New Developments in the Space Weather Modeling Framework

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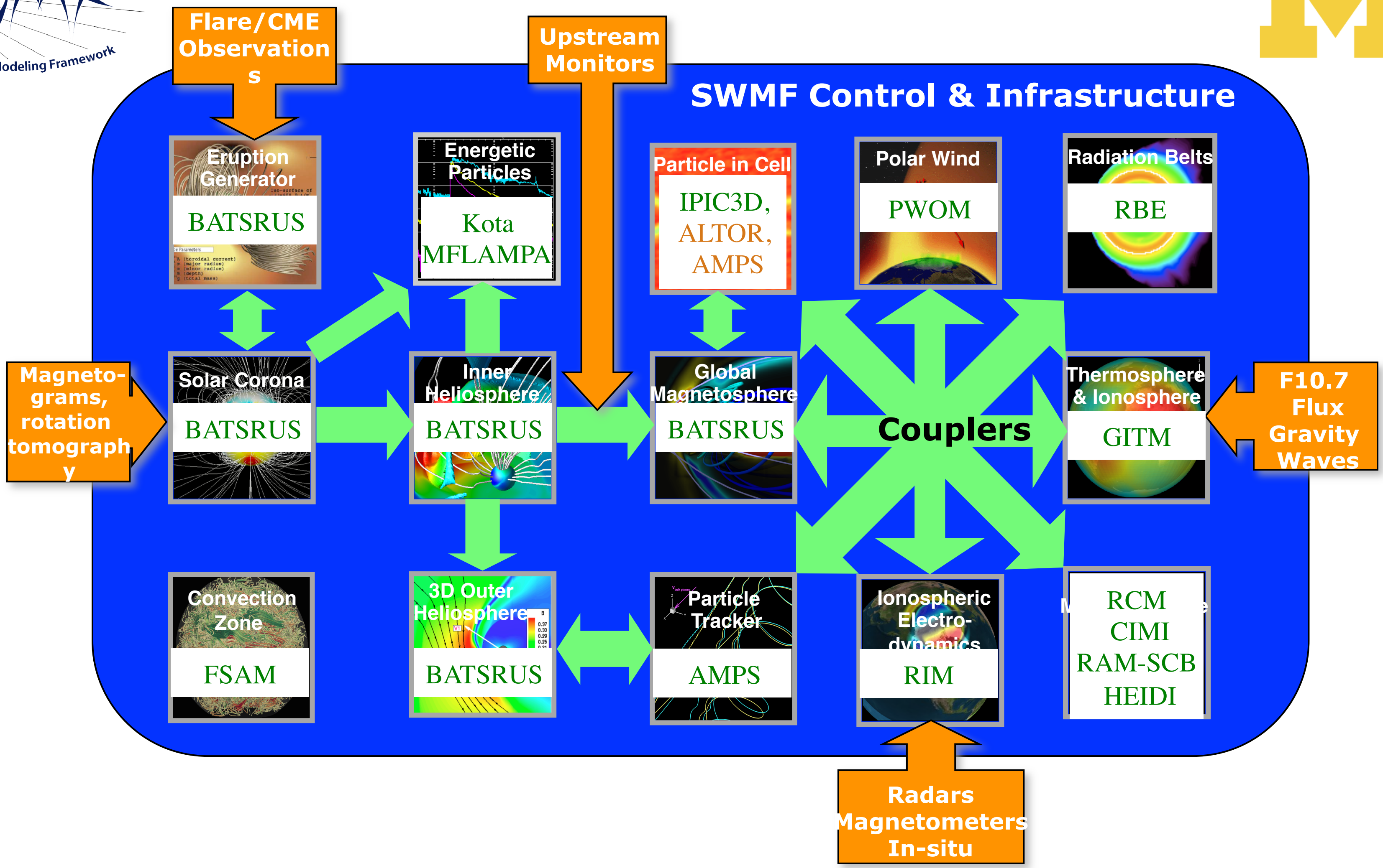


14 domains represented by 18 different models

594K lines of Fortran, 177K lines of C++ with MPI & OpenMP

Scripts, Makefiles, visualization macros, documentation, nightly tests.

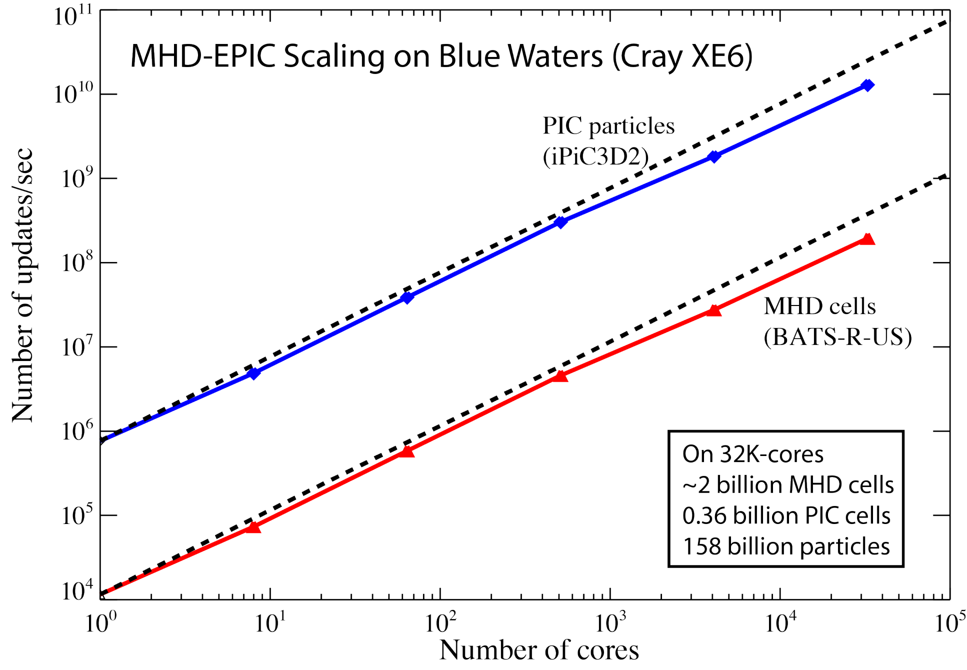
SWMF is freely available at http://csem.engin.umich.edu/tools/swmf and via CCMC

Beyond Ideal MHD in BATS-R-US

- **Anisotropic pressure for multiple ions and electrons**
  - Applications: magnetosphere, solar corona, solar wind…
- **5-moment closure for multiple ion and electron fluids**
  - Hydro equations with electromagnetic forces + full Maxwell equations.
  - Charge separation between ions and electrons is allowed.
  - Light waves, Langmuir waves, whistler waves included.
  - Application: cometary environment with multiple electron fluids
- **6-moment closure for multiple ion and electron fluids**
  - Anisotropic pressure equations are solved
  - Application: coupling with embedded Particle-in-Cell model.

MHD with Embedded PIC (MHD-EPIC

- **Combine the efficiency of the global MHD code with the physics capabilities of the local PIC code**
  - Applications: Ganymede, Mercury, Earth, Mars, Saturn …

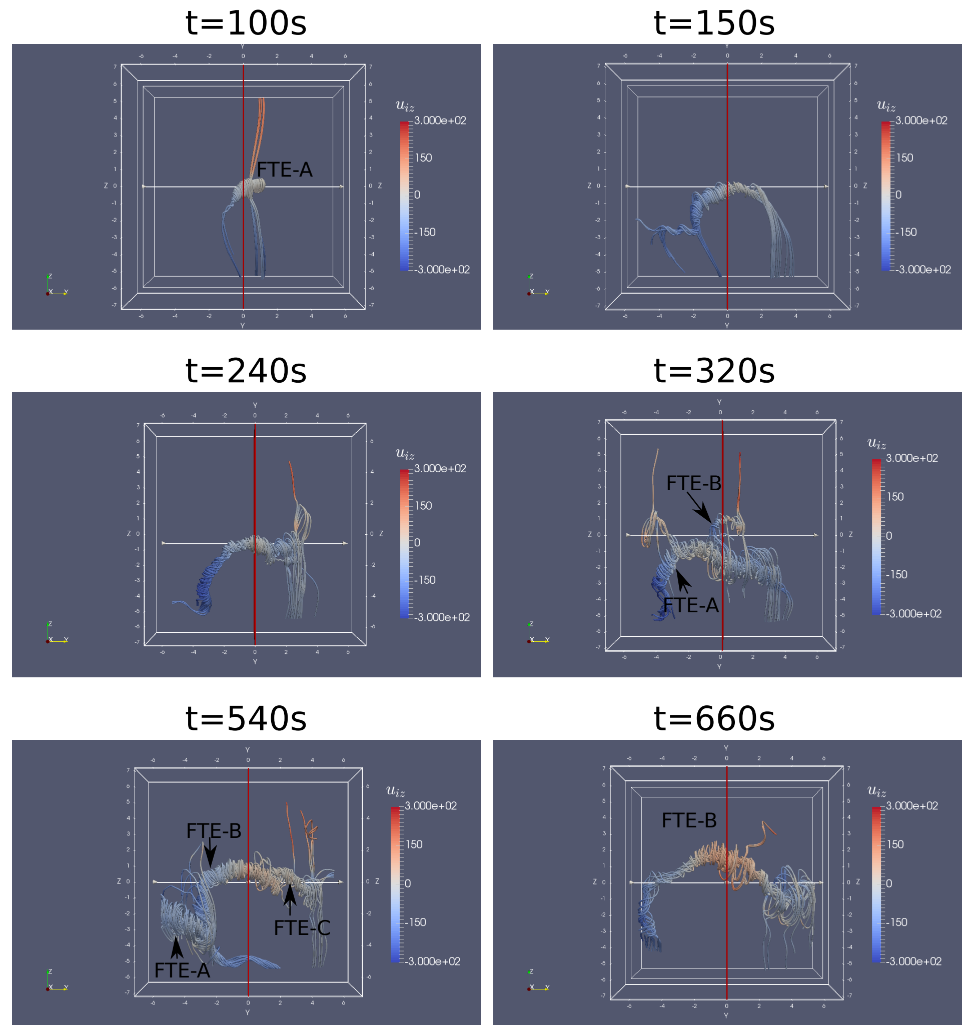


- **New Developments**
  - Rotated PIC boxes
  - Coupling with 5- and 6-moment equations
  - Energy conserving semi-implicit PIC algorithm (Lapenta 2016)
  - Further improvements reduce oscillations and noise (to be published)
- **Theoretical Advance**
  - Rescaling the ion and electron scales by changing Q/M can drastically reduce computational cost while the global dynamics is unaffected as long as there is sufficient scale separation (Toth et al. 2017)

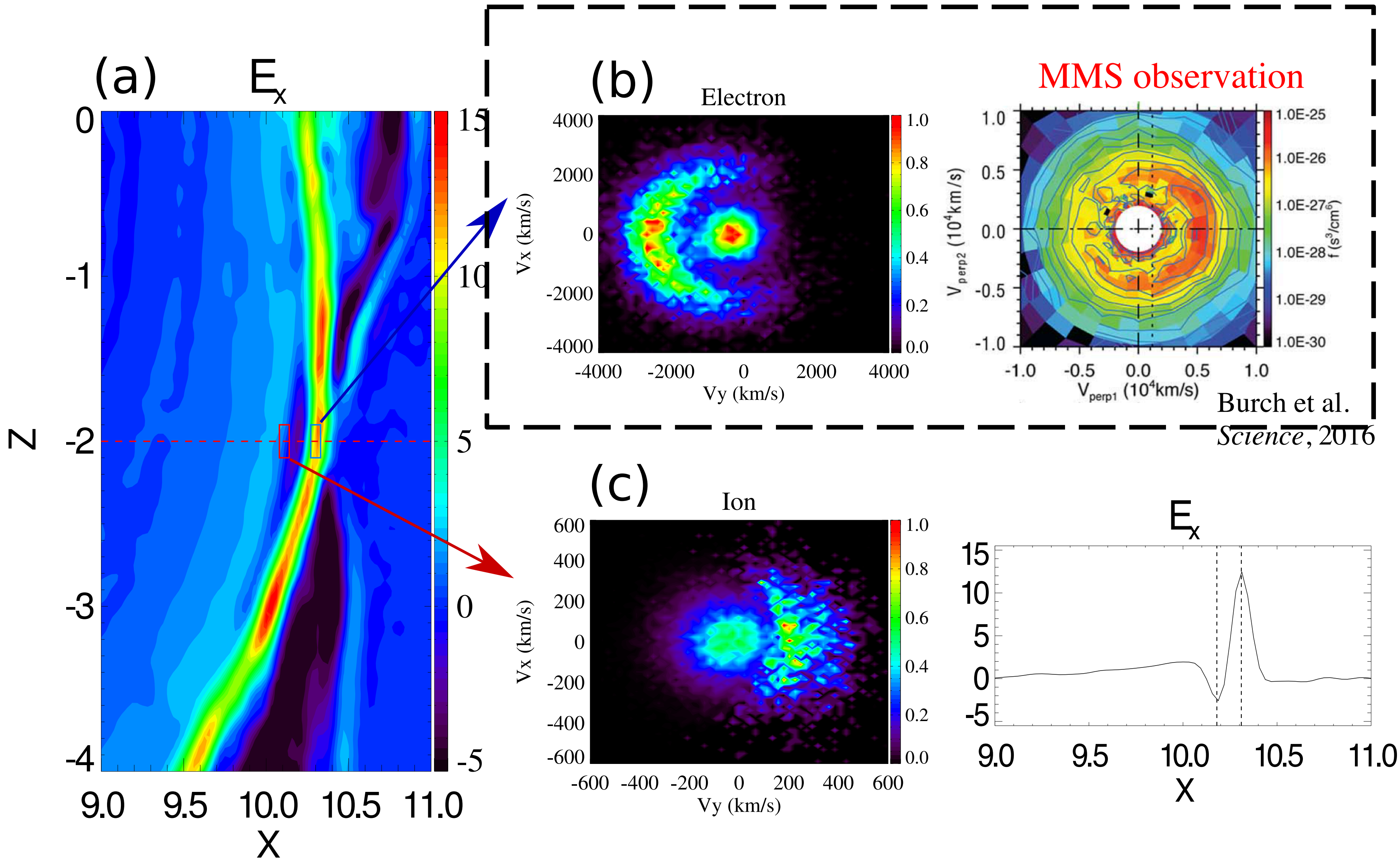
3D MHD-EPIC Simulation of Dayside Reconnection (Chen et al. 2017)

- Typical solar wind conditions: ρ= 5 amu/cm^3, U_X = -400km/s, B = [0,0,-5] nT
- Increase ion inertial length by a factor of 16, so d_i ~ 1/6 R_E and use m_i/m_e = 100
- Δx_{PIC} = 1/32R_E , 8B particles, ~18,000 core hours modeling 1min

p [nPa]

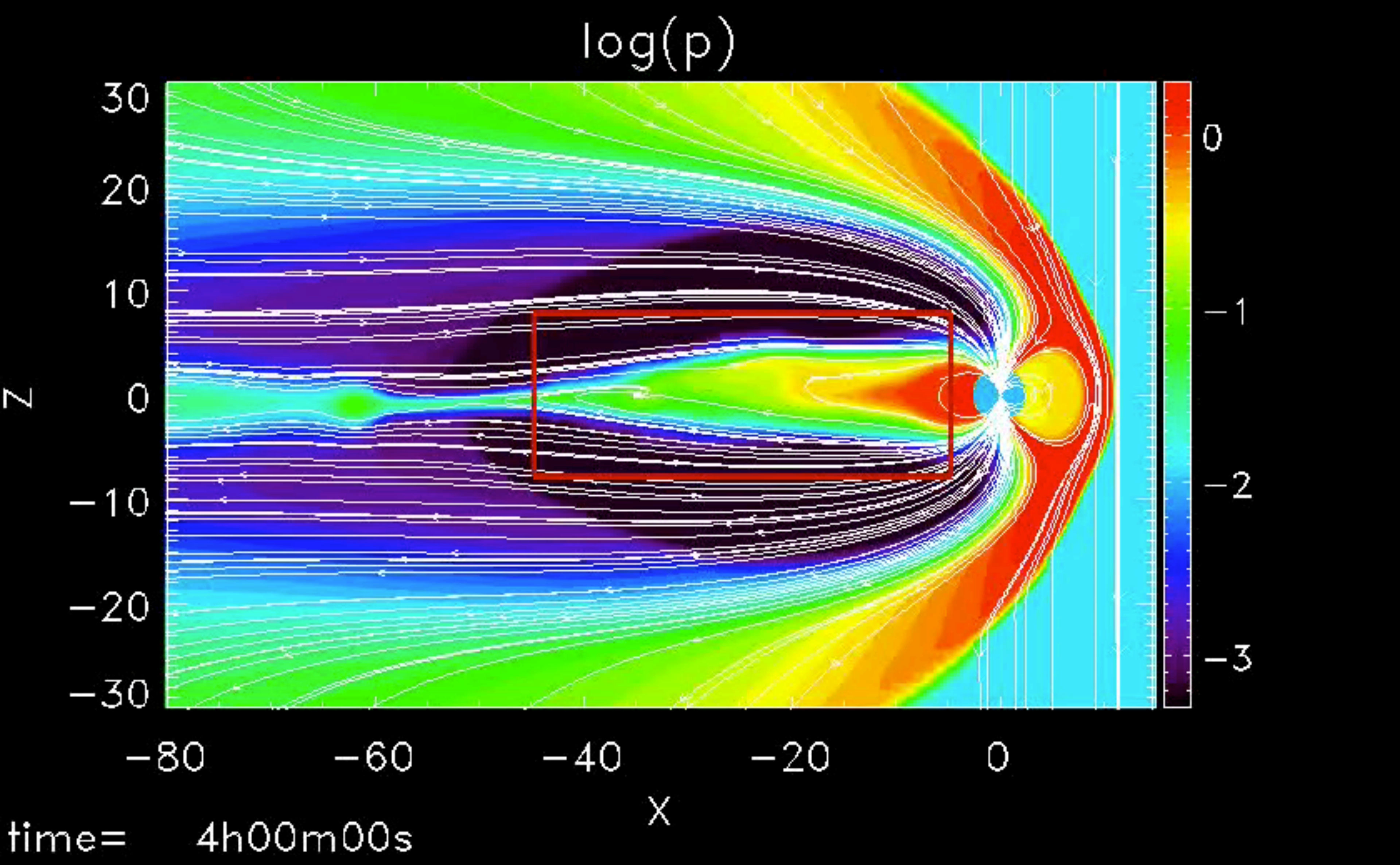


Crescent Distribution and Larmor Electric Field



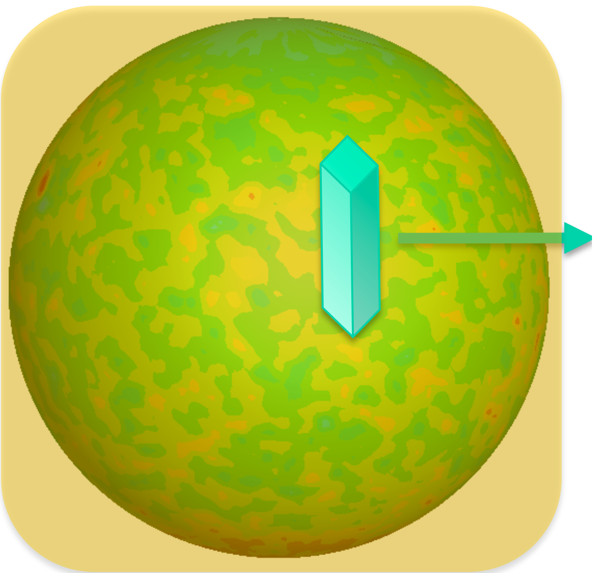
MHD-EPIC simulation of the magnetotail

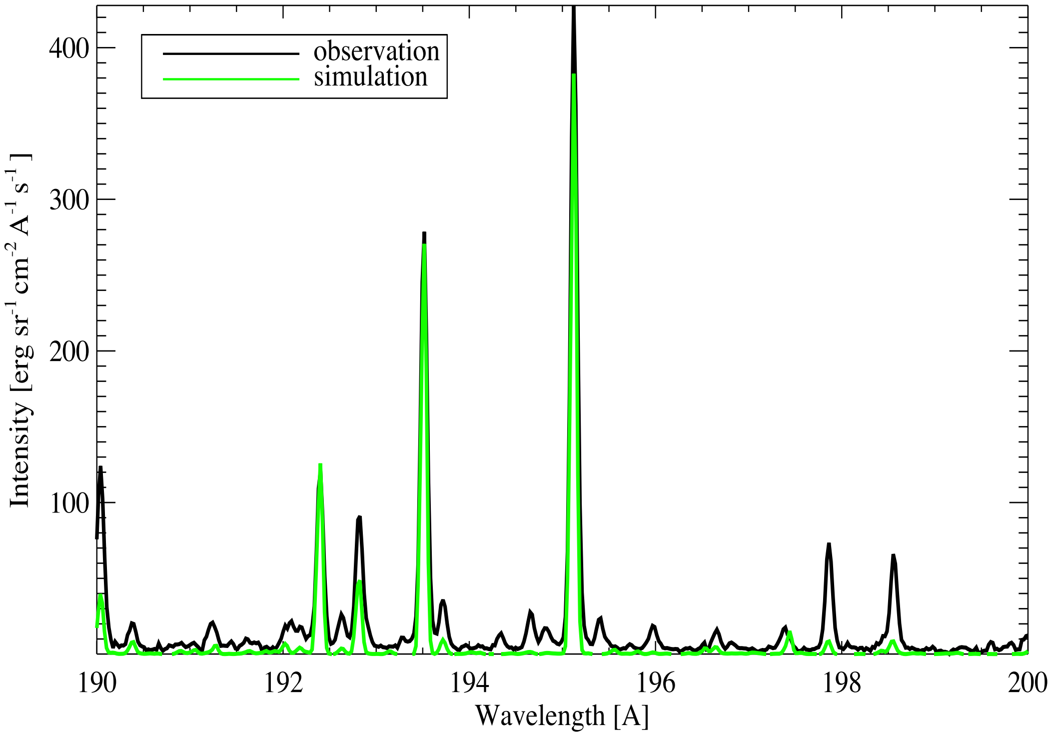
Solar wind: 10 amu/cc, 500 km/s, B_Z=-5nT changing to -15nT at t~6 hours.



SPECTRUM: Synthetic Spectra

- Post-processing tool inside the SWMF.
- Can mimic any spectroscopic observation of any instrument whose wavelength is covered by CHIANTI 8.0
- Takes into account thermal and non-thermal broadening, pressure anisotropy, separate electron temperature, bulk velocity
- Products: DEM, spectra, 1D slits, 2D images





Geospace Model at SWPC

SWMF configuration (Geospace v1.5)

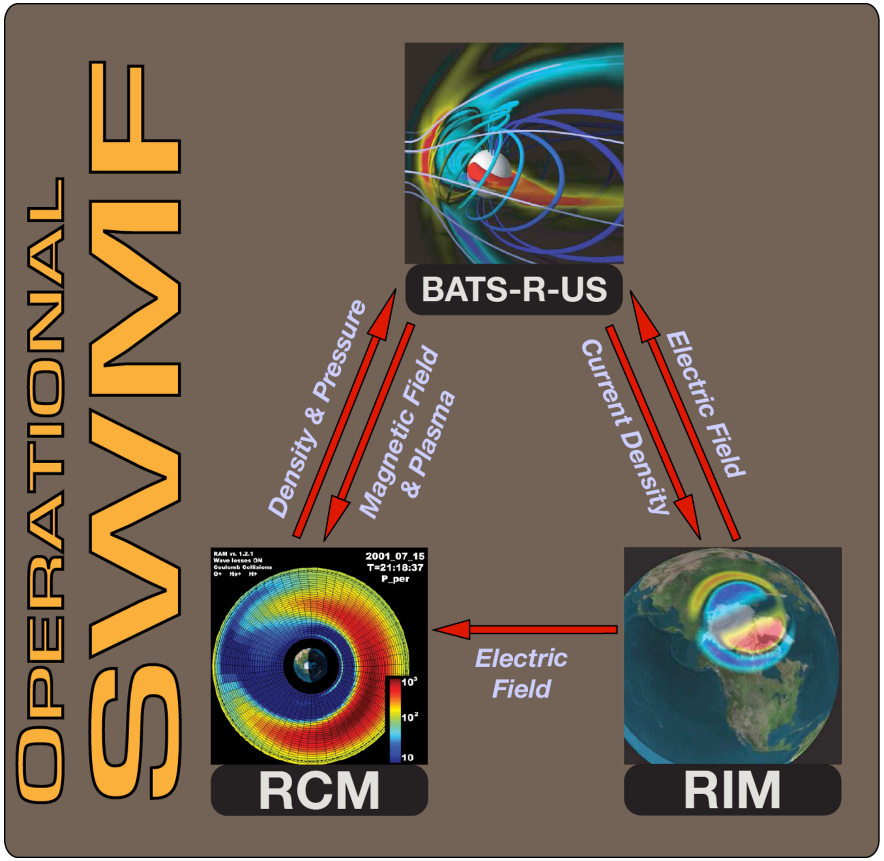
- BATS-R-US (UofM)
- RCM (Rice)
- RIM (UofM)
- RBE (Goddard)

Running

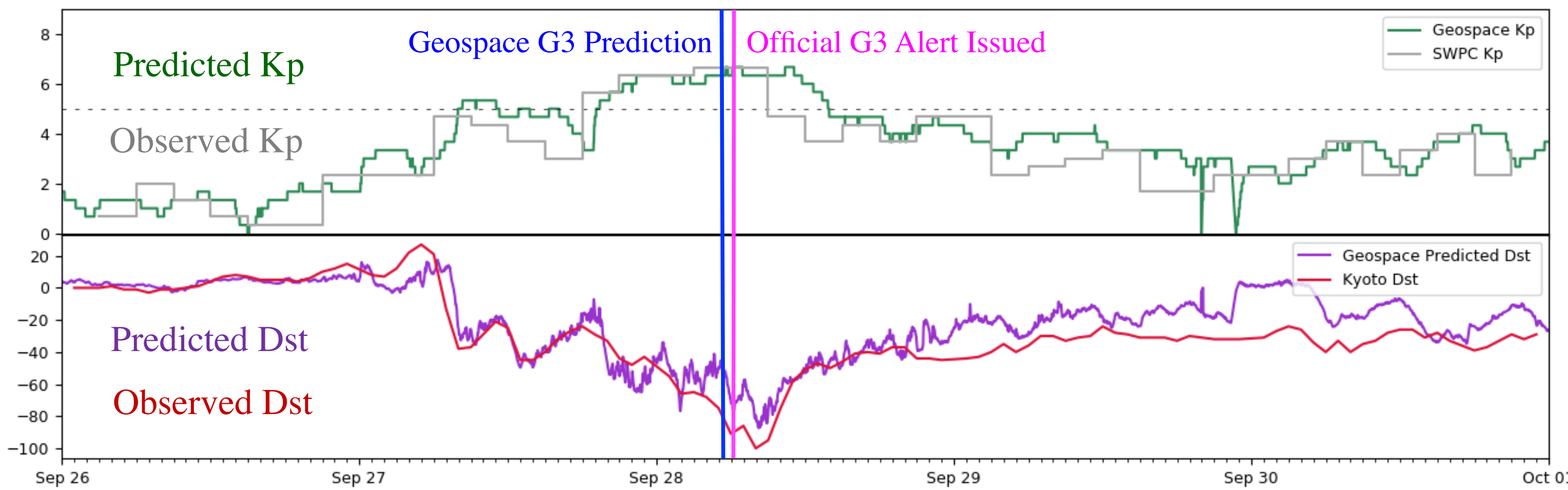
- Driven by real-time L1 observations propagated to the upstream boundary: 20m – 1h forecast
- Restart if solar wind speed increases suddenly. Also for data gaps etc.

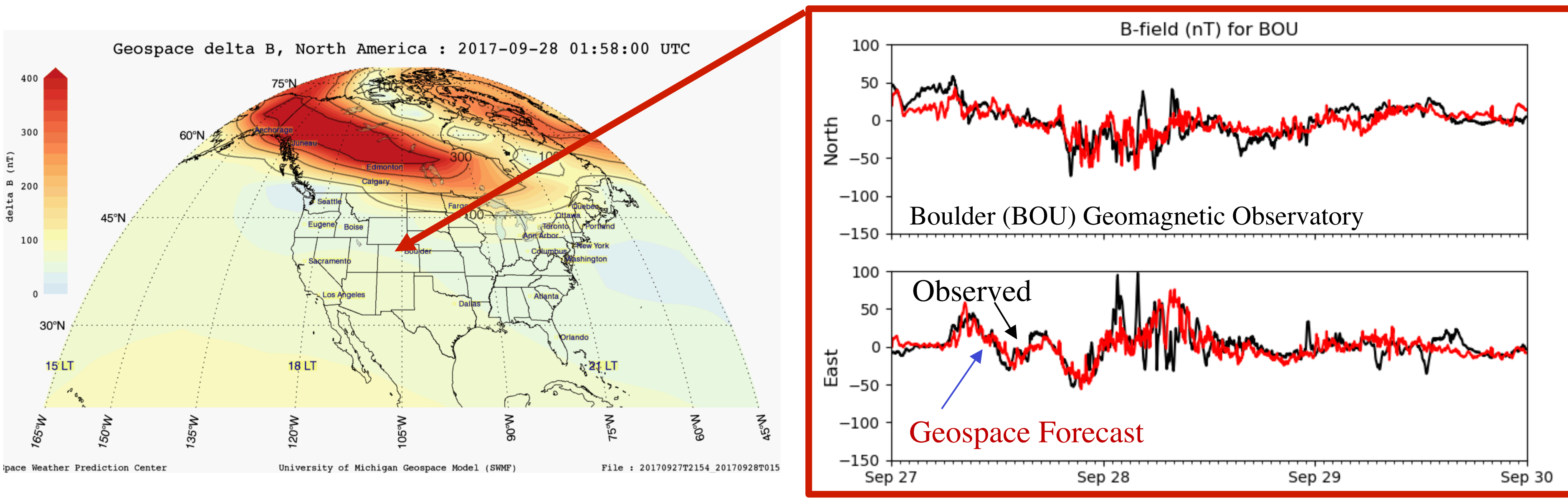
Some products

- Dst and Kp indexes
- Delta B on a 5 degree grid
- Geosynchronous orbit

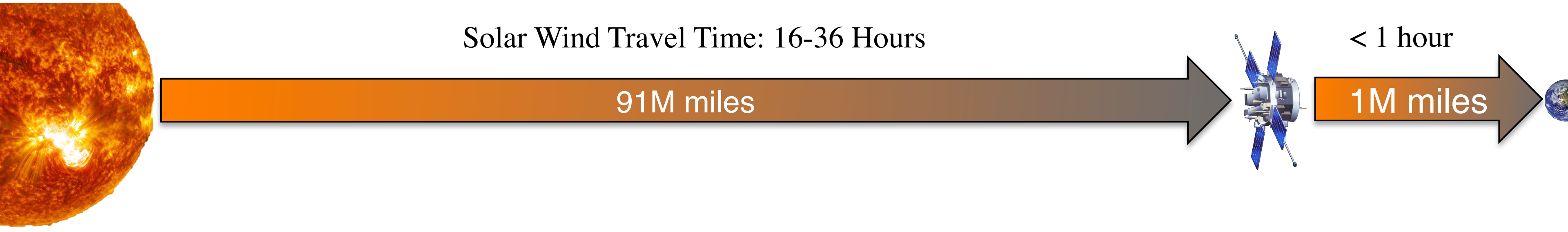


Global and Regional Geospace Forecasts

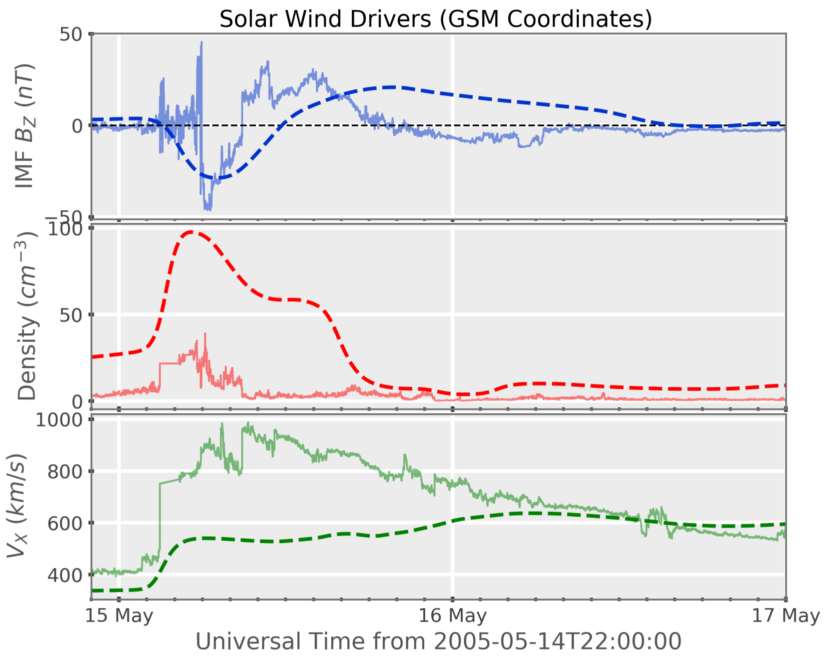




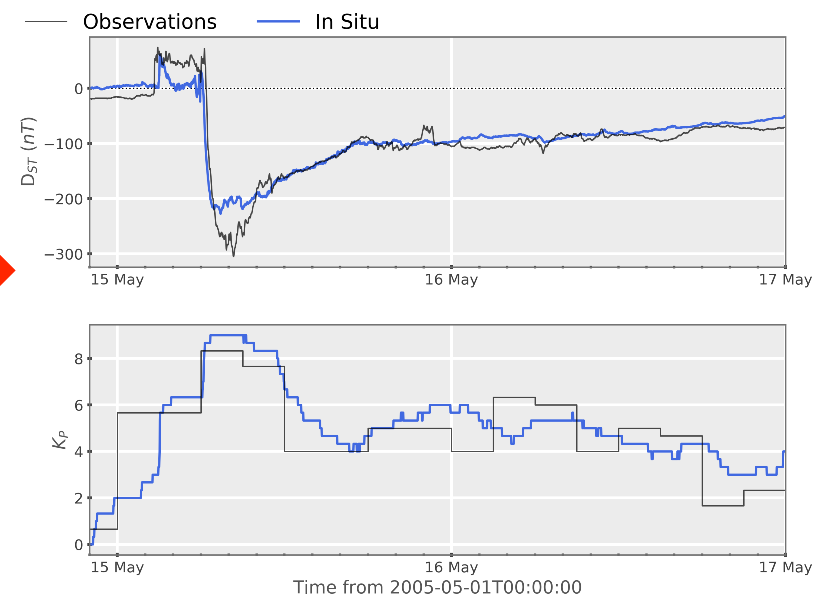
How to Increase the Forecast Time?



Corona/SW models get us to L1.

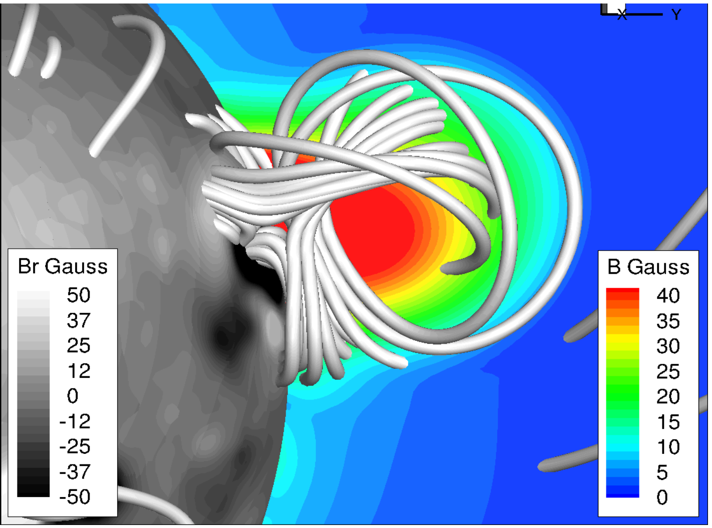


Magnetosphere models get us to the ground.



EEGGL to AWS☀M-R Forecasting

Event: 15:37UT July 12, 2012; Flare X1.4; CME 1500km/s; Dst=-139nT



Recommended Parameters

GL Flux Rope Parameters

Longitude: 81.50°

Latitude: -15.50°

Orientation: 155.00°

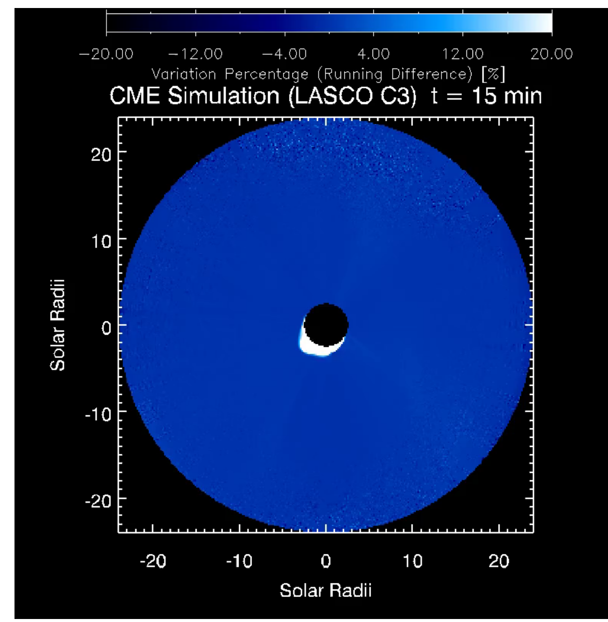
Radius[Rs]: 0.54

Bstrength[Gs]: 15.77

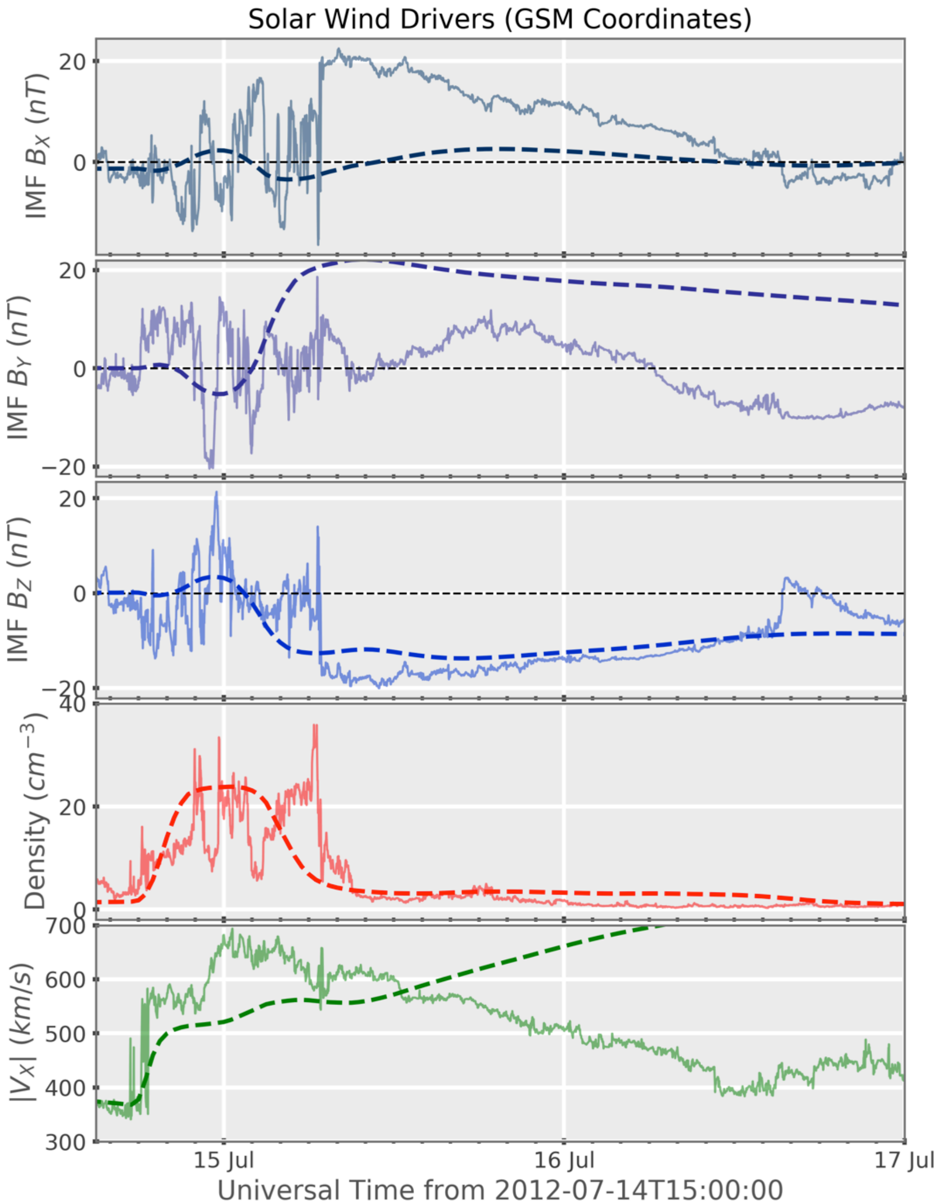
EEGGL: Eruptive Event Generator with Gibson-Low Configuration [M. Jin et al. 2017b]

AWS☀M-R: Alfven Wave Solar Model [Sokolov 2013, van der Holst et al. (2014)]

- CCMC Run on Request
- AWSoM-R Corona: 5 hours simulated
- AWSoM Heliosphere: 8 days simulated
- Run Time: 6 days 7hrs
  - 144 CPUs



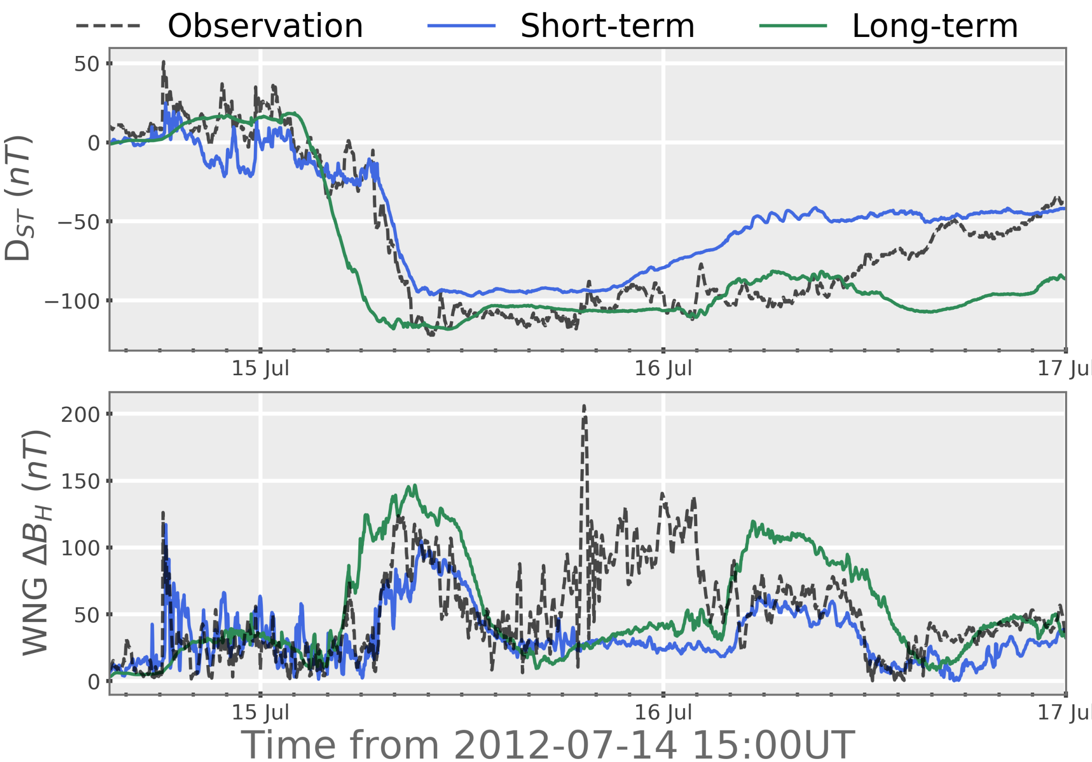
Solar wind and IMF at L1



AWSOM-EEGGL prediction at L1

- Arrival time is shifted by 13 hours (compare to ~50-hour transit time)
- Initial velocity and density are about right
- Jump across shock is about right
- IMF B_Z is good
- Overall too smooth

Surface B Forecast & Metrics



AWSoM-EEGGL prediction of Dst, ΔB_H

- Amplitudes are good
- Too smooth variation
- **Still good skills**

	ΔB_H (100 nT Threshold)		
	PoD	PoF	Heidke
L1 Obs. + Geospace	0.5760	0.0211	0.5871
EEGL-AWSOM + Geospace	0.5732	0.0564	0.5431

Summary & Future Directions

New Capabilies

- New BATS-R-US physics: anisotropic multi-fluid, 5- and 6-moment closures
- MHD-EPIC improved and used for magnetosphere simulations
- SPECTRUM: new validation tool for synthetic spectral calculations
- Geospace Model
  - SWPC setup can be used at CCMC too
- Promising Sun-to-mud simulations
  - AWSoM-R + EEGGL driven Geospace model
  - All components are available at CCMC

Work in progress

- Adaptive MHD-EPIC using AMPS
- Validation of Geospace model with
  - multi-fluid, multi-ion MHD, higher grid resolution
  - anisotropic MHD+CIMI
- Multi-fluid solar corona model
- Vector magnetogram based CME generation
- …