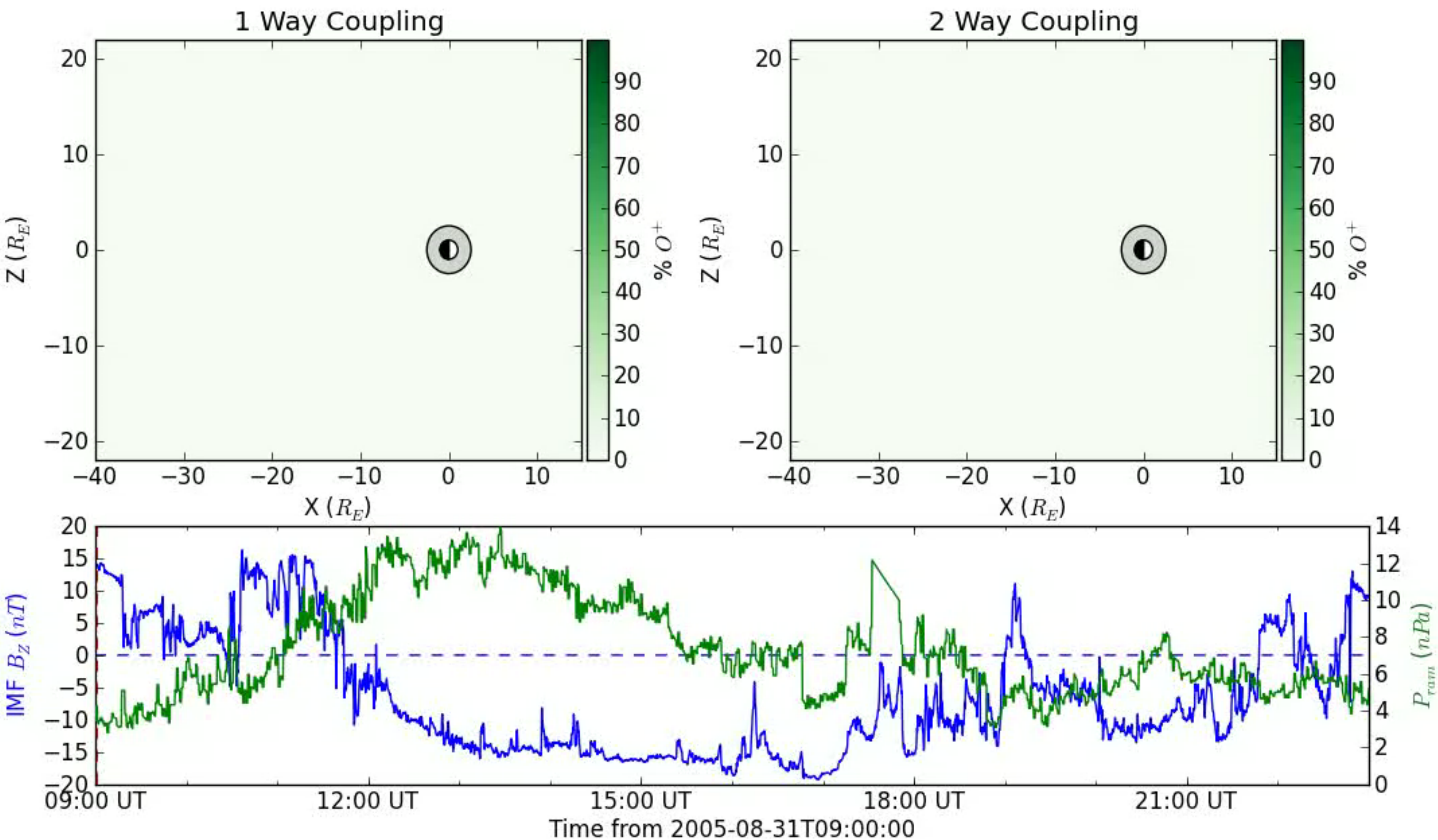
(D. Welling et al.)



Ionospheric Input Comparison

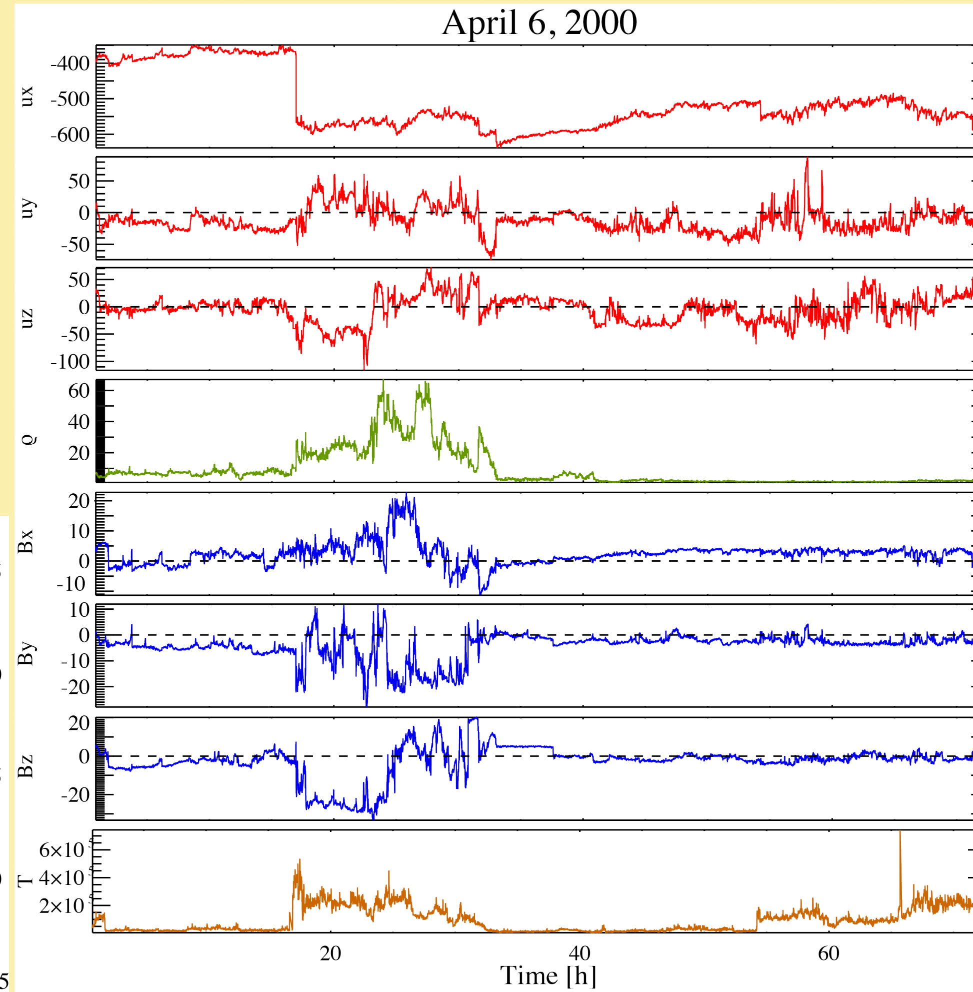


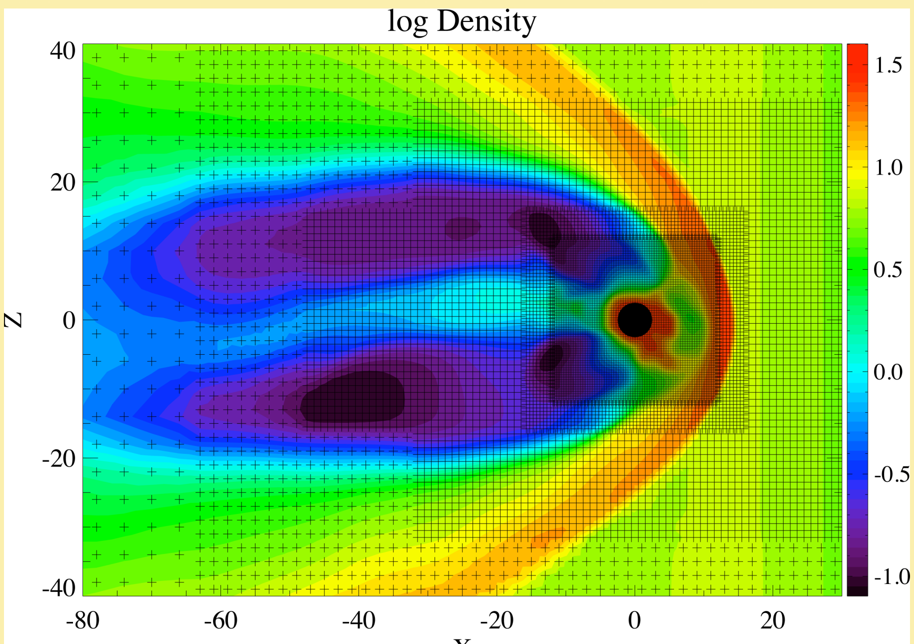
Magnetospheric Oxygen Ratio



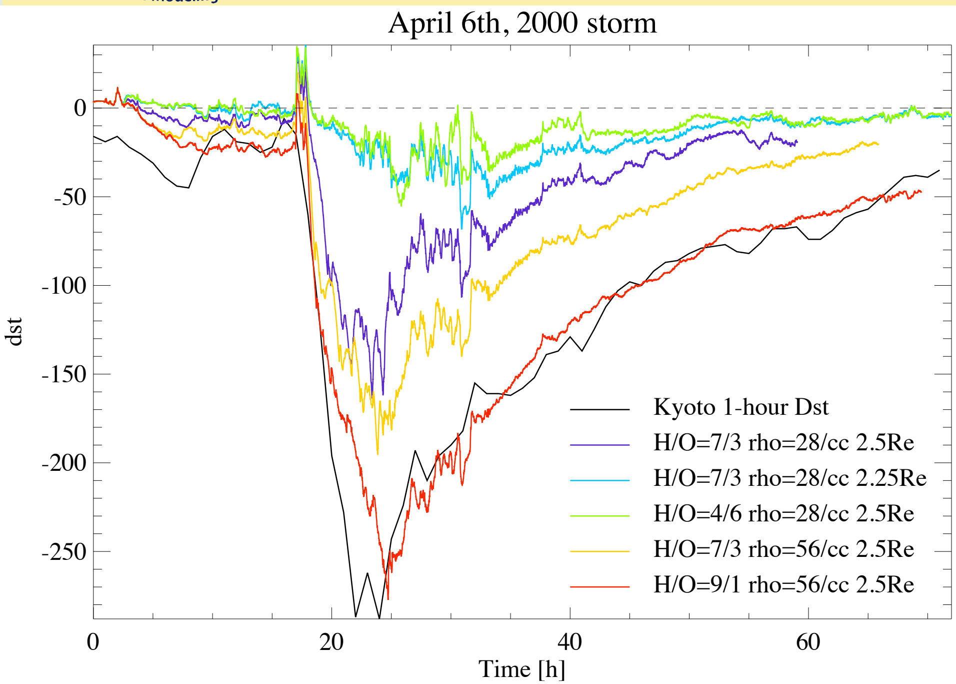
Improving Storm Simulations
(X. Meng and Y. Yu)

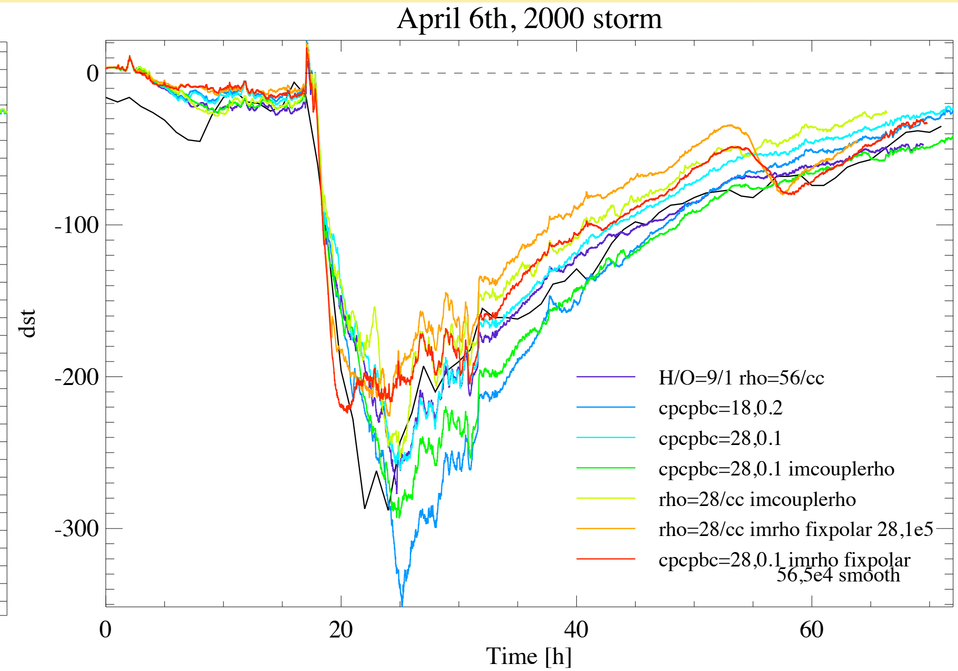
- **SWMF:**
  runs faster than real time on 64 cores (SWPC)
- **BATSRUS:**
  inner boundary density = a + b*CPCP
- **RCM:**
  density ratio H/O (7/3 - 9/1)
  decay rate (10hr)
- **RIM:**
  lower boundary (10° - 40° latitude)





April 6, 2000 Storm: Dst



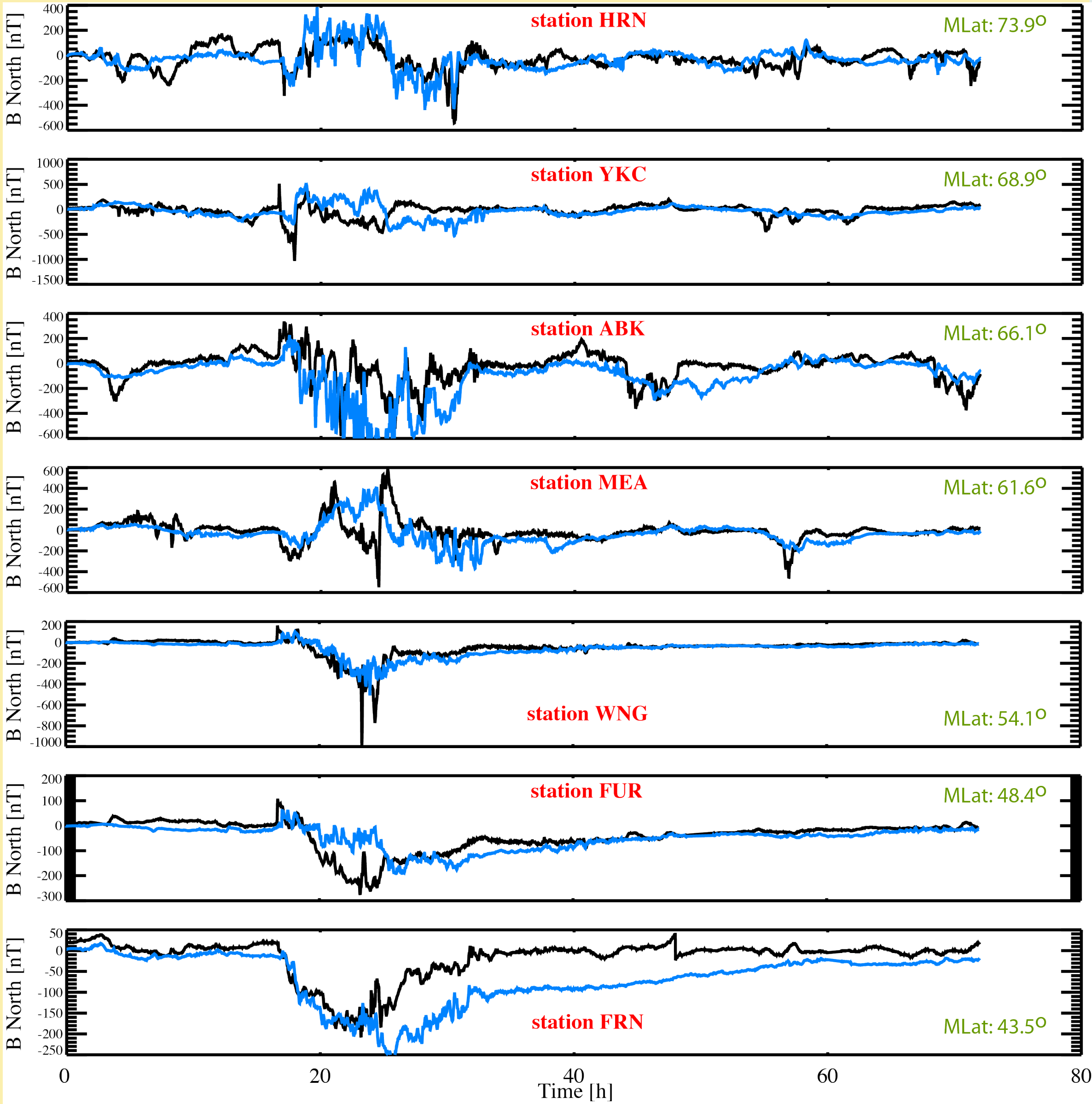


- **Optimize Dst prediction for many storms**
  - Vary H/O ratio in RCM, add decay
  - Couple or not with RCM density
  - Vary GM grid resolution
  - Vary location of and density at GM inner boundary
  - Vary CPCP dependent density at GM inner boundary
  - …

Synthetic Magnetometers
(Y. Yu)

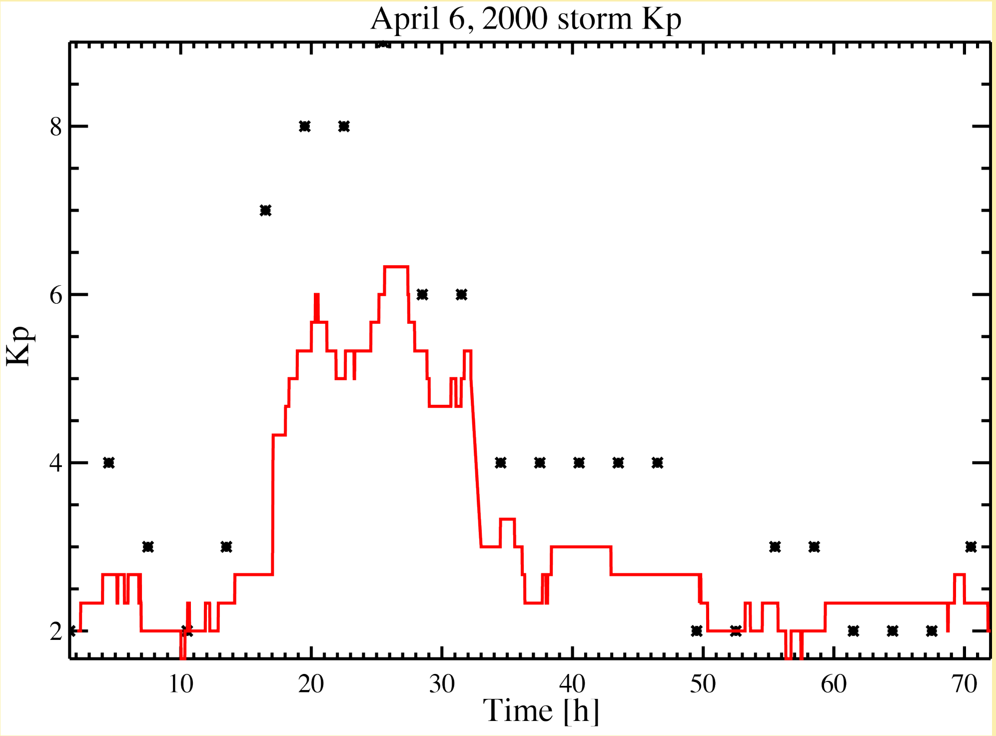
April 6, 2000
observations
simulation

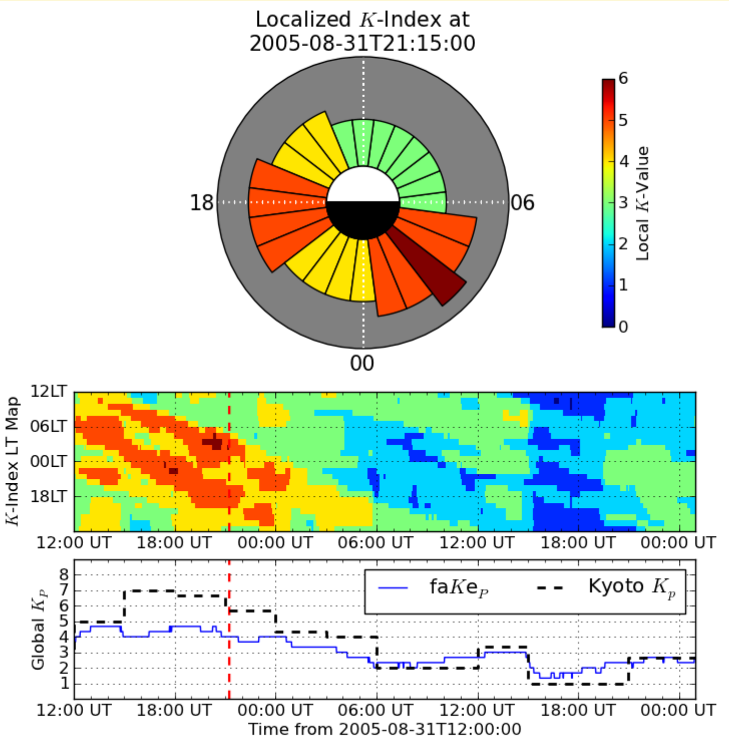
- **Multiple magnetometer locations**
- **Perturbations are calculated from the Biot-Savart integrals of currents in**
  - BATSRUS domain
  - Gap region
  - Ionosphere domain
- **GM and IE contributions are added up in a post-processing step**



Synthetic Kp Index
(D. Welling)

- 24 virtual magnetometers at constant latitude.
- H-component is converted to dH, then local K.
- Average of local K yields KP.
- Provides localized K data for quick-look activity monitors.
- Can be used as inputs for KP-dependent models.

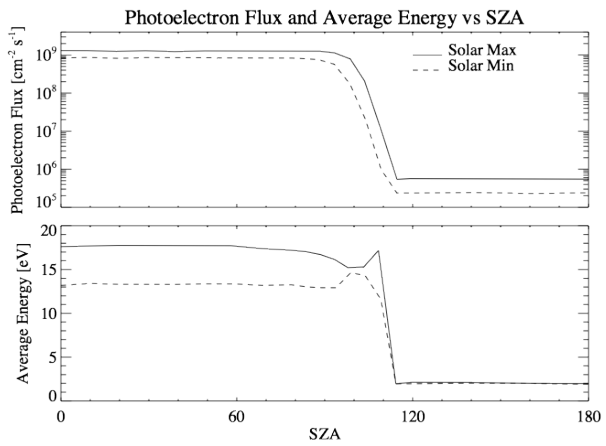




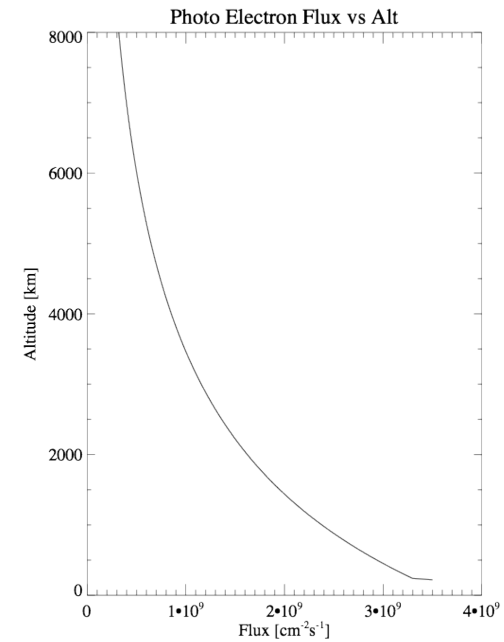
Adding Photoelectrons to PWOM

A. Glocer

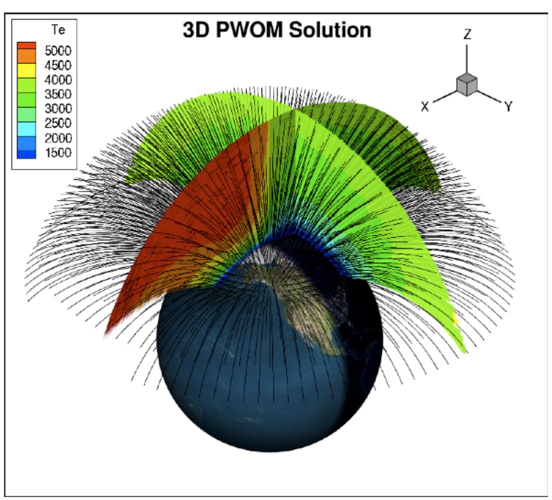
1) Define Photoelectron Flux at base using *Su et al*. [1998]



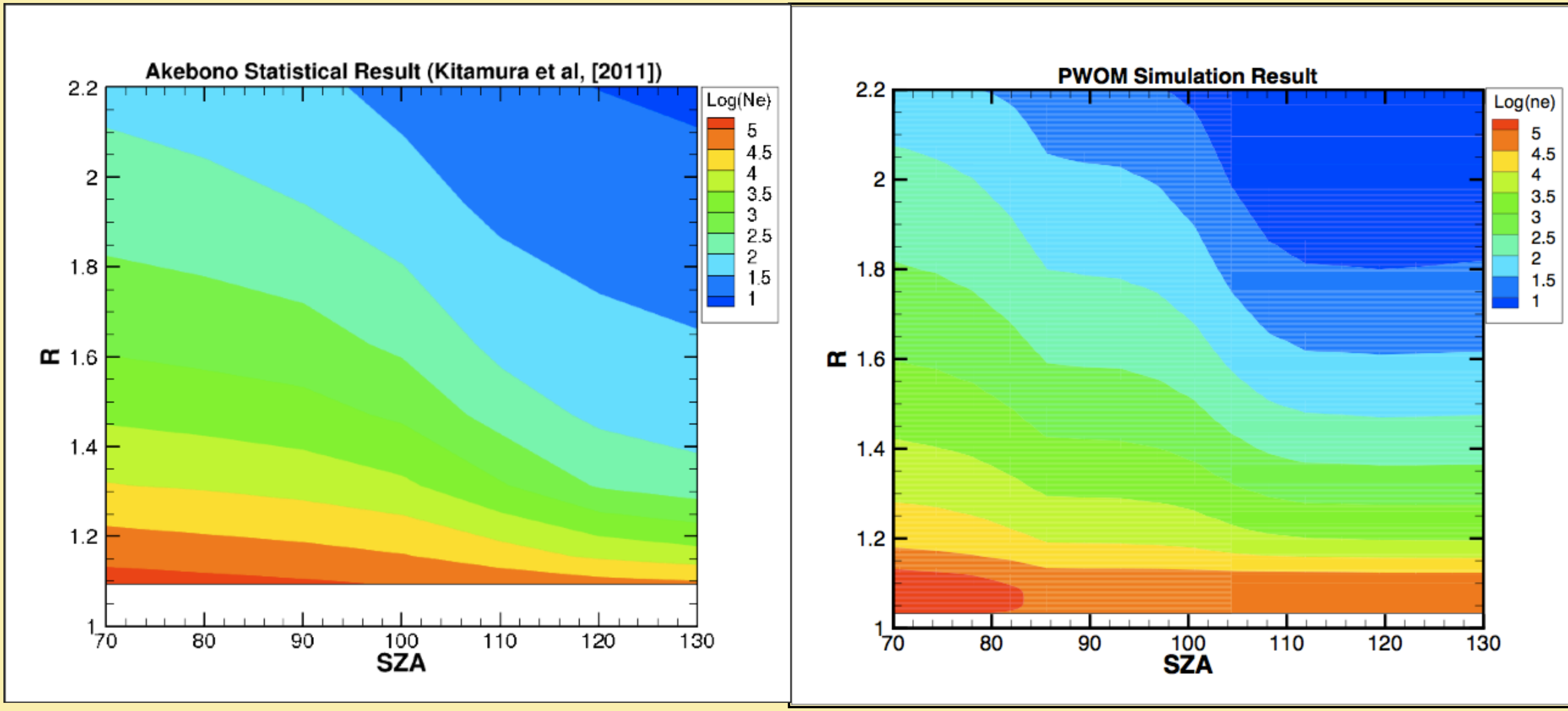
2) Use calculated electric and gravitational potential to get an analytical solution for the photoelectron flux (*Khazanov et al* [1997])



3) Put the photo-electron flux into the electron momentum equation which alters the T_e and $E_{||}$



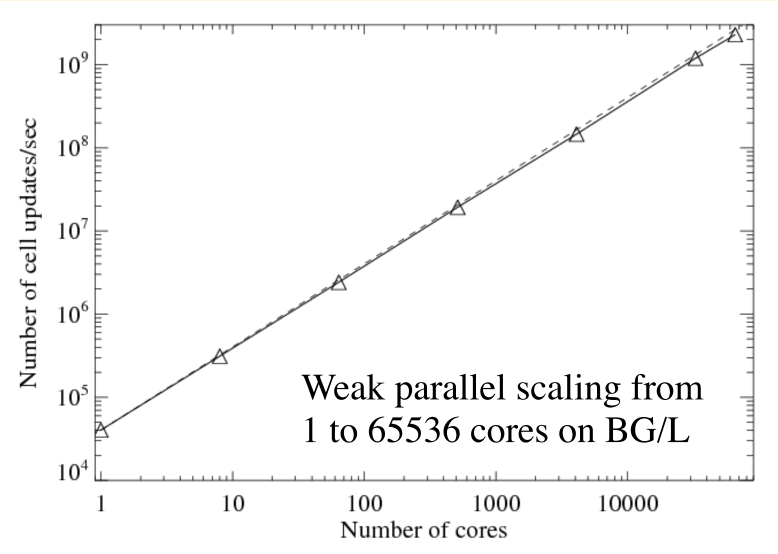
SZA Dependence of N_e



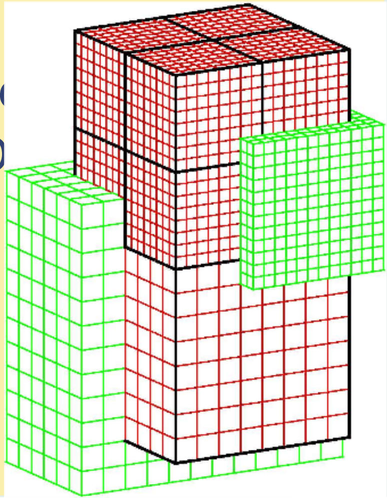
- Comparison of Empirical fit to Akebono data and PWOM calculation
- Similar electron densities and SZA dependence is visible.

BATS-R-US

Block Adaptive Tree Solar-wind Roe Upwind Scheme



- **Physics**
  - Classical, semi-relativistic and Hall MHD
  - Multi-species, multi-fluid, anisotropic pressure
  - Radiation hydrodynamics multigroup diffusion
  - Multi-material, non-ideal equation of state
  - Solar wind turbulence, Alfven wave heating
- **Numerics**
  - Conservative finite-volume discretization
  - Parallel block-adaptive grid using BATL
  - Cartesian and generalized coordinates
  - Splitting the magnetic field into $B_0 + B_1$
  - Divergence B control: 8-wave, CT, projection, parabolic/hyperboli
  - Shock-capturing TVD schemes: Rusanov, HLLE, AW, Roe, HLLD
  - Explicit, point-implicit, semi-implicit, fully implicit time stepping
- **Applications**
  - Heliosphere, sun, planets, moons, comets, HEDP experiments
- **100,000+ lines of Fortran 90 code with MPI parallelization**



Anisotropic Pressure
(X. Meng, G. Toth, T. Gombosi)

- **Ion pressure is anisotropic in collisionless space plasmas**
  - For now electron pressure is assumed to be isotropic but independent
- **We have implemented the anisotropic MHD equations into BATSRUS**
  - Derived wave speeds for classical and semi-relativistic cases
  - Use kinetic stability conditions to limit anisotropy and get proper jump conditions across shocks
  - Optional ad hoc relaxation terms (e.g. wave-particle interaction)
- **Magnetosphere simulations**
  - Comparison with Themis data during quiet time
  - Comparison with Cluster data during storm time

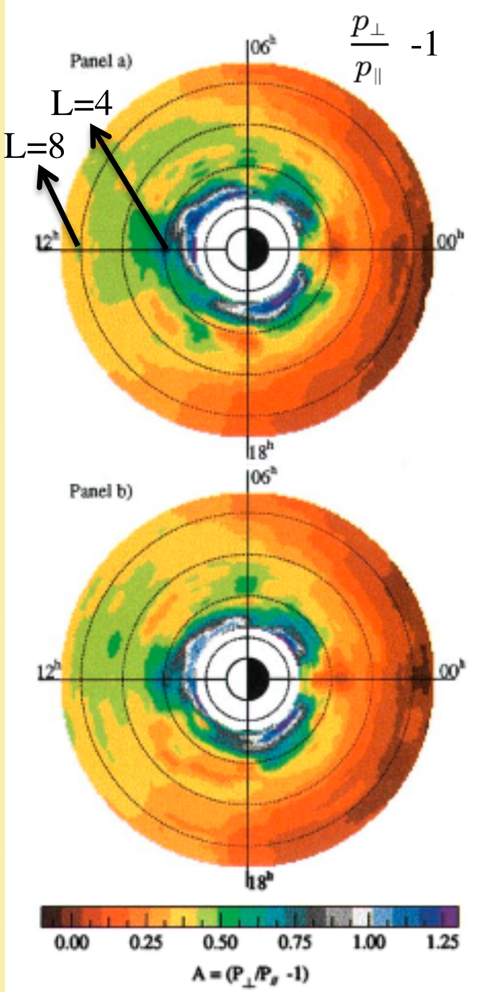
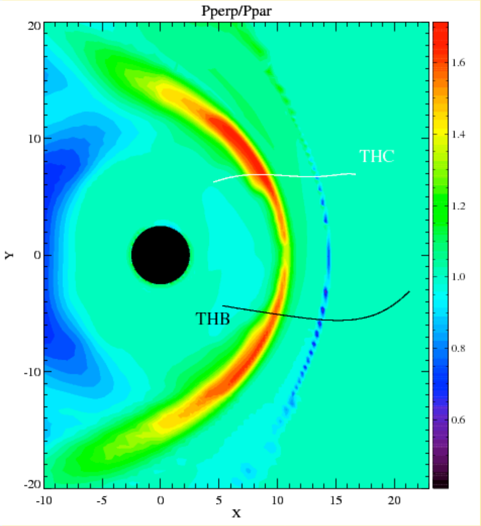
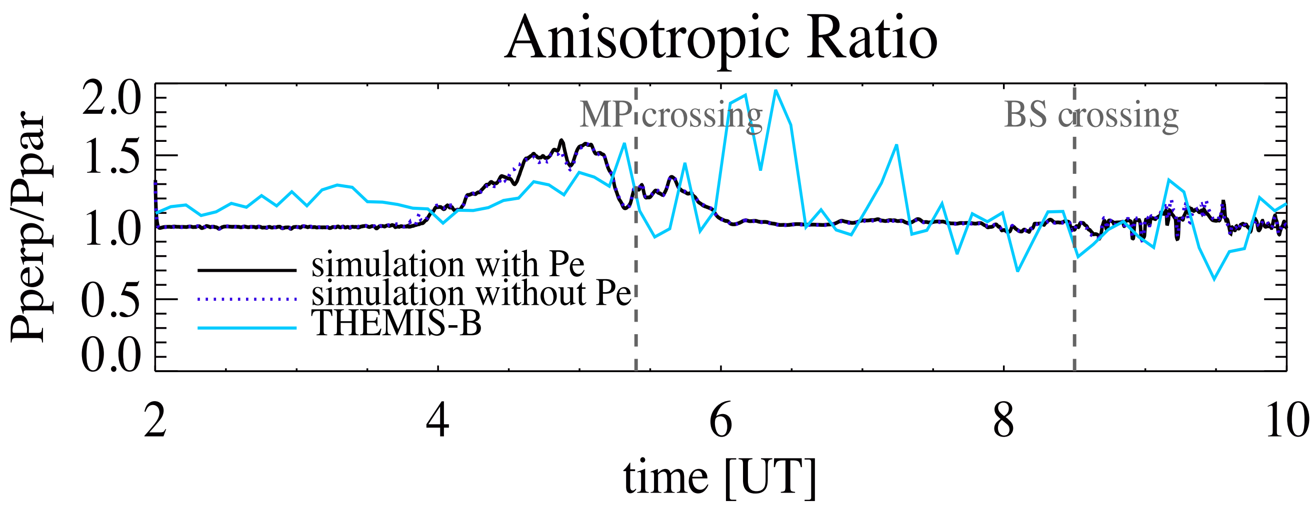


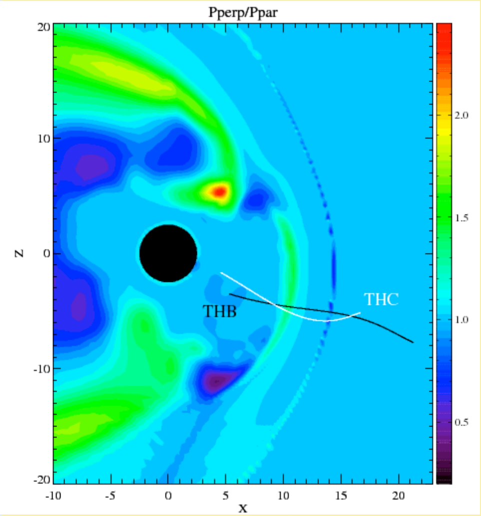
Plate 2. Images of pressure anisotropy A in the equatorial plane for (a) $AE<100$ nT and (b) 100 nT$<AE<$600 nT. The black dotted circles are at $L = 2, 4, 6$, and 8, respectively.

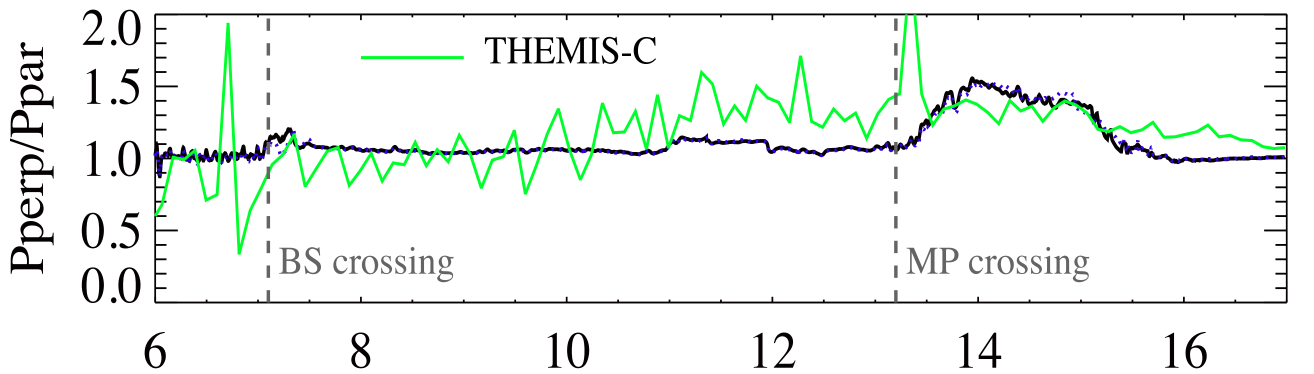
(De Michelis 1999)

Quiet time: July 29, 2008 Anisotropic Pressure Comparison with Themis



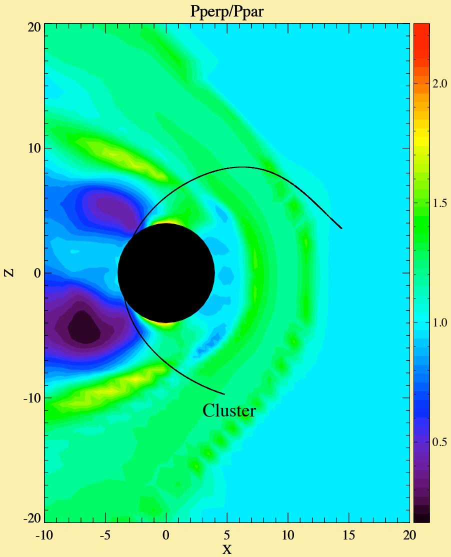


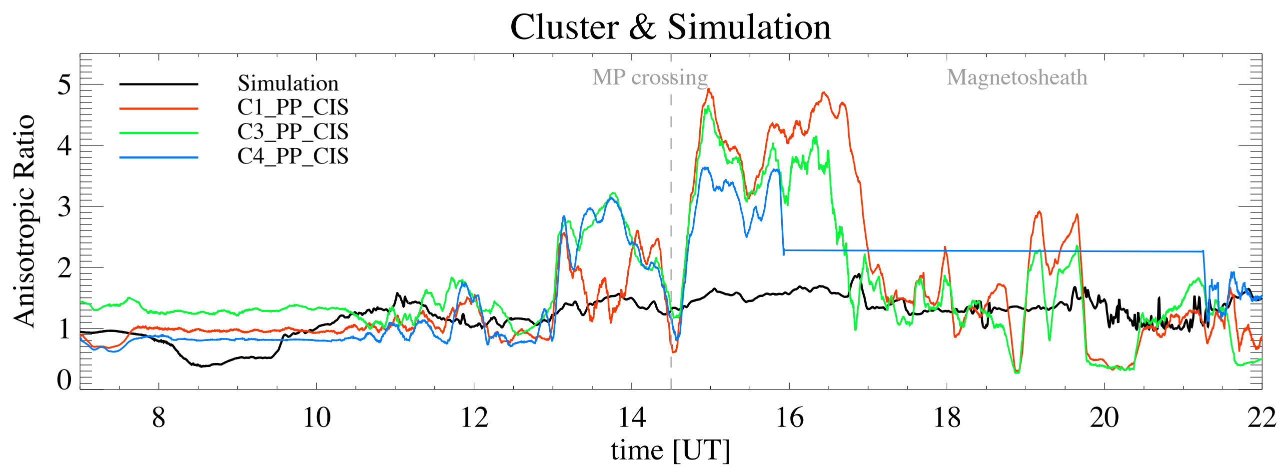


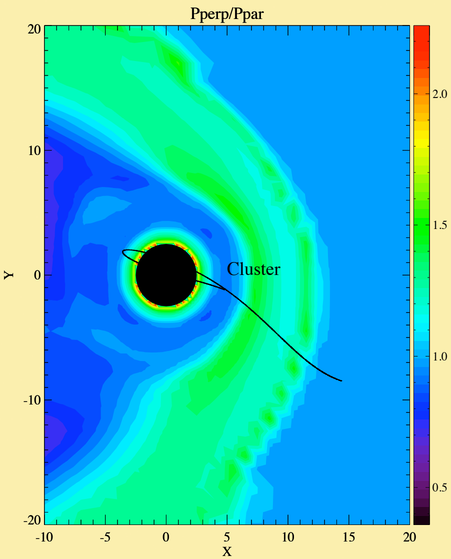


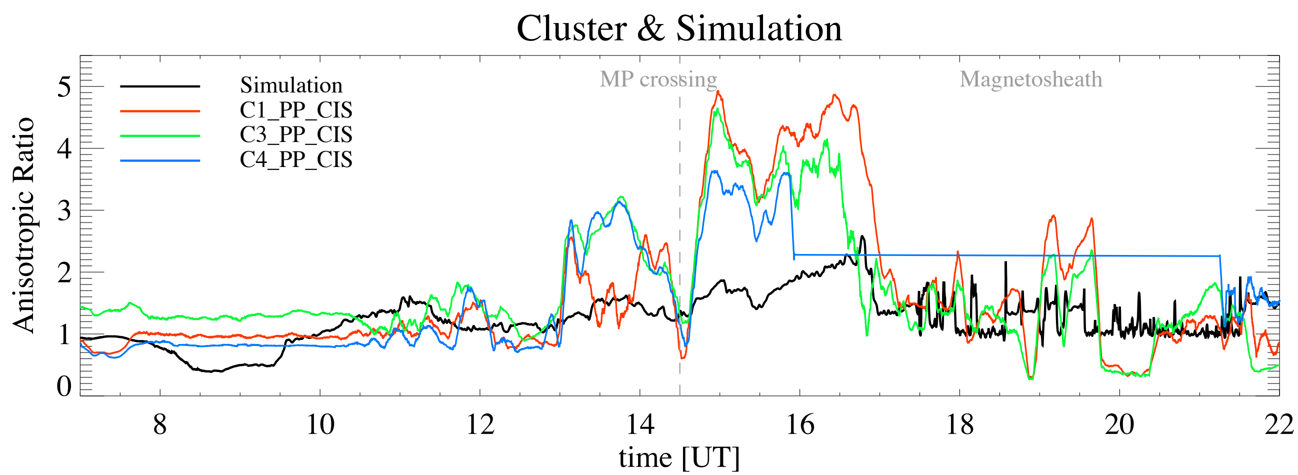
Simulated anisotropy shows similarities with data.

Storm Time: March 31, 2001
Anisotropy comparison with Cluster



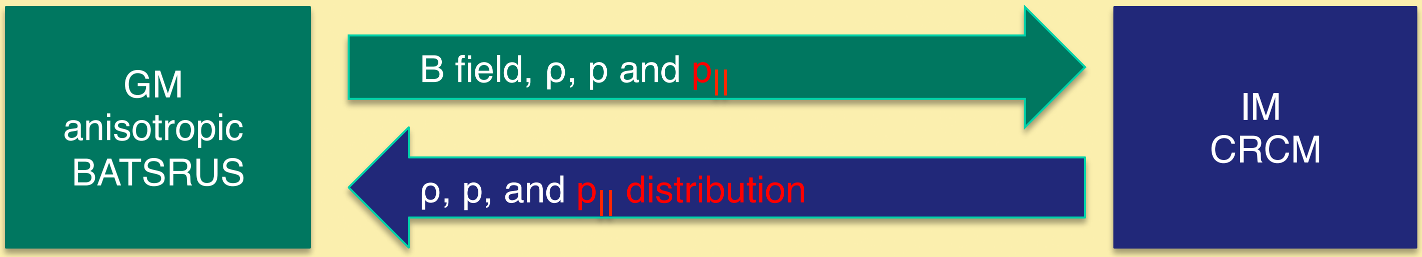






Increased resolution at MP and increased instability relaxation time

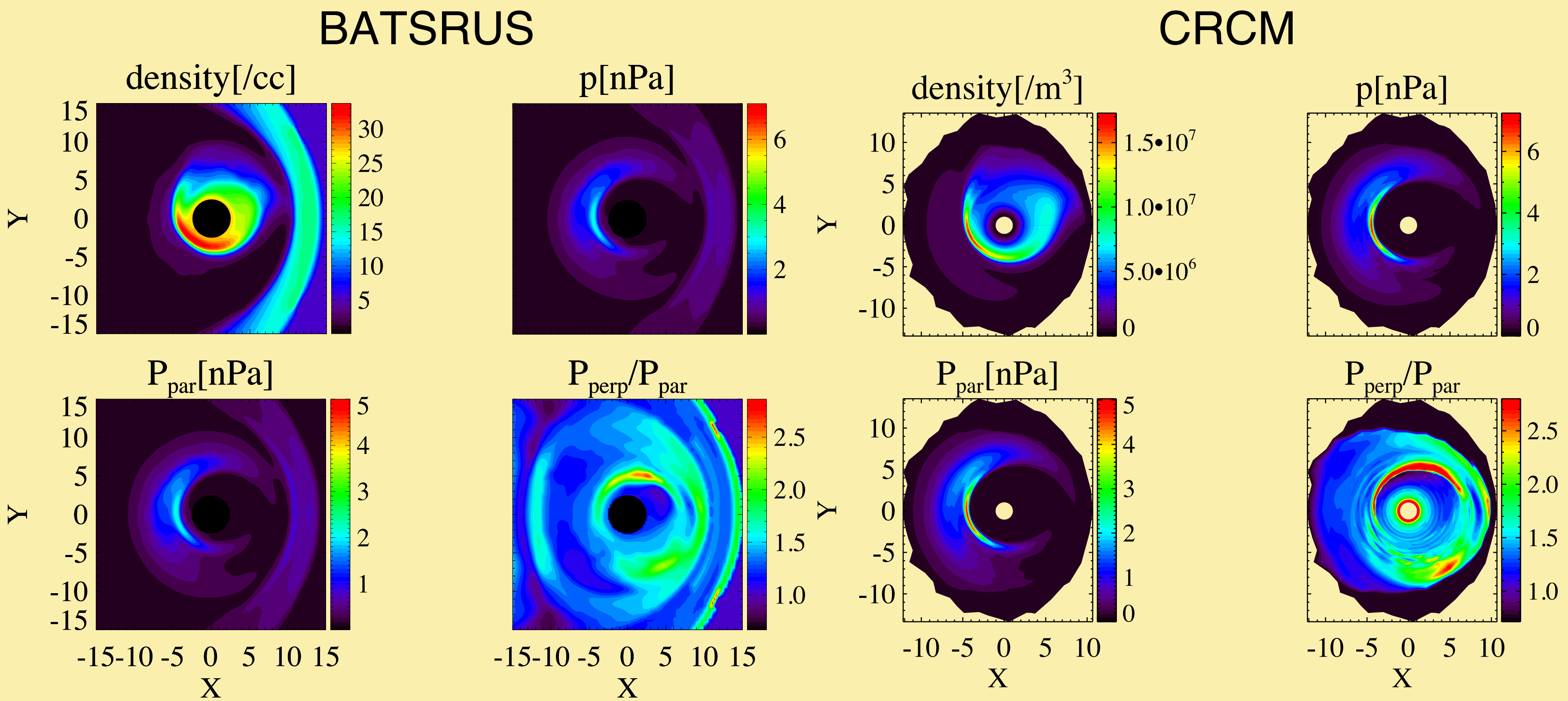
BATSRUS – CRCM coupling
(X. Meng, G. Toth, A. Glocer, M-C. Fok)



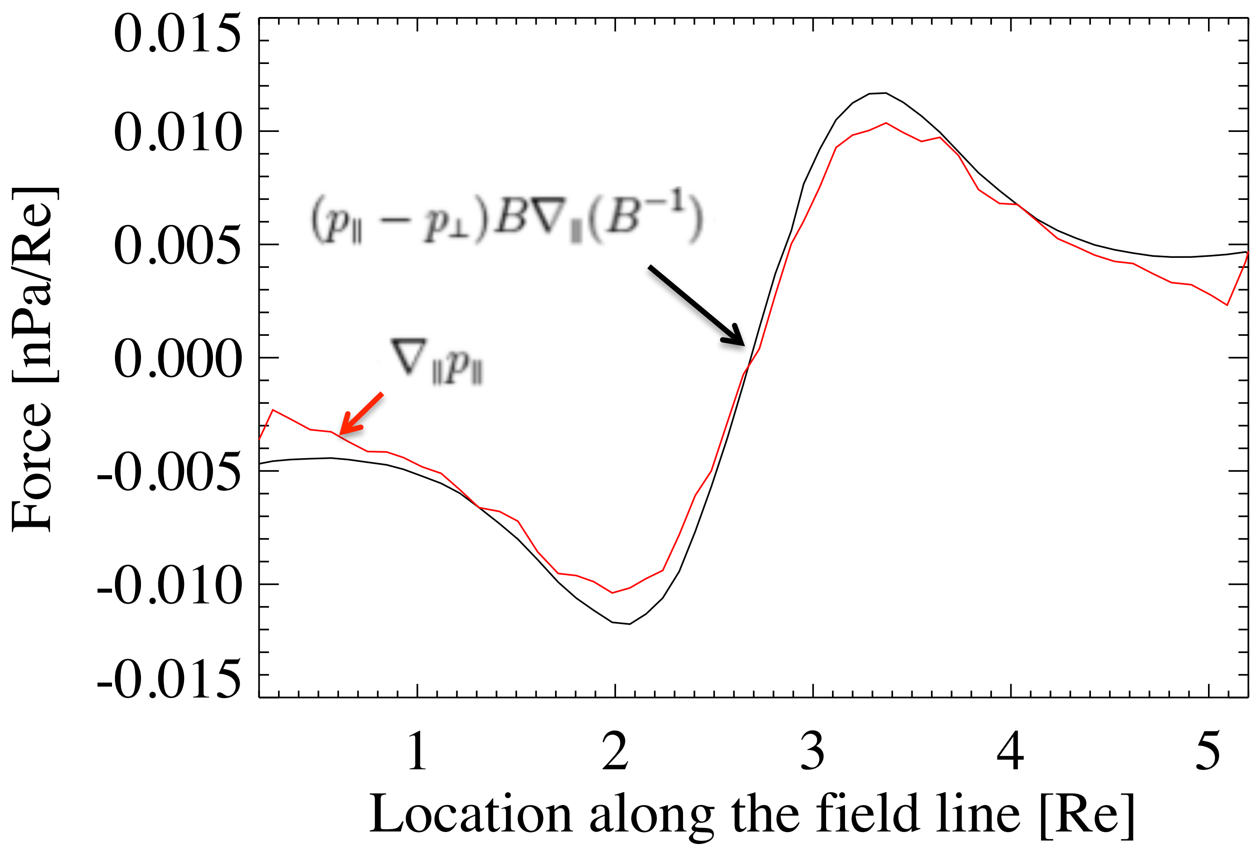
- BATS-R-US sends to CRCM:
  - Magnetic field information as inputs for CRCM
  - Density, total and parallel pressures at minimum B of each field line as boundary conditions for CRCM
- CRCM sends to BATS-R-US:
  - Density, total pressure, parallel pressure at minimum B of each field line
  - Minimum B for each field line
- BATS-R-US does the following:
  - It traces all cell centers back to their ionospheric foot points along field lines and interpolates the minimum B, density and pressures at minimum B to that foot point.
  - It then calculates density and pressures for the cell center using the local B field and formulas derived from Liouville's theorem

Verification

- Idealized constant solar wind with slightly southward IMF
- Compare densities and pressures in the Z=0 plane

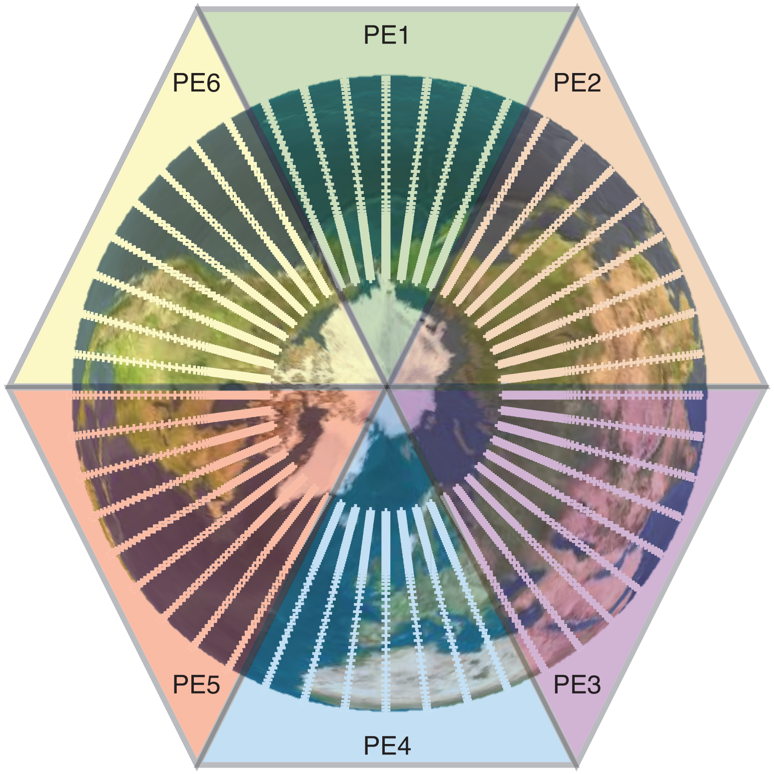


Testing Force Balance Along Field Line

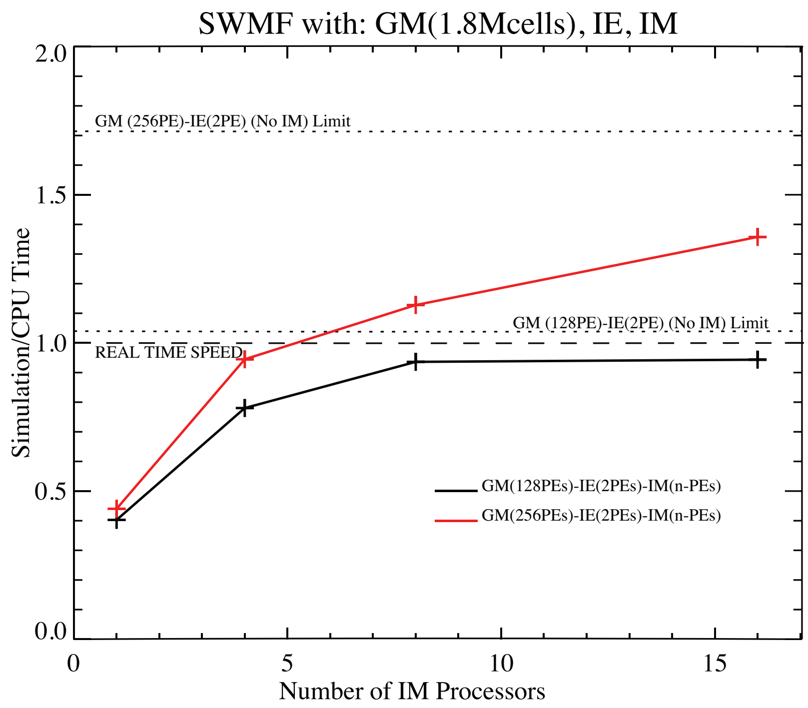


Parallelizing CRCM
(A. Glocer)

CRCM Domain Decomposition



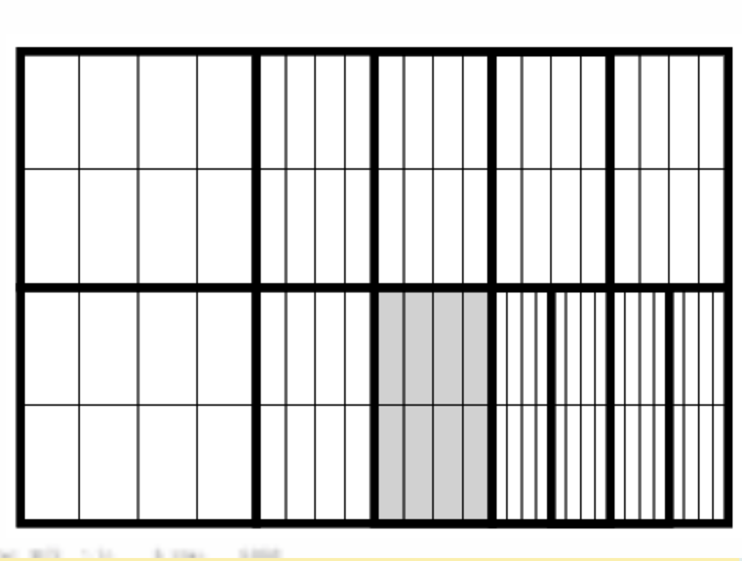
Parallel Performance



Block Adaptive Tree Library (BATL)

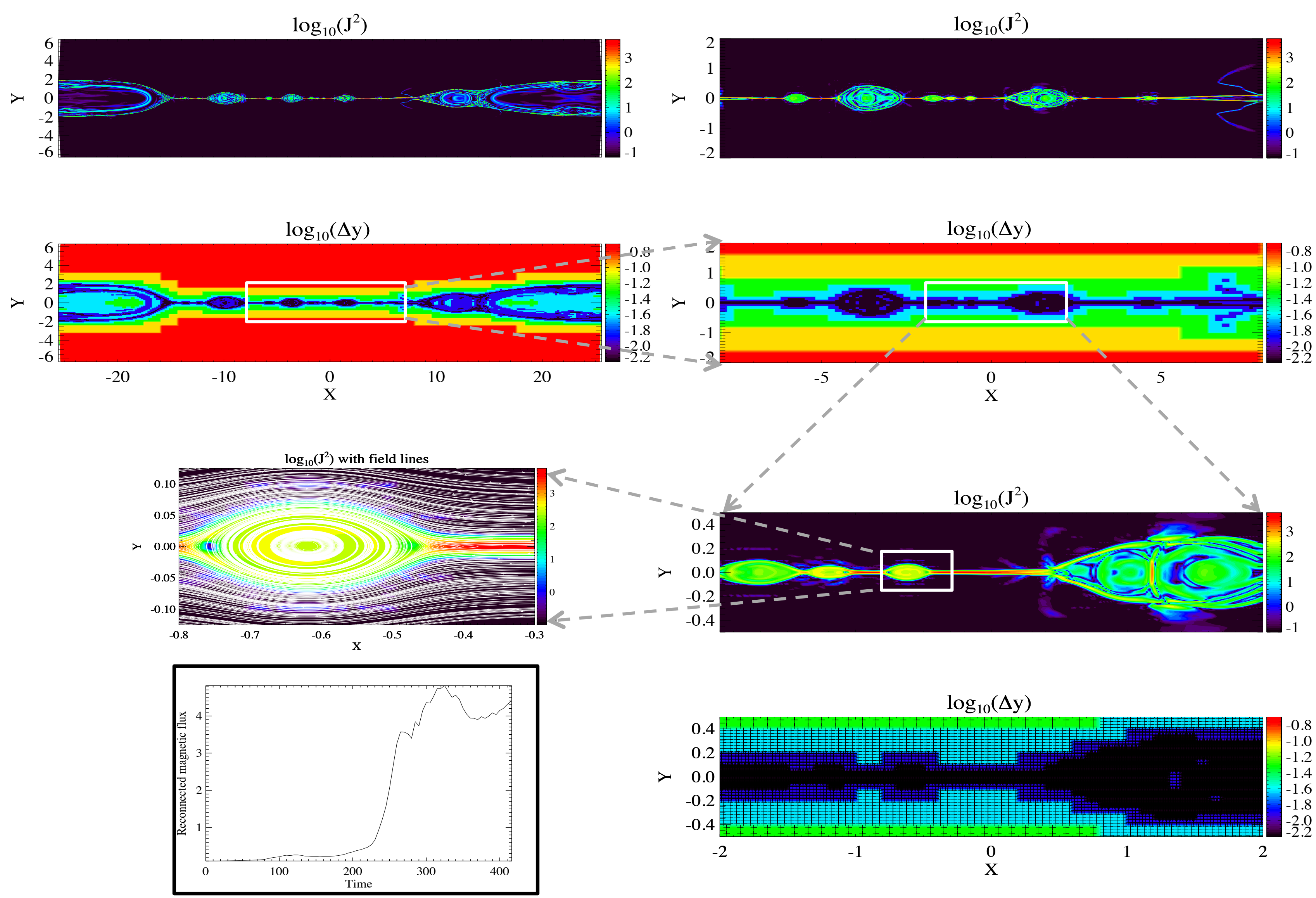
(Bart van der Holst, Gabor Toth and Lars Daldorff)

- **BATL**
  - New stand-alone AMR library for BATS-R-US and possibly other codes
- **Features**
  - Supports 1, 2 and 3D block-adaptive grids
  - Allows AMR in a subset of the dimensions
  - Supports different time steps per block
  - Arbitrary number of ghost cells
  - Written in Fortran 90 and MPI
  - Object oriented style with unit tests



- **Algorithms**
  - Tree information is stored in global simple integer arrays
  - Message passing with self-described data
  - Second order accurate prolongation and restriction operators
  - Efficient grid adaptation with flexible criteria
- **Status**
  - BATSRUS now uses BATL for all runs on Cartesian grids
  - Curvilinear grid implementation is almost done

High Resolution Reconnection in 2D
$\eta = 10^{-4}$ and $S = 5 \times 10^5$



Summary

- SWMF is available for registered users and through CCMC
- Most of the geospace models of the SWMF are mature
  - CCMC has been using BATSRUS-RCM-RIM-RBE for many years for runs-on-request as well as real-time now-casting.
- New inner magnetosphere models (RAM-SCB, CRCM) were added
  - Both resolve pitch angle. RAM-SCB calculates a self-consistent B field.
- CRCM parallelization allows faster than real-time simulations
- PWOM validation with newly added photo-electron model
- Multi-ion BATSRUS is now used in many applications
- Anisotropic MHD and CRCM coupling is under testing
- Block Adaptive Tree Library (BATL) developed for BATSRUS
- Verification, validation and continuous testing are part of the SWMF development process