Improvements for Operations in the Space Weather Modeling Framework

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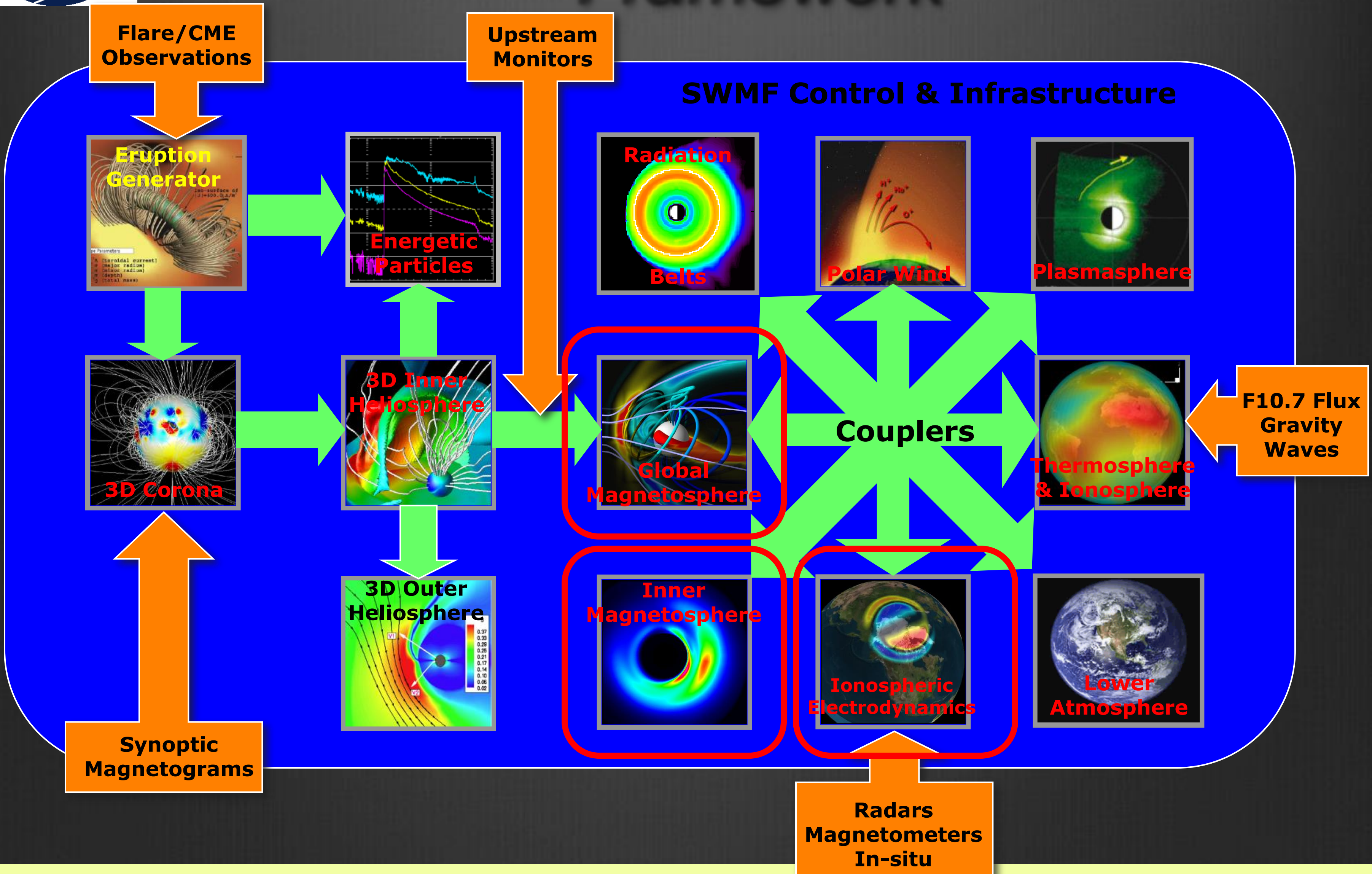
Space Weather Modeling Framework

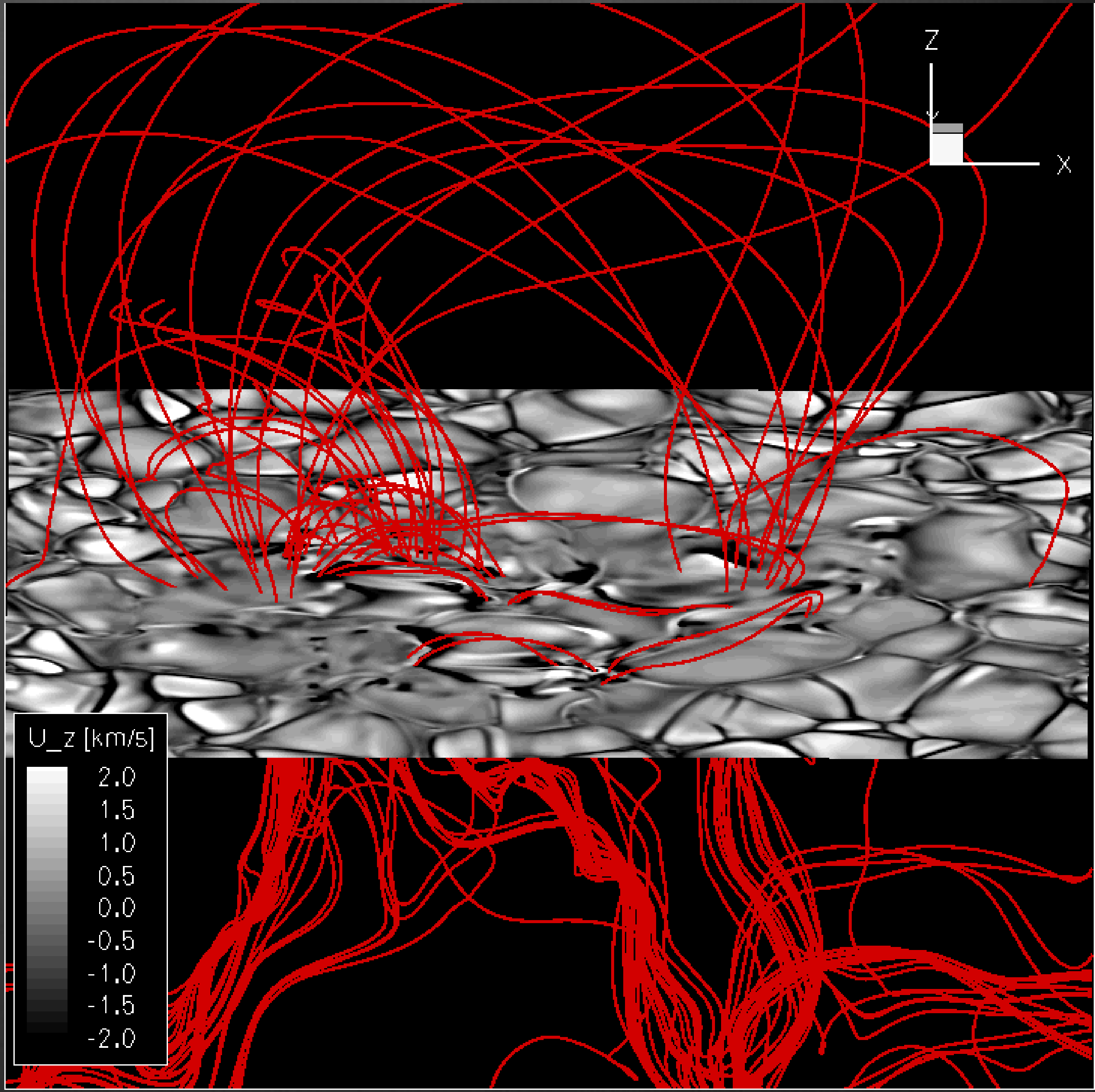


The SWMF is freely available at http://csem.engin.umich.edu

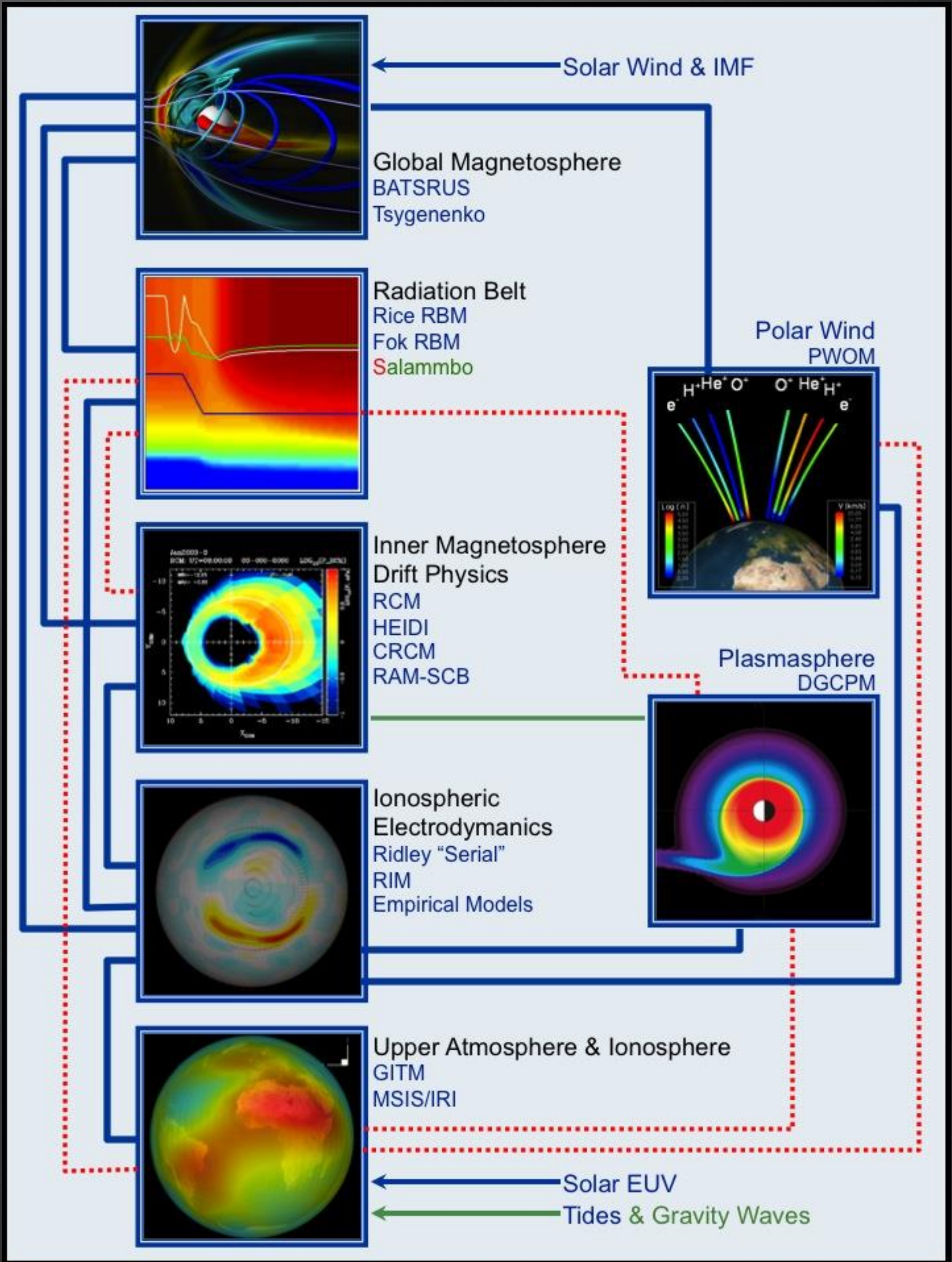
Flux Emergence

We have run BATSRUS as a regional model to self-consistently model flux emergence from the convective zone through the photosphere (Manchester and Fang).

30x30x40 Mm shown
Gray scale is vertical velocity; Red lines are magnetic field lines.

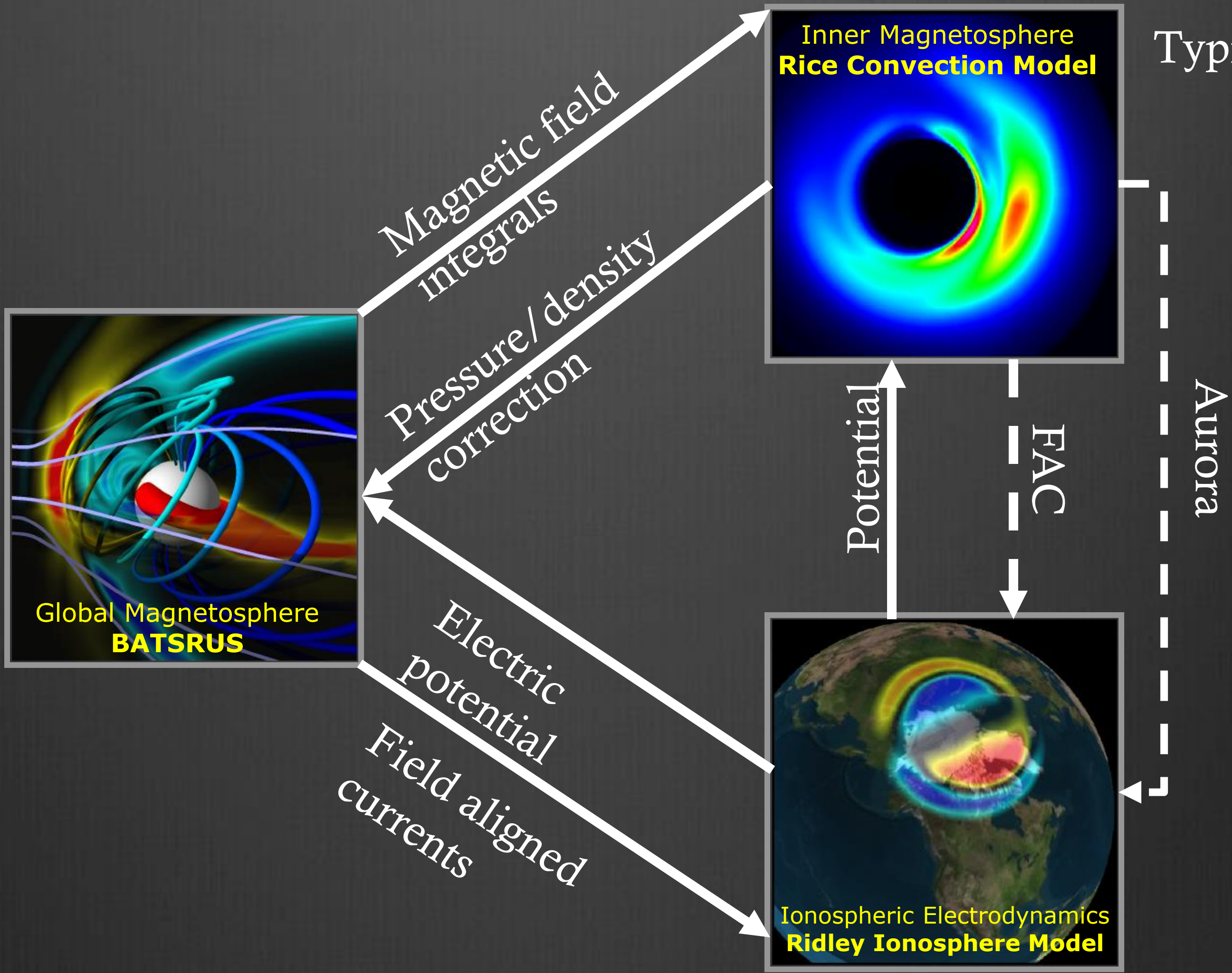


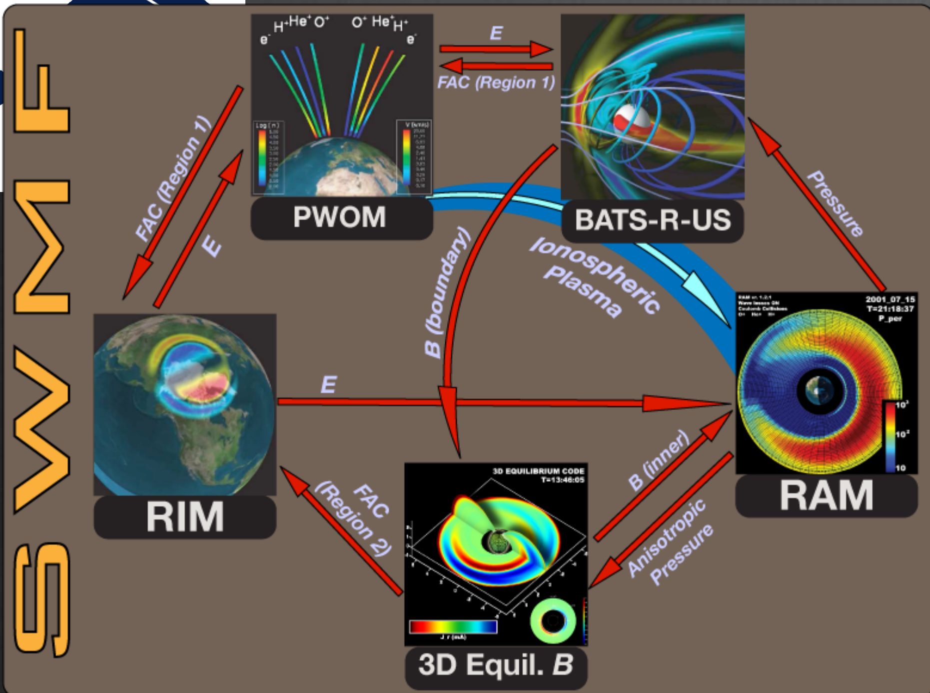
Near-Earth Models of the SWMF

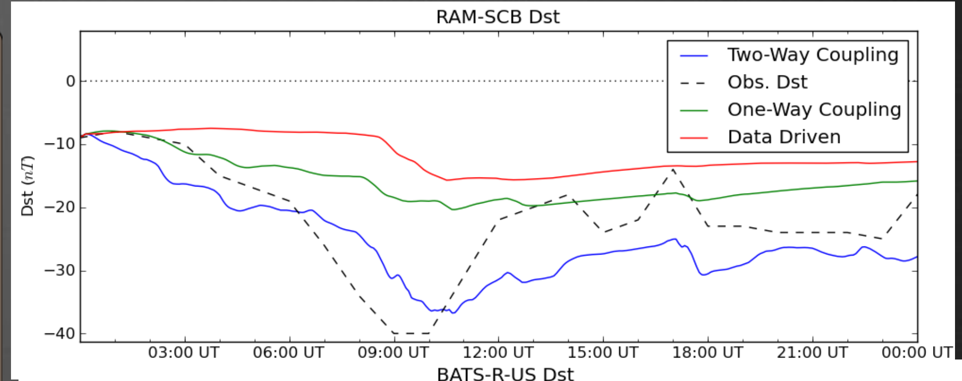


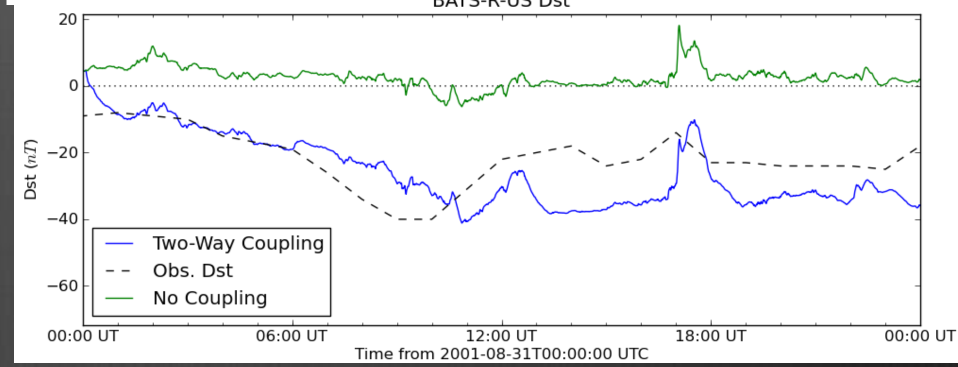
Magnetosphere-Ionosphere Coupling

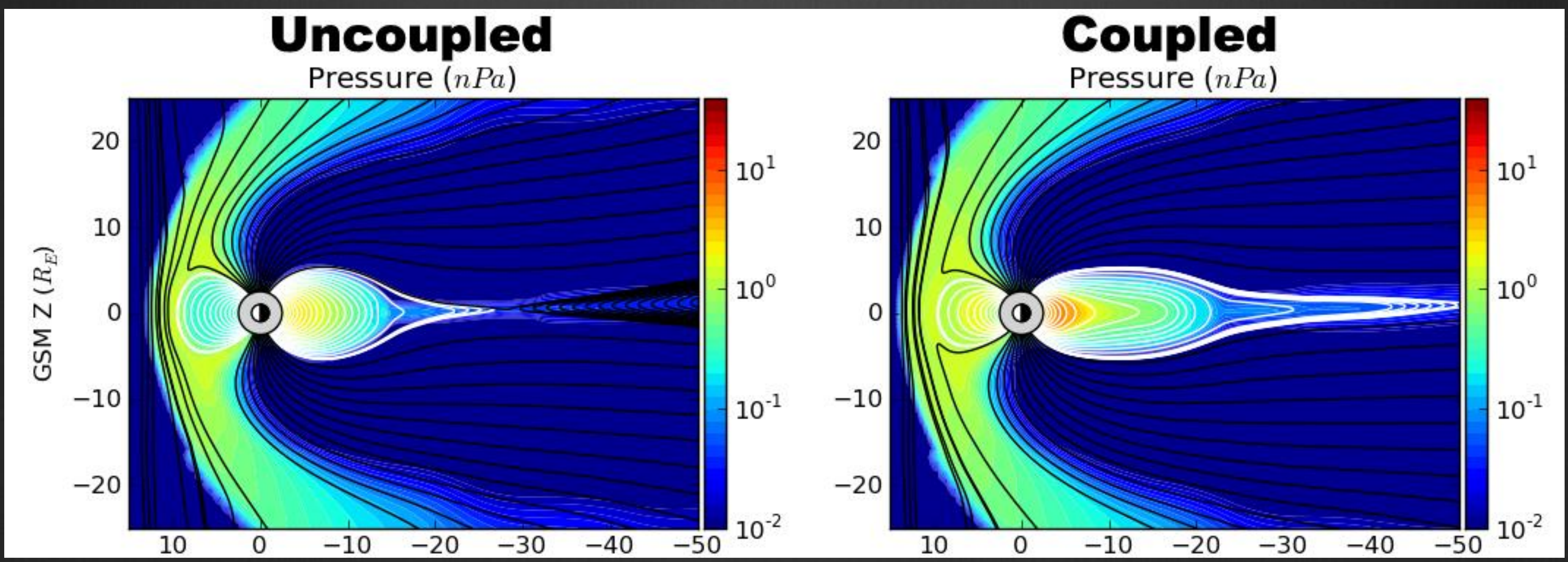
Typically RCM




SWMF
PWOM
BATS-R-US
RIM
RAM
3D Equil. B
E
FAC (Region 1)
FAC (Region 1)
E
Pressure
Ionospheric Plasma
B (boundary)
E
B (inner)
Anisotropic Pressure
FAC (Region 2)

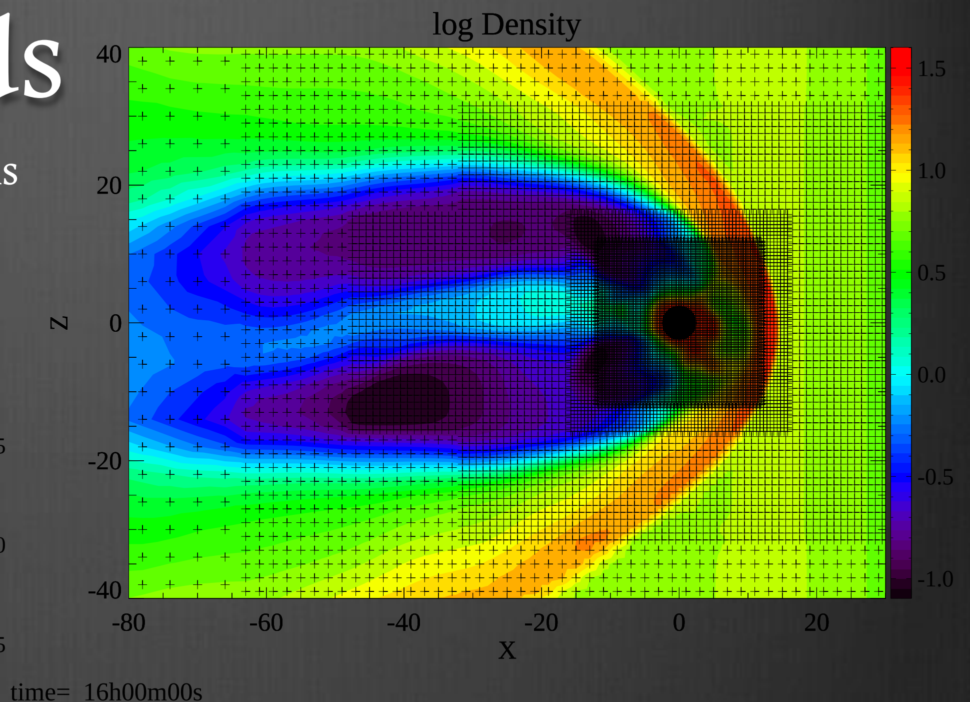

RAM-SCB Dst
Two-Way Coupling
Obs. Dst
One-Way Coupling
Data Driven
Dst (nT)
0
−10
−20
−30
−40
03:00 UT
06:00 UT
09:00 UT
12:00 UT
15:00 UT
18:00 UT
21:00 UT
00:00 UT


BATS-R-US Dst
Two-Way Coupling
Obs. Dst
No Coupling
Dst (nT)
20
0
−20
−40
−60
00:00 UT
06:00 UT
12:00 UT
18:00 UT
00:00 UT
Time from 2001-08-31T00:00:00 UTC

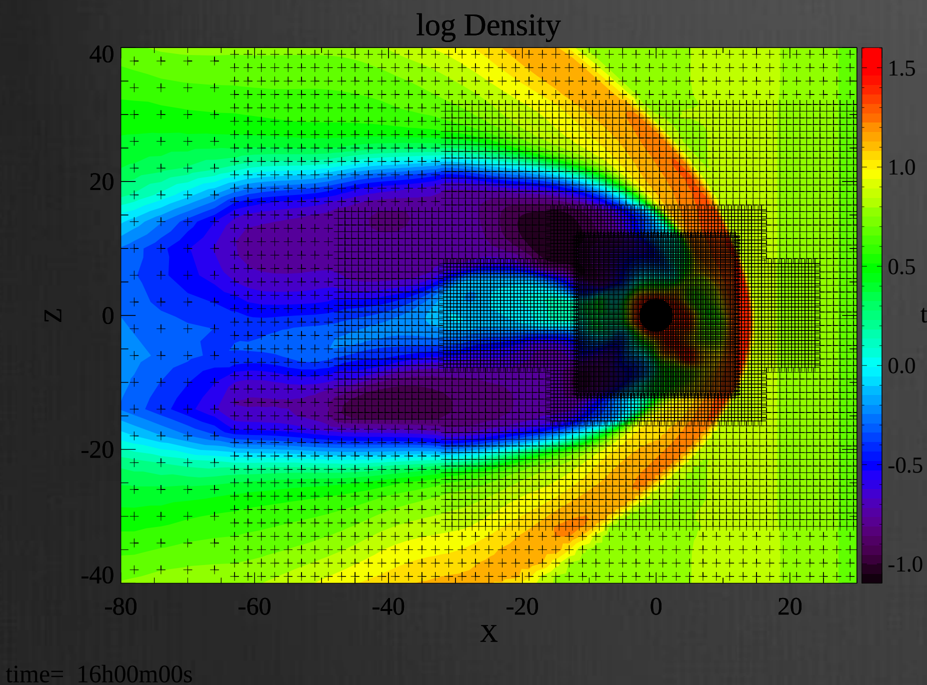

Uncoupled
Pressure (nPa)
Coupled
Pressure (nPa)
GSM Z (R_E)
20
10
0
−10
−20
10
0
−10
−20
−30
−40
−50
10^1
10^0
10^-1
10^-2

Testing Grids

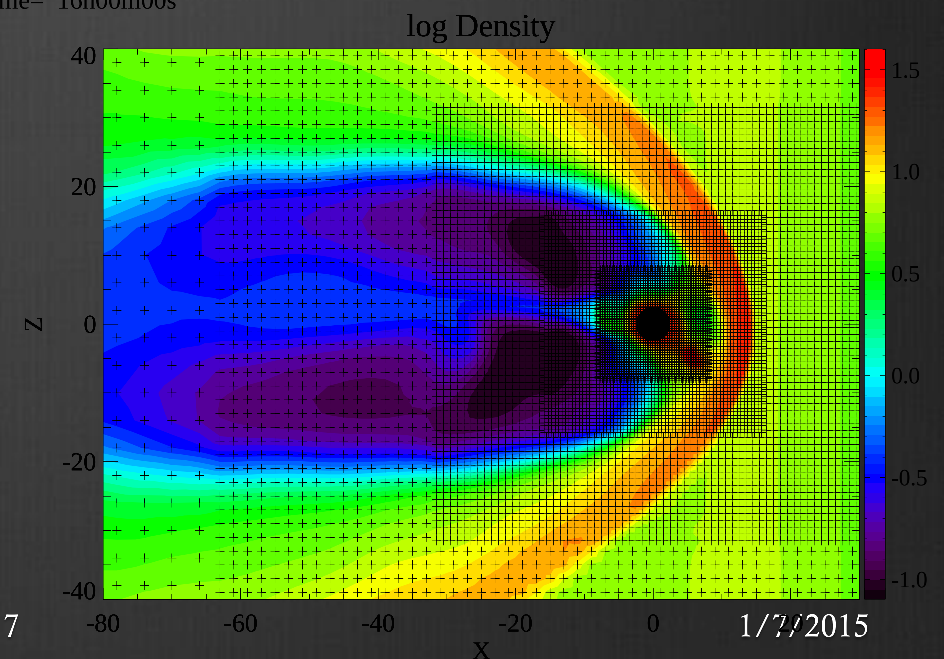
Grid 2: 1.02M cells



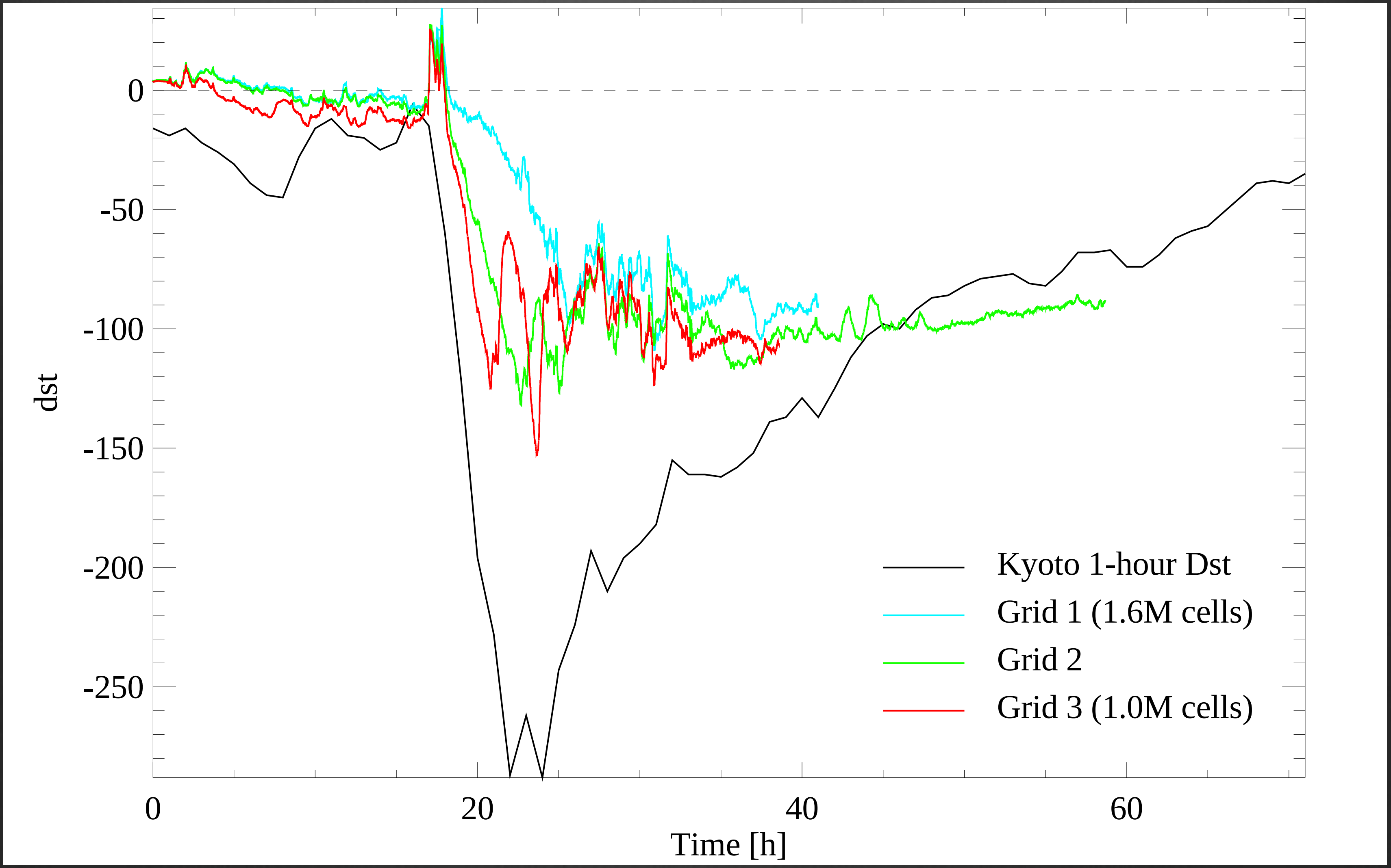
Grid 1: 1.61M cells



Grid 3: 1.00M cells



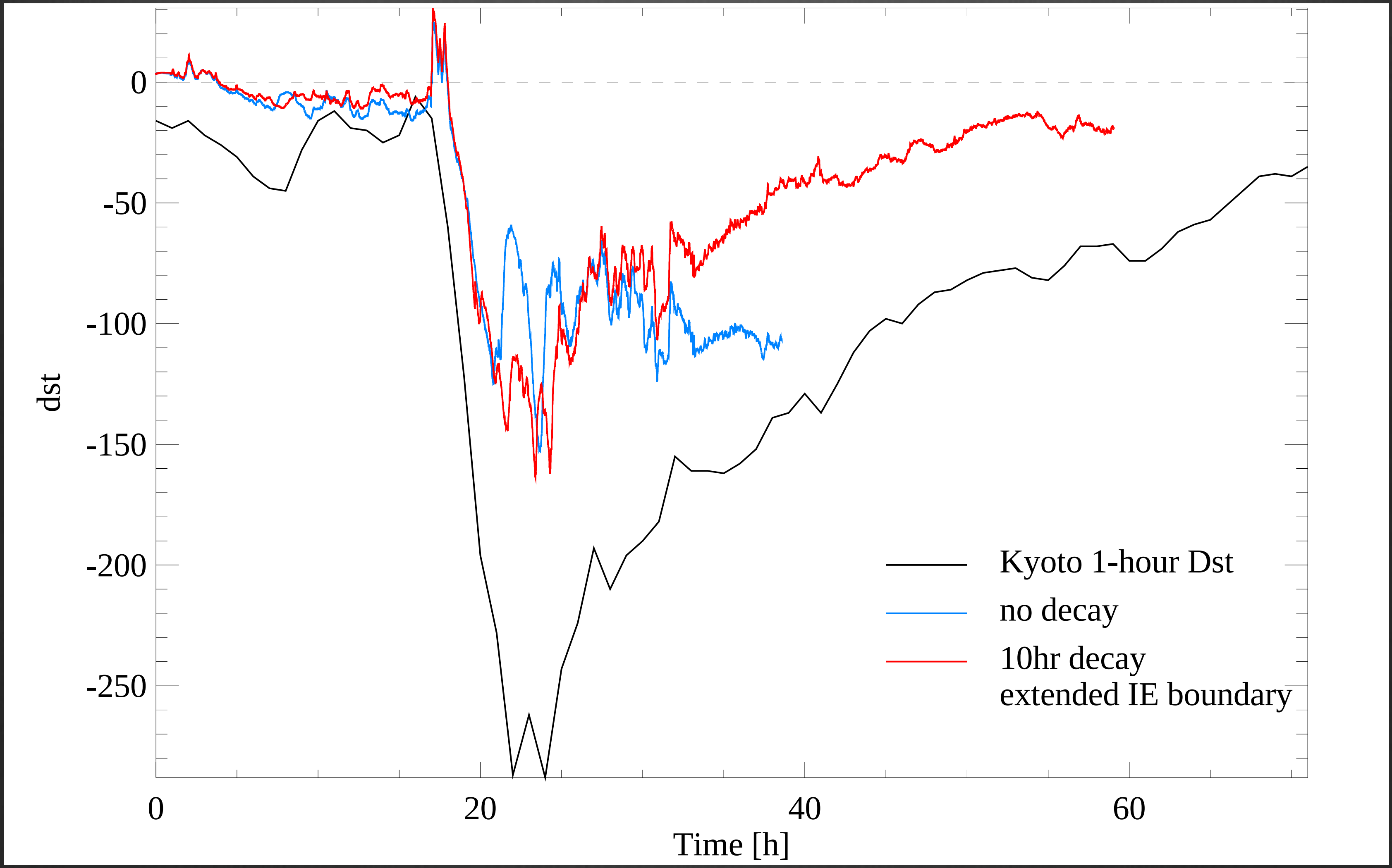
D_{st} For Different Grids



Recovery

- We have noticed that the Inner Magnetosphere Model (RCM) tends to not recover after a storm
- There are many possible reasons for this:
  - Plasma injected too deep into the inner magnetosphere, where MHD code can not get rid of it (inside boundary)
  - Plasma close to the inner boundary of the MHD code (inside IM) could diffuse Earthward, inside the boundary of MHD
  - Flushing out of the inner magnetosphere may not be accurately modeled in the recovery phase (strong E-field, low density)
  - Loss processes not adequate in IM
    - MHD not feeding it proper O+/H+ ratio
    - MHD not feeding it proper temperature
    - Some processes not accounted for
- Mimic losses artificially through a 10 hour loss process
  - Ensures that the ring current always decays back to background

With Losses



0
-50
-100
-150
-200
-250
dst
0
20
40
60
Time [h]
Kyoto 1-hour Dst
no decay
10hr decay
extended IE boundary

Density

- The density flowing into the inner magnetosphere is crucial
  - Total density can determine the energy content of the ring current
  - Mass and temperature determine gradient-curvature drift, so how far the particles penetrate towards the Earth
  - Species can set loss rates
    - Charge exchange
- Some of the density in the magnetosphere comes from the solar wind
- Some of the density in the magnetosphere comes from the ionosphere
  - Recent studies have shown that during southward IMF, significantly more density is from the ionosphere

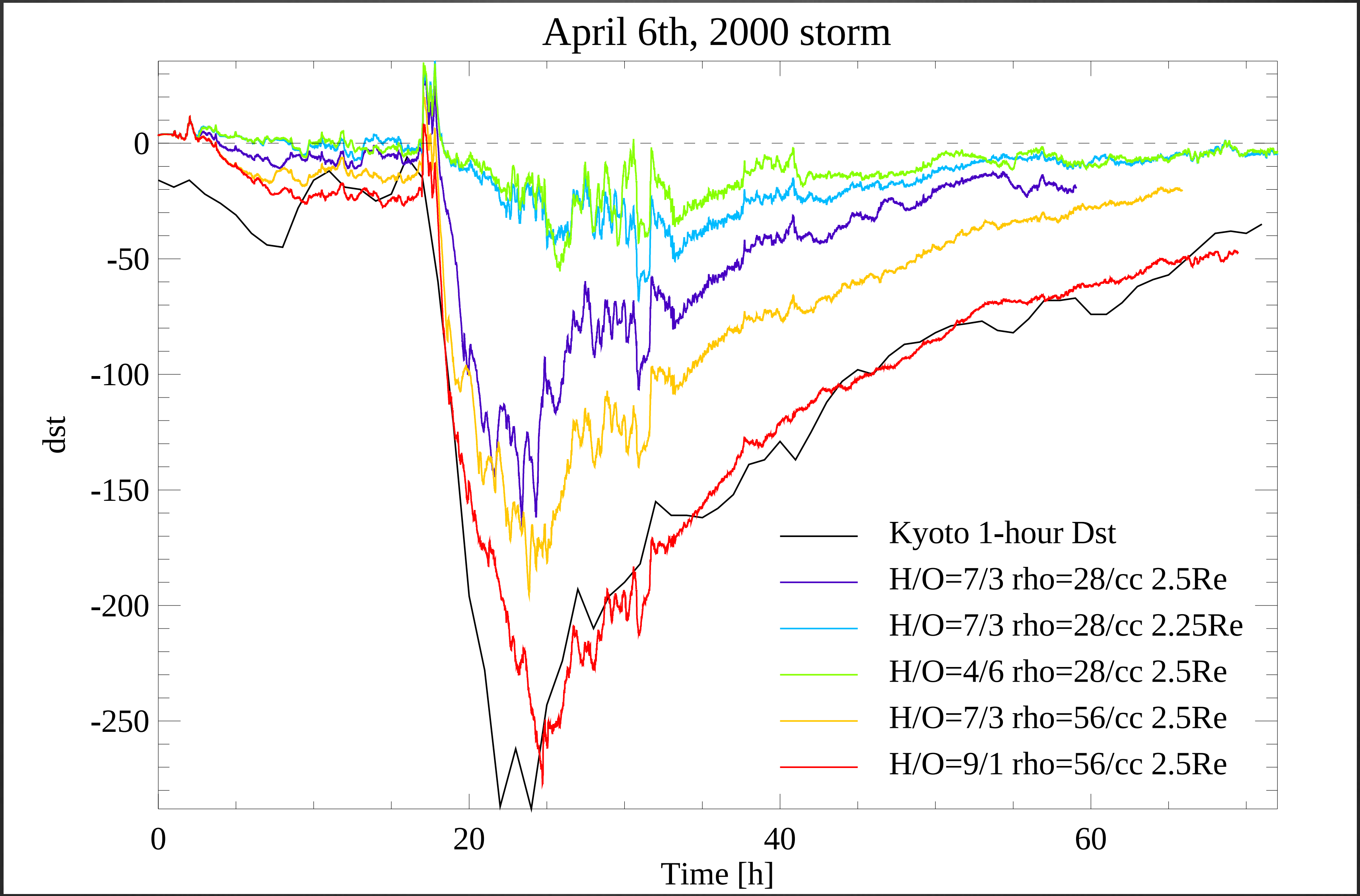
Density, cont.

- The BIG problem is specifying the amount of ionospheric plasma (O+ and H+) that enters the magnetosphere
  - Empirical models exist for Cusp outflow
  - First principles codes exist for outflow
    - Computationally intensive
    - Something else to break
- Decided to do something very simple:
  - Background outflow (basically H+)
  - Elevated outflow during strong driving (O+ outflow)
  - Density = Base + CPCP*factor

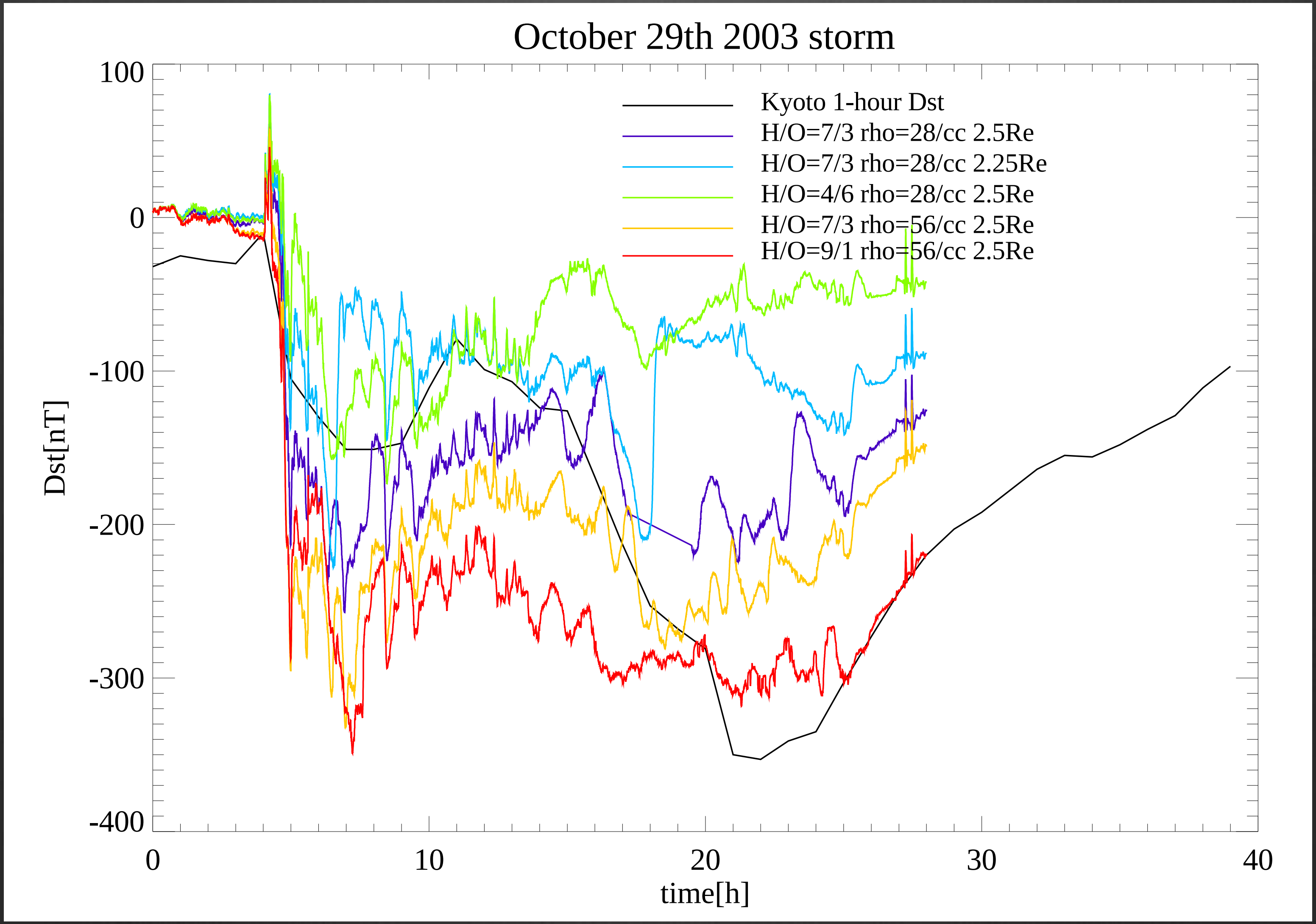
More Density

- Another issue!
  - How to tell inner magnetosphere how much is O+ and how much is H+
    - Should be done with a multifluid code (we have this, but not robust)
    - Allow it to change based on (self-consistent) Kp (Empirical relationship – Young et al.)
    - Simple option – hard code a ratio (worst choice, but easiest to implement and test)
  - We need to spend more effort on this aspect!
- Density is hard!
  - Outflow rates? Ratios? Solar wind entry?
  - Need to get it all right!

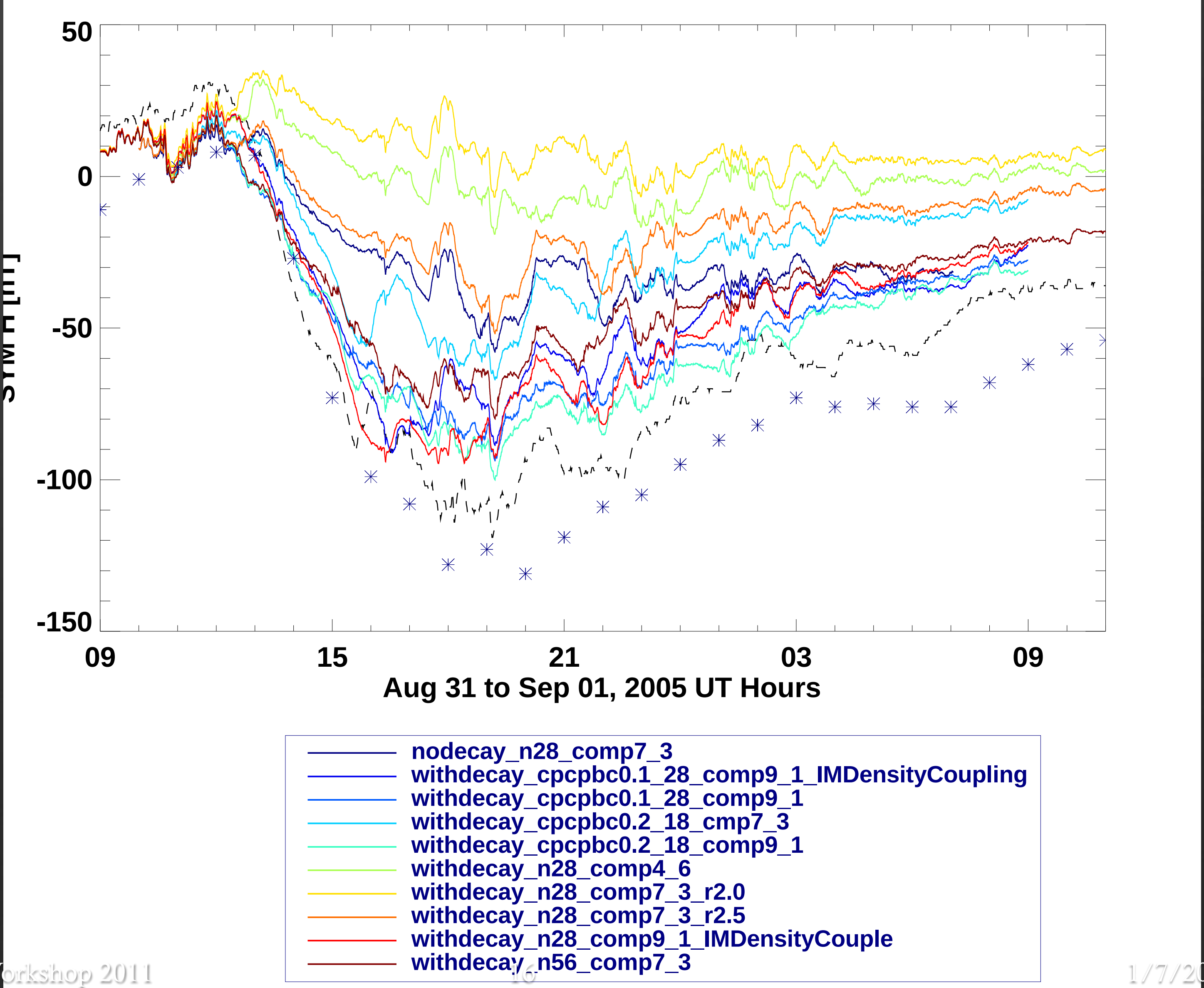
Density Changes



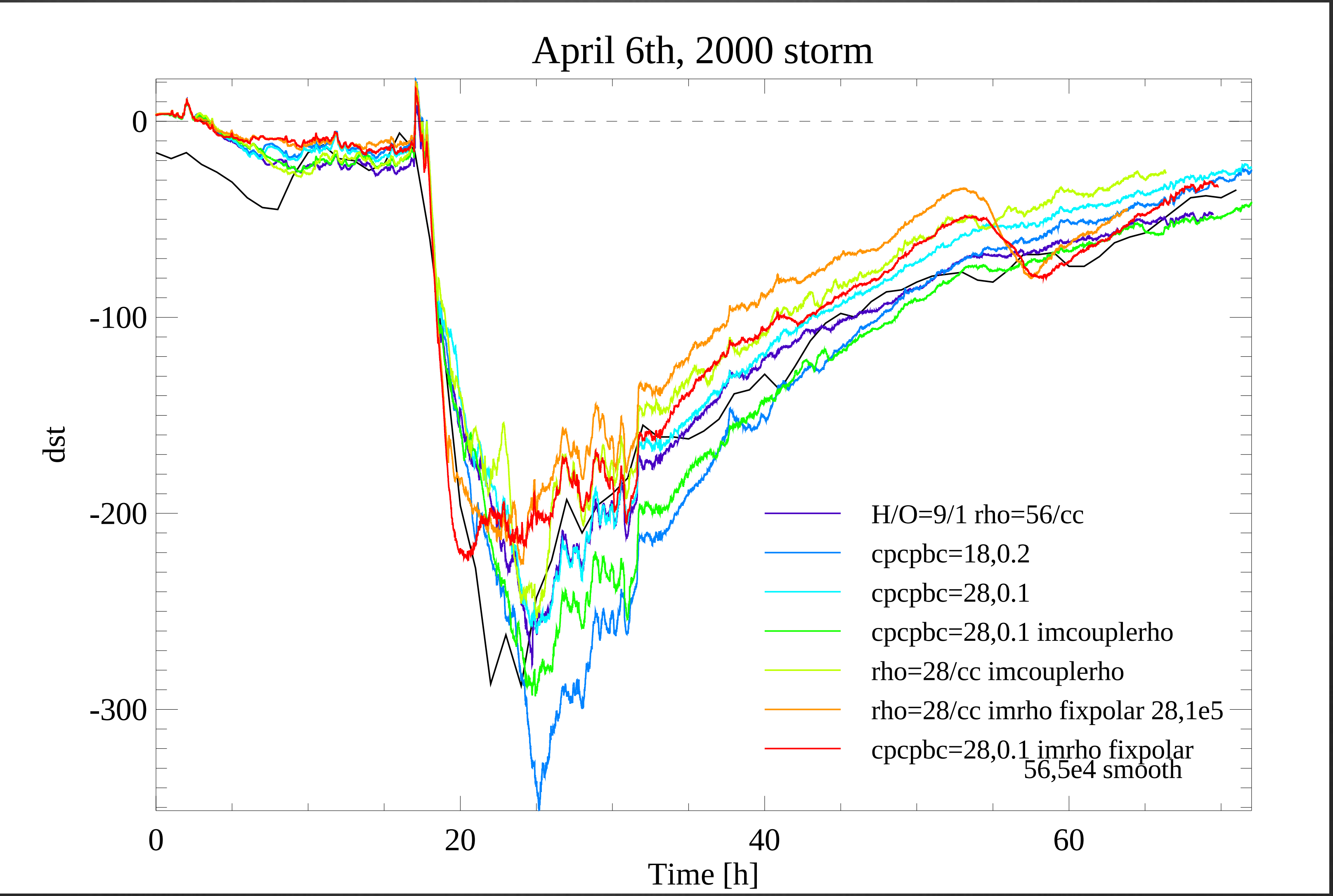
More Density Changes



More More Density Changes



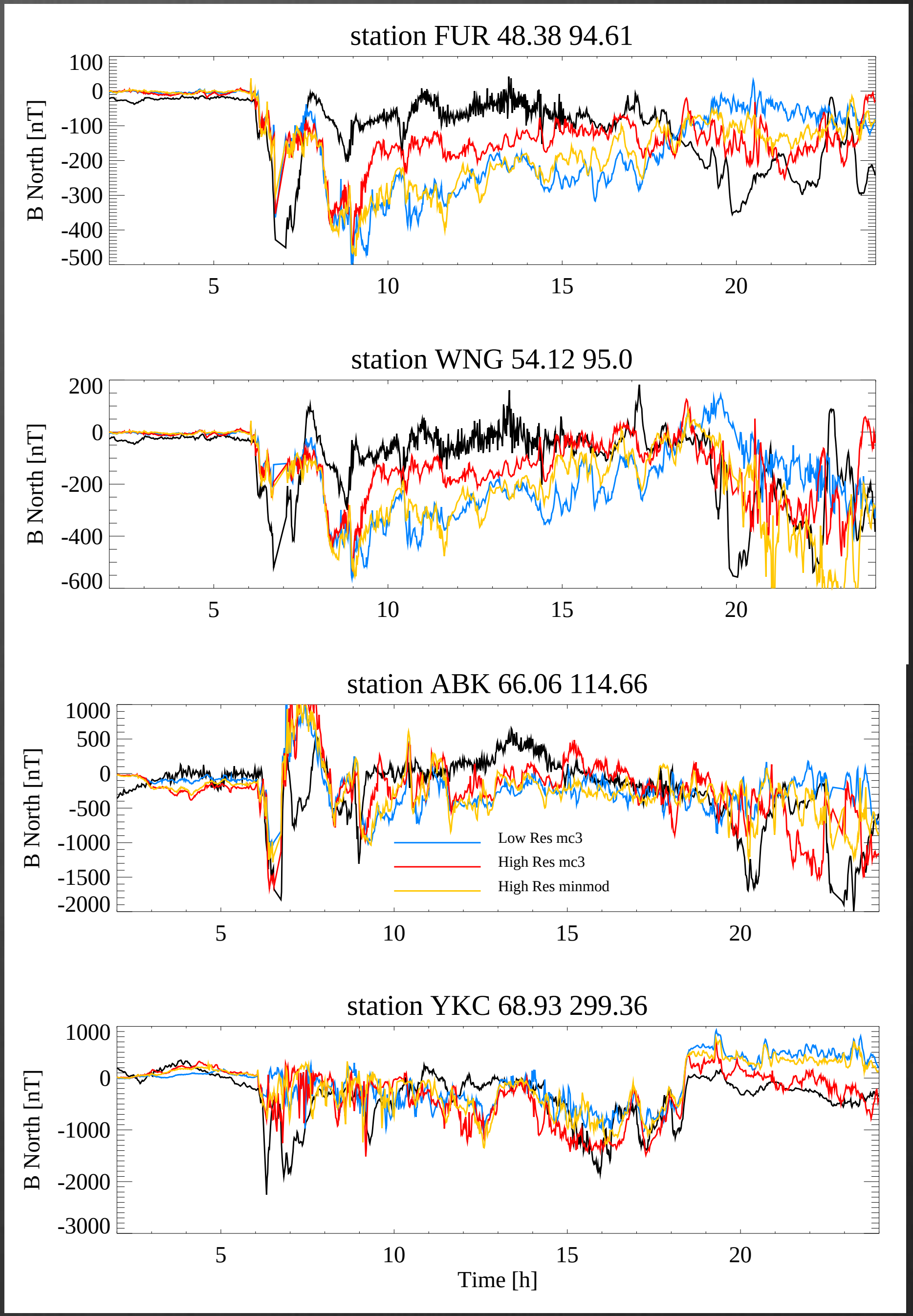
Even More



April 6th, 2000 storm
0
-100
-200
-300
dst
0
20
40
60
Time [h]
H/O=9/1 rho=56/cc
cpcpbc=18,0.2
cpcpbc=28,0.1
cpcpbc=28,0.1 imcouplerho
rho=28/cc imcouplerho
rho=28/cc imrho fixpolar 28,1e5
cpcpbc=28,0.1 imrho fixpolar
56,5e4 smooth

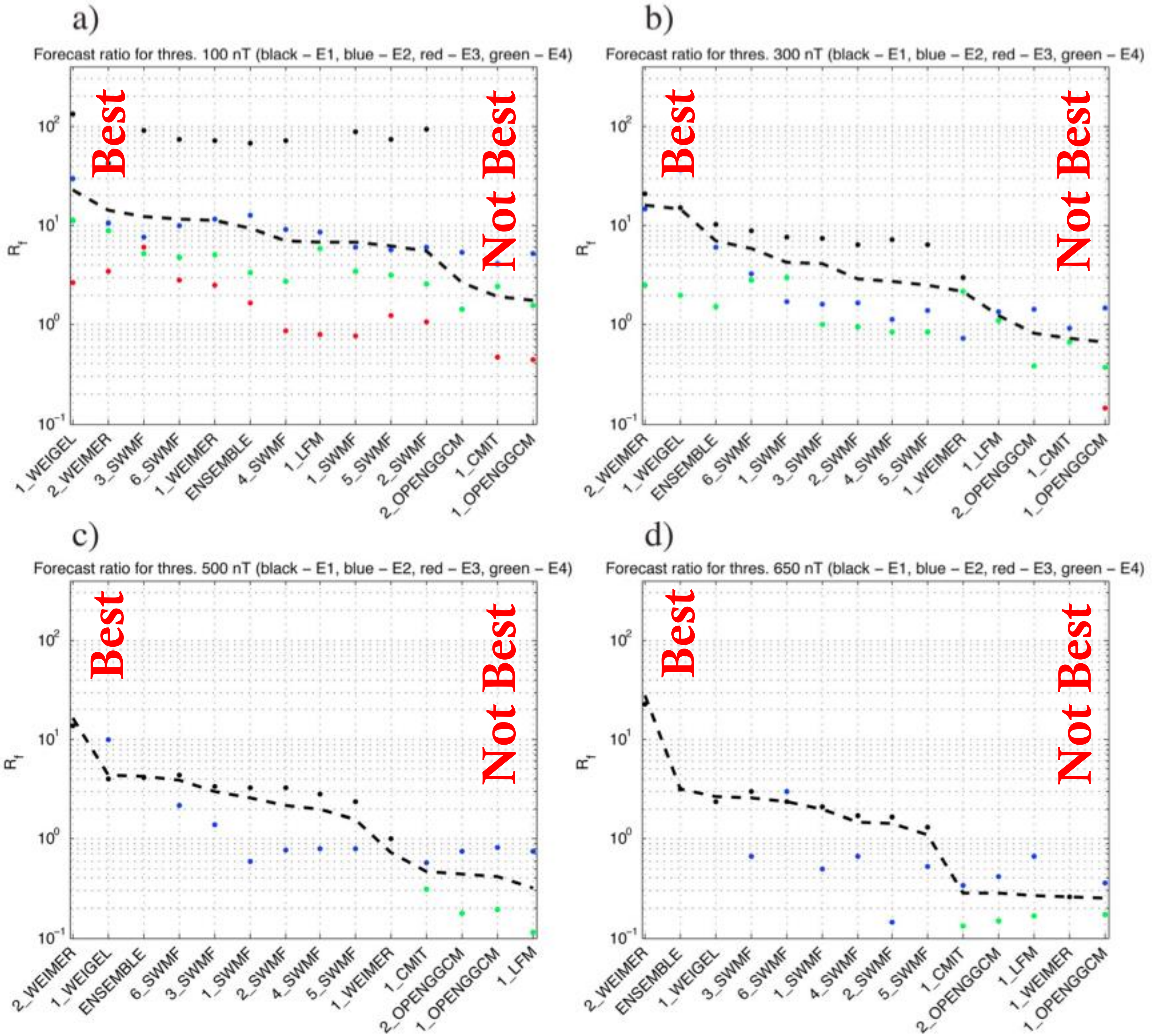
Ground-Based Magnetometers

- The SWMF can calculate ground-based magnetometer perturbations while it is running
- Biot-Savart integrals within:
  - The global magnetosphere
  - The ionosphere
    - Hall and Pedersen
  - Field-Aligned Currents in the gap region between ionosphere and inner boundary of MHD code.
- At high-latitudes, Hall is dominant.
- At low-latitudes, magnetosphere is dominant.
- At mid-latitudes, all are important.



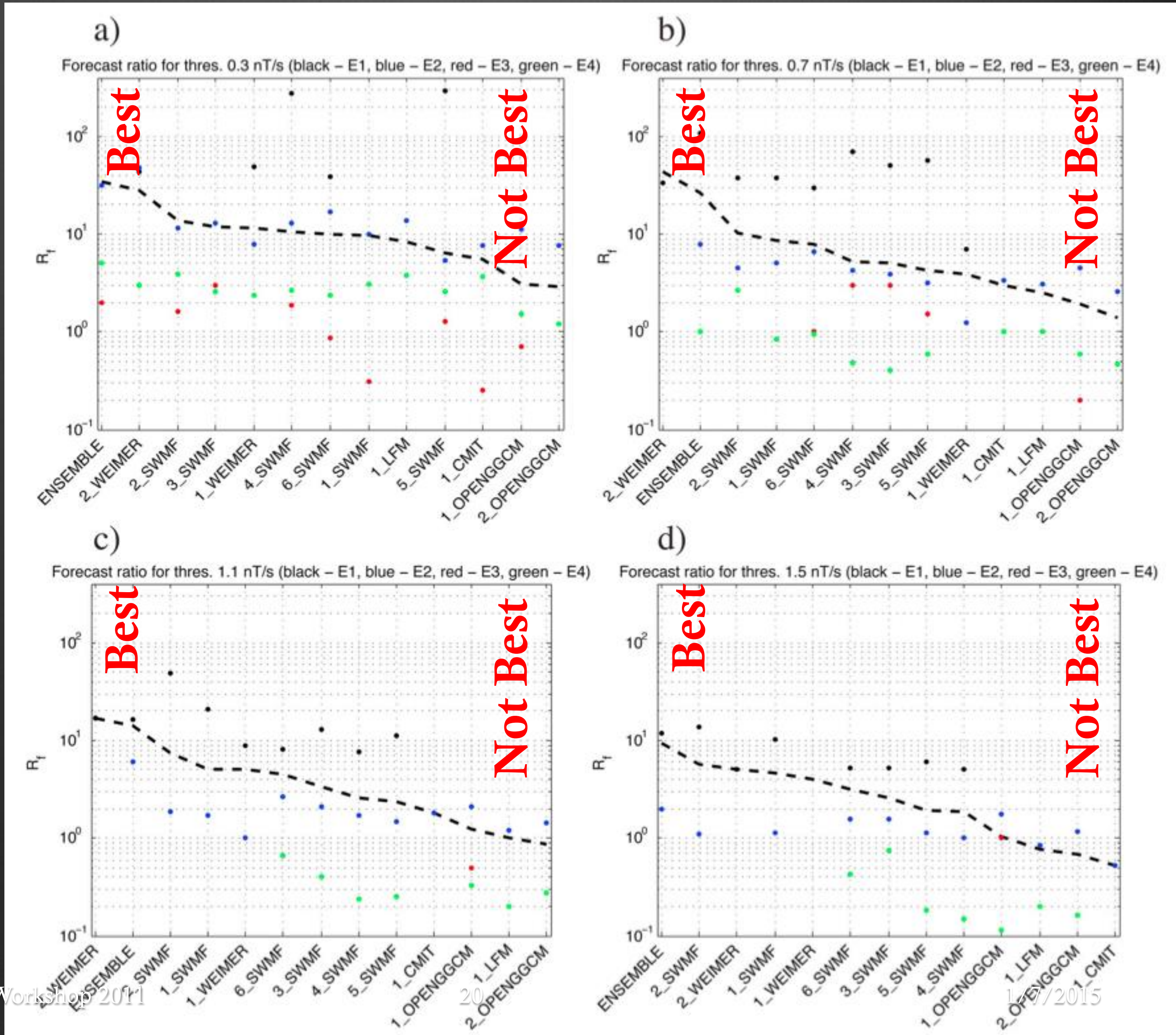
Pulkkinen et al.

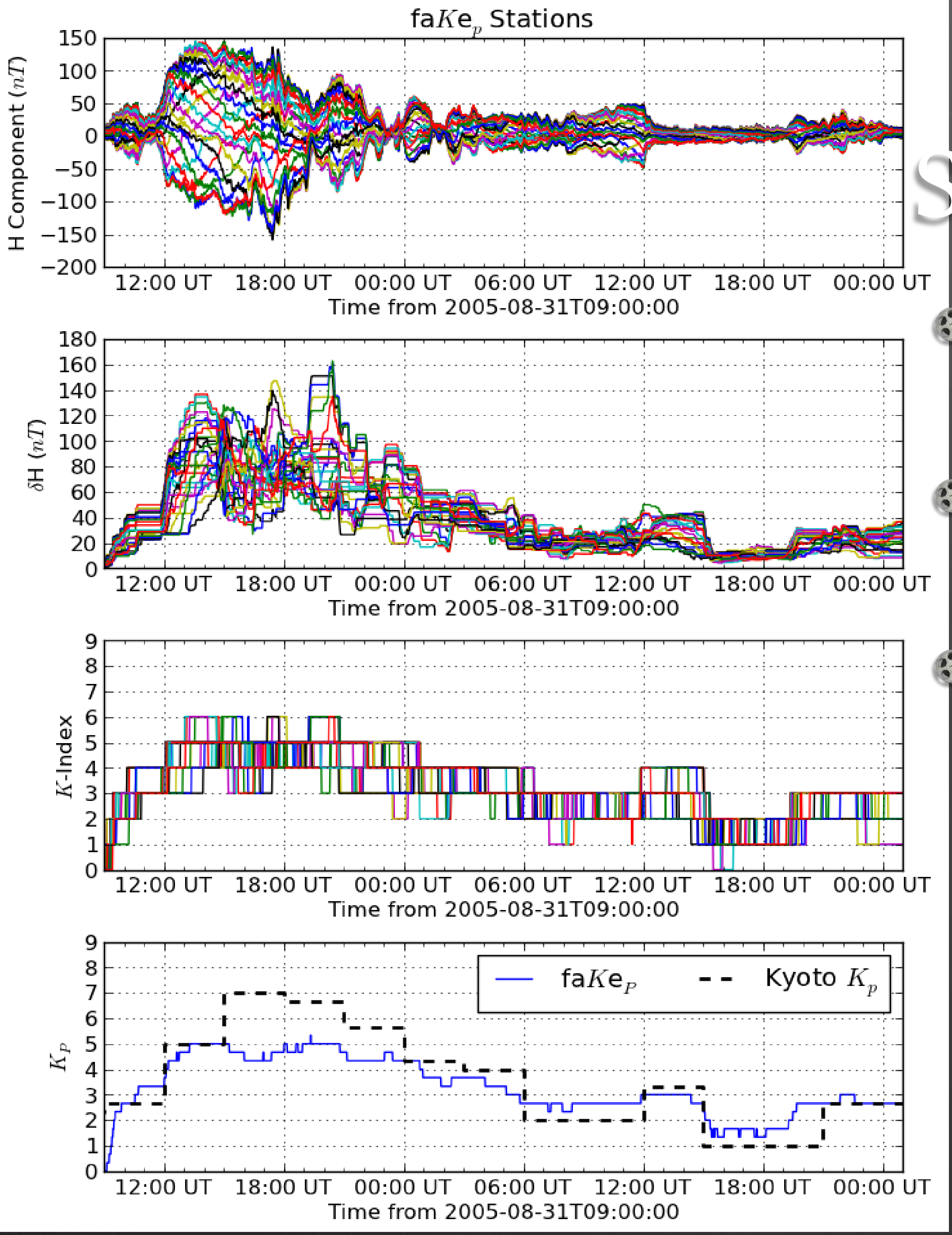
Exceeding magnitude threshold (100nT, 300 nT, 500 nT, 600 nT) predictions for the GEM Challenge events



Pulkkinen et al.

Exceeding dB/dt threshold (0.3nT/s, 0.7 nT/s, 1.1 nT/s, 1.5 nT/s) predictions for the GEM Challenge events



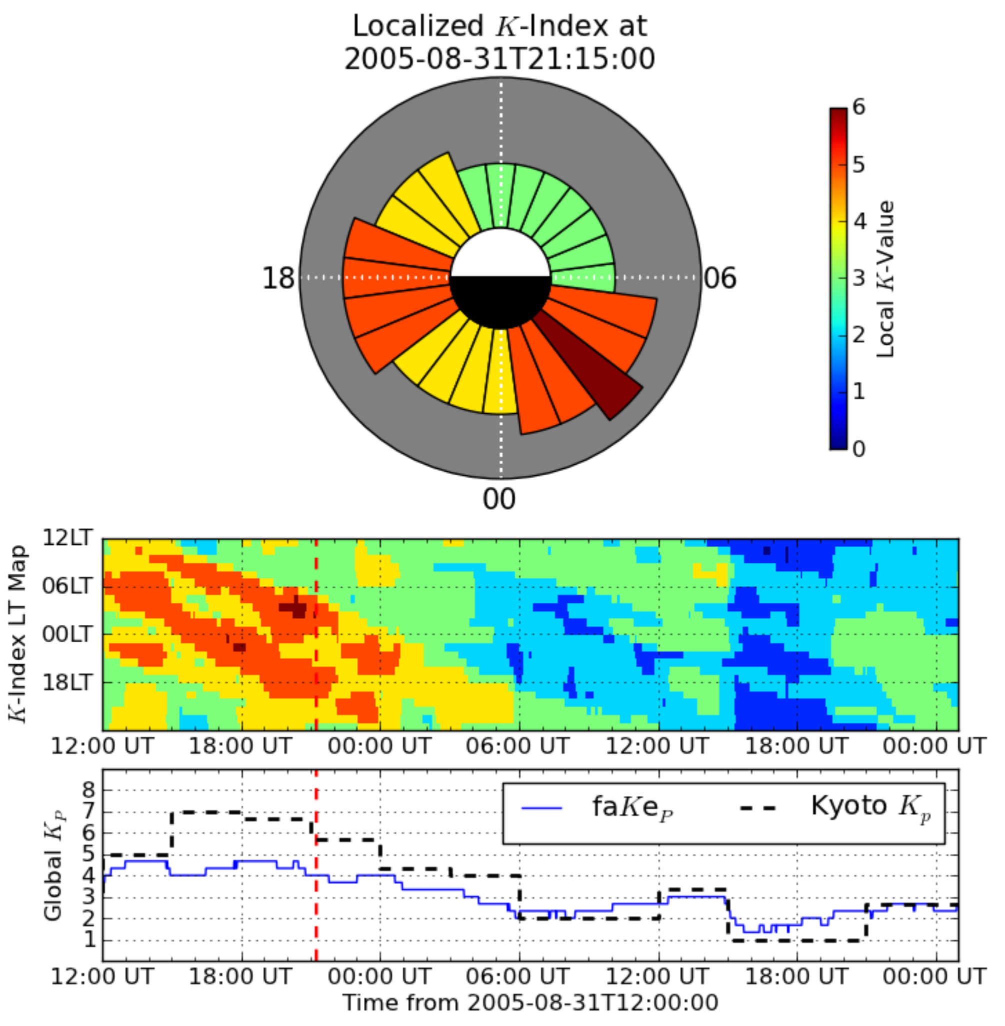


faKe$_P$: Synthetic K_P Index

- 24 virtual magnetometers at constant latitude.
- H-component is converted to dH, then local *K*.
- Average of local K yields K_P.

$faKe_P$:Synthetic K_P Index

- Data-model validation for $faKe_P$ is underway.
- Provides localized K data products for quick-look activity monitors.
- Can be used as inputs for K_P-dependent values (D_{LL}, Young et al. composition, etc.) for new, expanded model couplings.



Summary

- The Space Weather Modeling Framework can simulate many aspects of the Sun-Earth system
- The SWMF has many models of the near-Earth space environment coupled together to accurately represent the magnetospheric environment
- In order to more accurately model the magnetosphere during storms, we have:
  - Added a decay time to the inner magnetosphere model (RCM)
  - Added a cross polar cap potential dependent ionospheric outflow
  - Changed the ratio of O+/H+ for the inflow to the RCM
  - More work is needed to validate the physics!
- The magnetic field calculations in the SWMF include currents from the entire domain
  - The ground-based perturbations are ok, but not spectacular
  - High-latitude delta-Bs are not as sensitive to numerics as Dst prediction
  - We can produce a regional Kp index

Thank You!