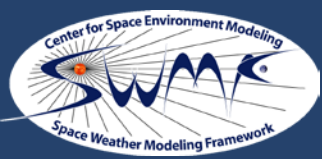


An aerial photograph of a university campus, likely the University of Michigan, with a blue color overlay. The image shows various academic buildings, parking lots, and green spaces. The text is overlaid on the image.

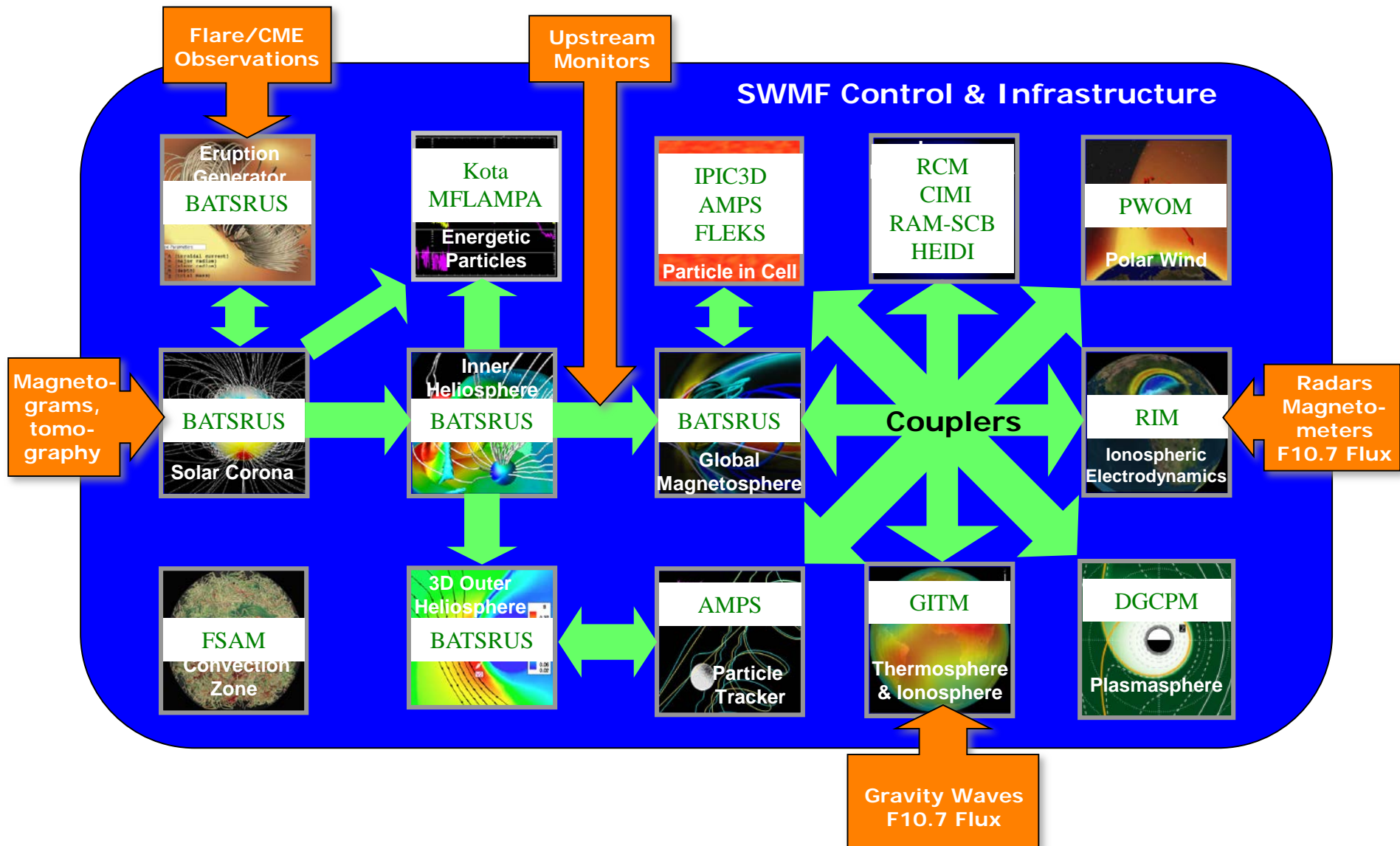
Transitioning Research Models to Operations

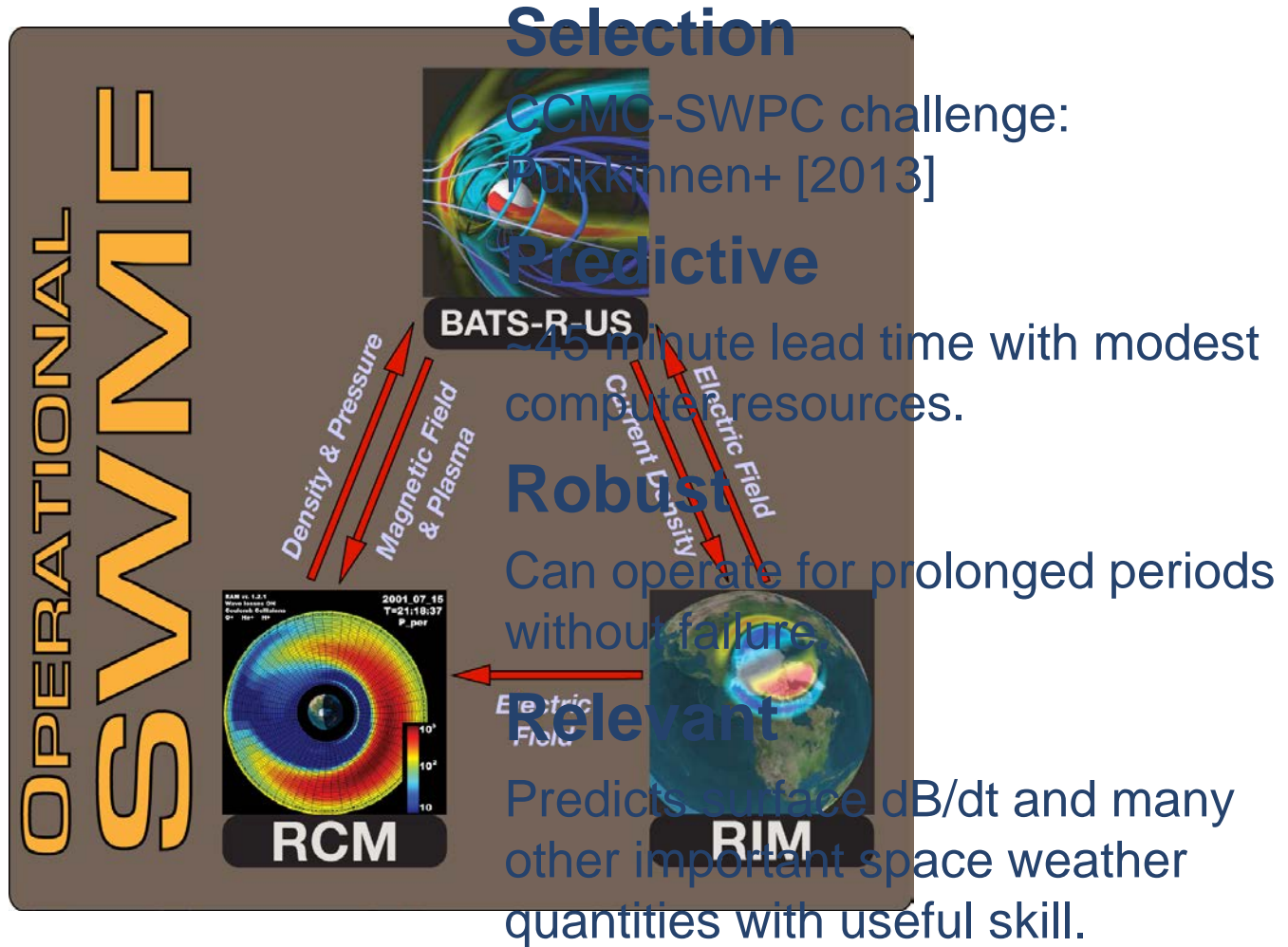
Gábor Tóth
Zhenguang Huang, Daniel Welling

**Department of Climate and Space
Center for Space Environment Modeling
University Of Michigan**



- M Space Weather Modeling Framework**
- M Transitioning the Michigan Geospace Model to NOAA**
- M Improving the Geospace Model**
- M Examples of Operation-to-Research: O2R**
- M Research: starting from the Sun**
- M Observational needs**
- M Summary and Future Directions**





FY 2016 goal: deploy SWMF into operations at NOAA SWPC

- SWMF driven by observed solar wind values
- Must pass NCEP 30-day robustness test

U. of Michigan's role was to support this transition

- Development of model & output products
- Validation & verification of results
- Technical support to resolve issues
- Implementing features required for operations

Continuing effort after Michigan Geospace v1 transitioned

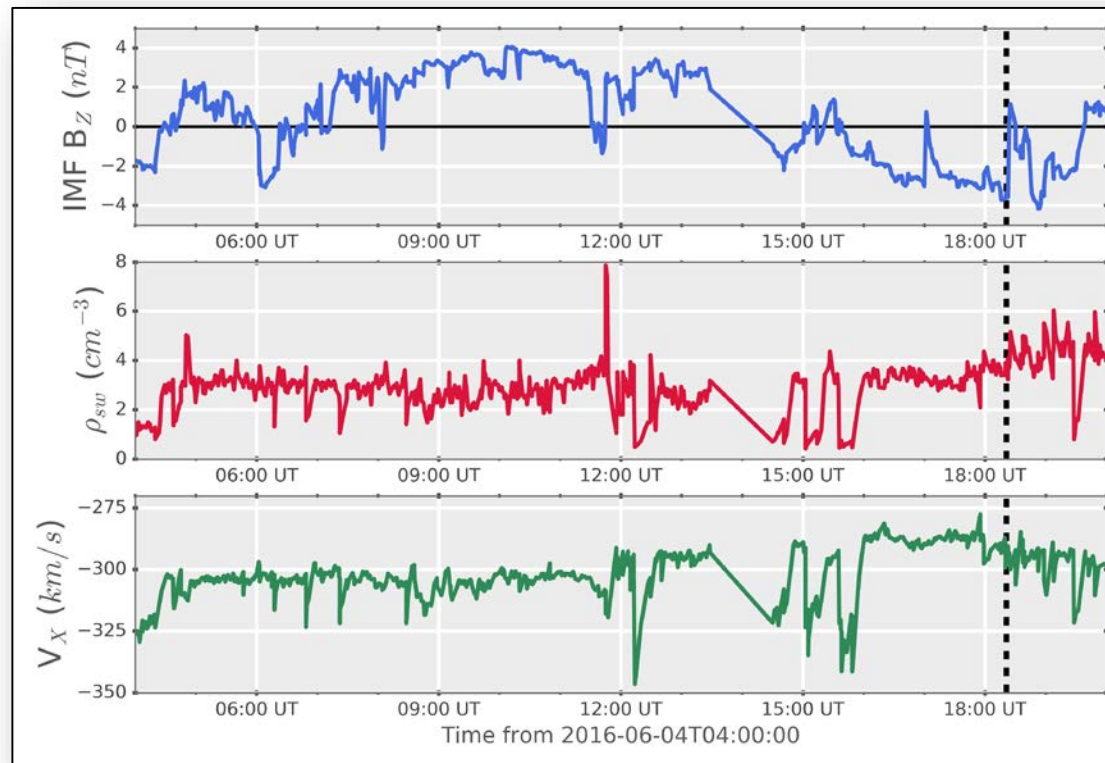
- Improve model & output products
- Help porting the model to new platforms
- Contract renewals: long term effort requires funding

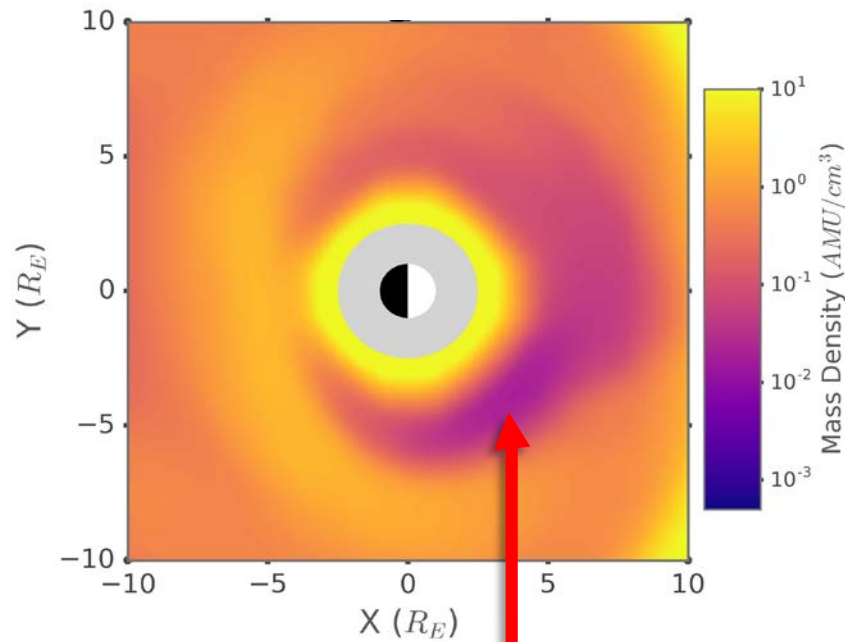
On June 4th 2016 the model halted during the 30-day test

- Not a crash, but code progression ceased.
- Timestep dropped to near-zero values.

Solar wind conditions were unusually calm

- Earthward velocity dipped below 300 km/s.
- No significant transients.





RCM couples pressure and density to MHD

- Only from warm ring-current population

Quiet-time ring current decays to negligible levels

- MHD density pushed below 0.01 cm^{-3}
- Alfvén speed becomes huge

Code stops progressing

Engineering Solution:

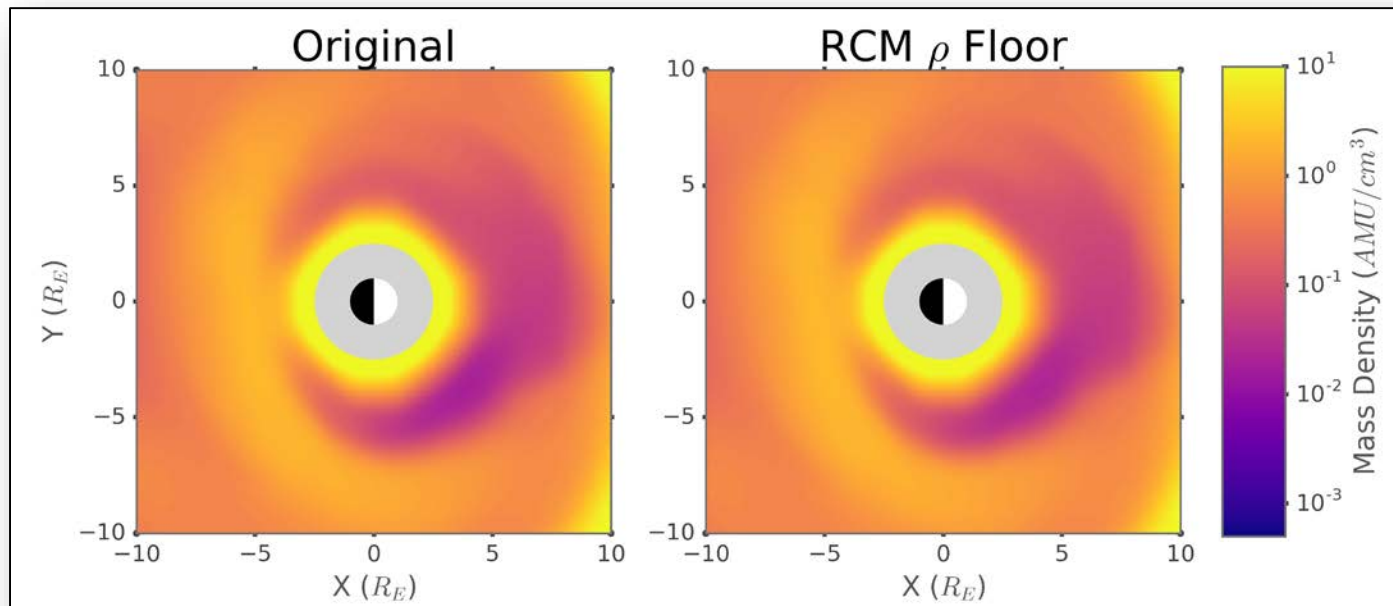
- Watch code & restart if no progression.

Science Solution (O2R):

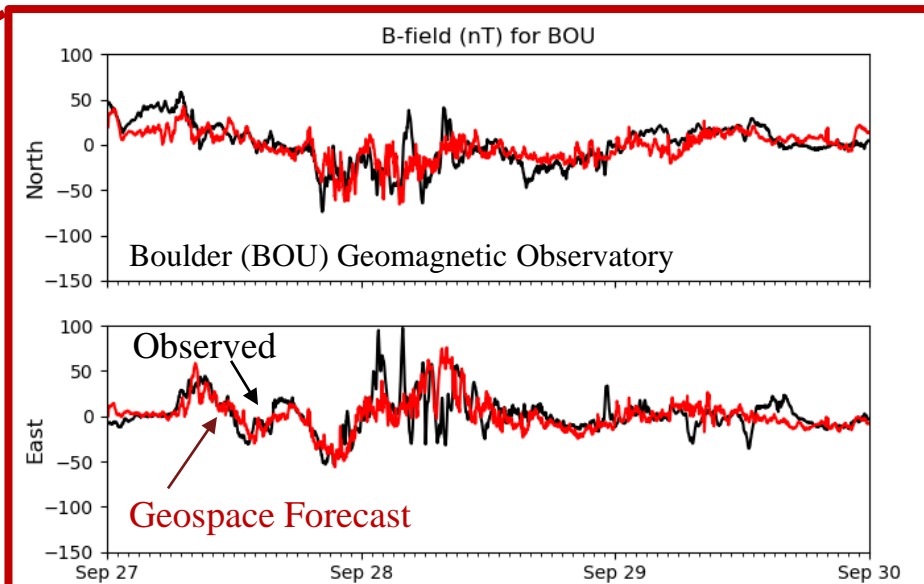
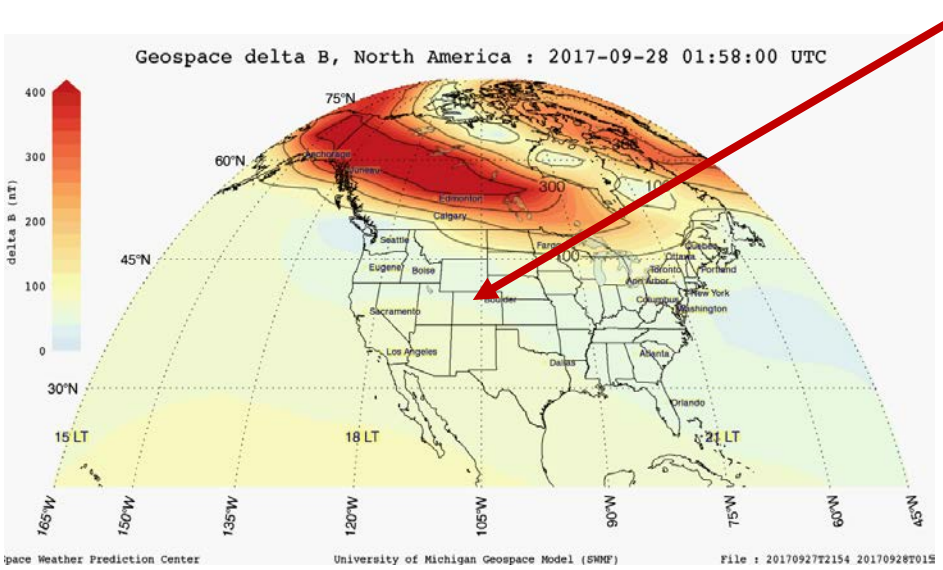
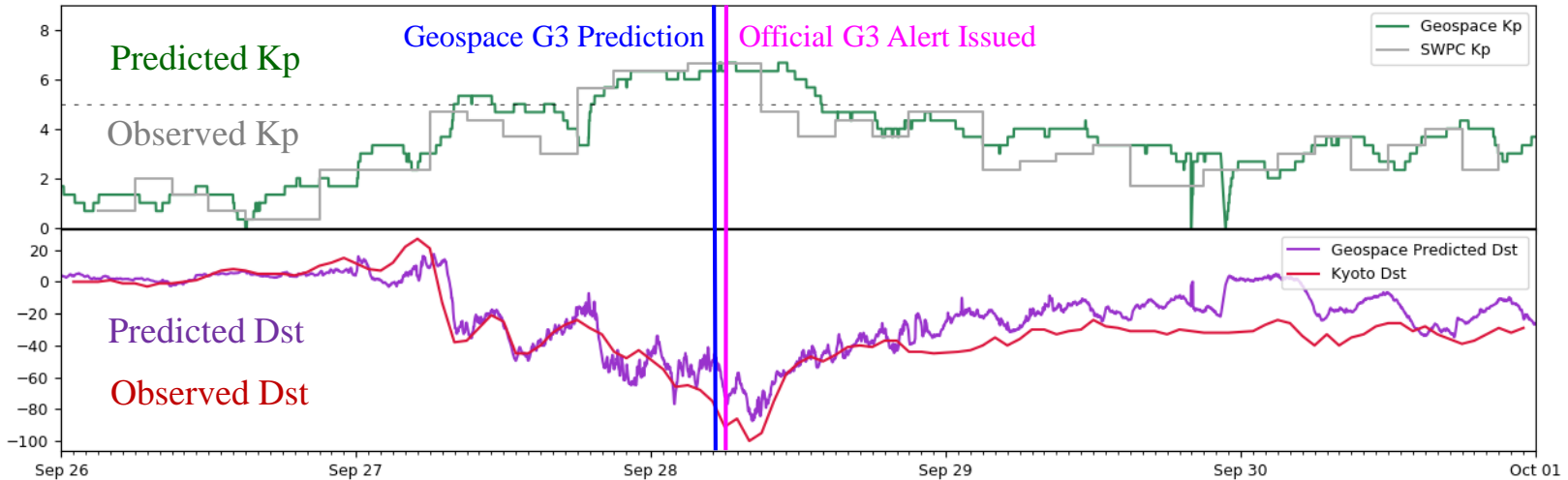
- Add plasmasphere model to the SWMF

Numerical Algorithmic Solution:

- Limit minimum density when coupling RCM to BATS-R-US



Global and Regional Forecasts at SWPC



- **Fully automates the Pulkkinen+ [2013] study**
 - Compiles code and executes six event simulations on a supercomputer in ~1 day
 - Runs each event multiple (5) times to cover variations due to sensitivity
 - Produces plots, all metrics in Pulkkinen+ [2013] & more
- **Measures performance and tracks progress of the SWMF Geospace model**
- **O2R example**
 - We have started a similar automated evaluation suite for solar simulations

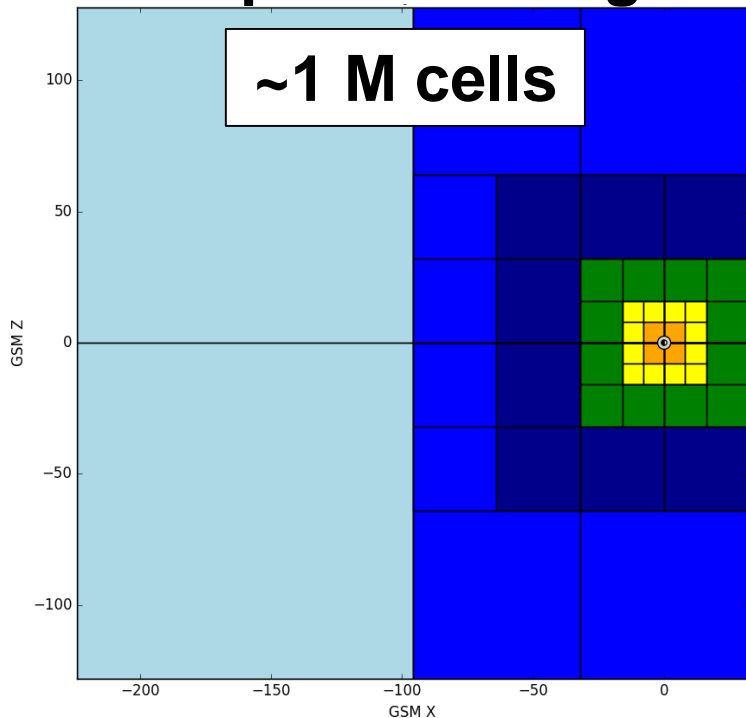
- Improved the performance of Biot-Savart integration for virtual magnetometer grid by orders of magnitude: parallelization and implemented Igor Sokolov's new method
- Replaced fixed dipole magnetic field in MHD with IGRF dipole
- Geospace v1.5 added RBE radiation belt model (M. Fok)

Threshold	POD	POFD	HSS
0.3 [nT/s]	0.724 (+0.031)	0.098 (-0.010)	0.637 (+0.040)
0.7 [nT/s]	0.621 (+0.053)	0.073 (+0.009)	0.581 (+0.032)
1.1 [nT/s]	0.530 (+0.043)	0.062 (+0.008)	0.507 (+0.021)
1.5 [nT/s]	0.453 (+0.041)	0.051 (+0.007)	0.442 (+0.020)

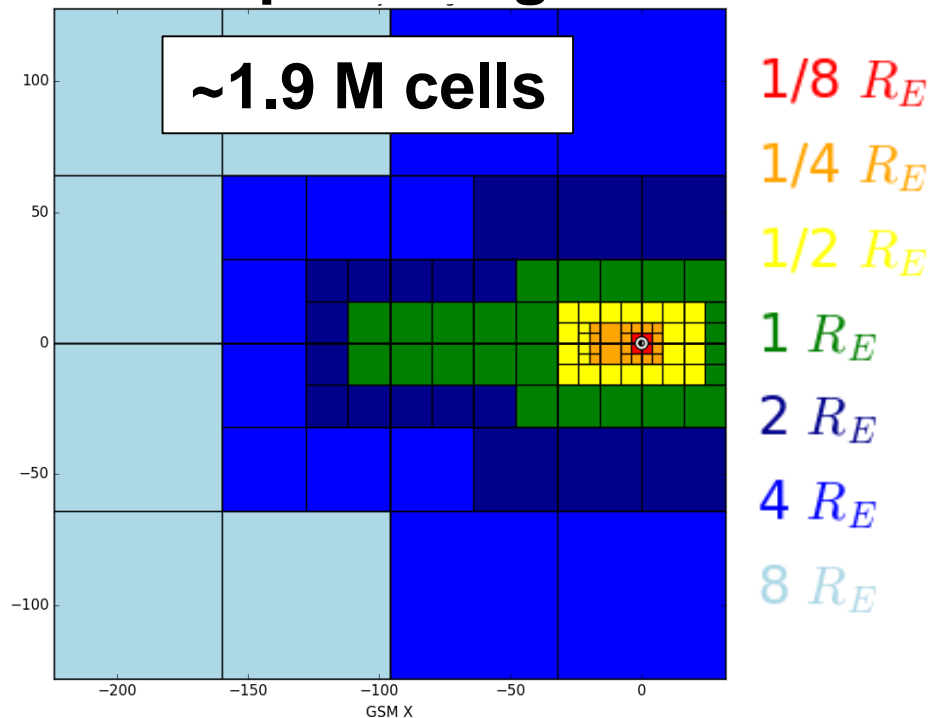
Geospace v2 transitioning soon



Geospace v1-1.5 grid



Geospace v2 grid

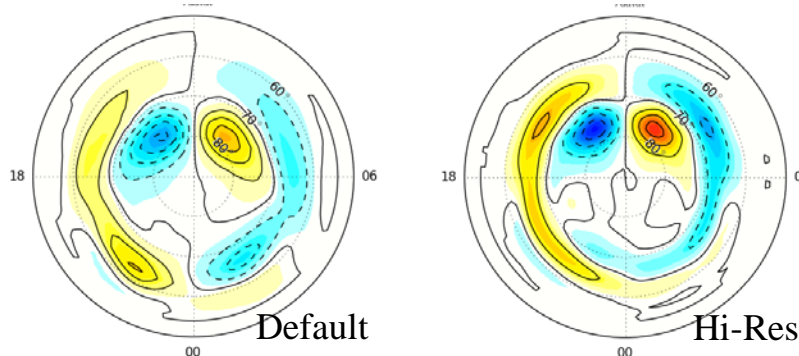


Geospace v2 improvements:

Higher MHD resolution

Improved auroral conductance model

Expanded output products

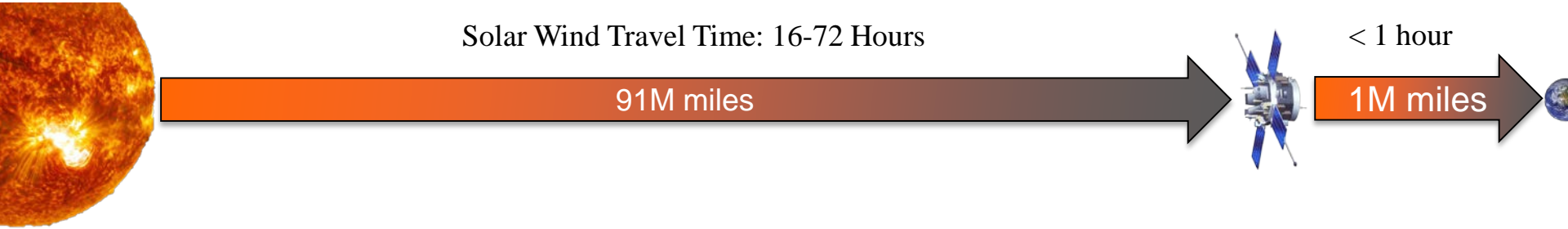


Improved Metrics from v1 to v2

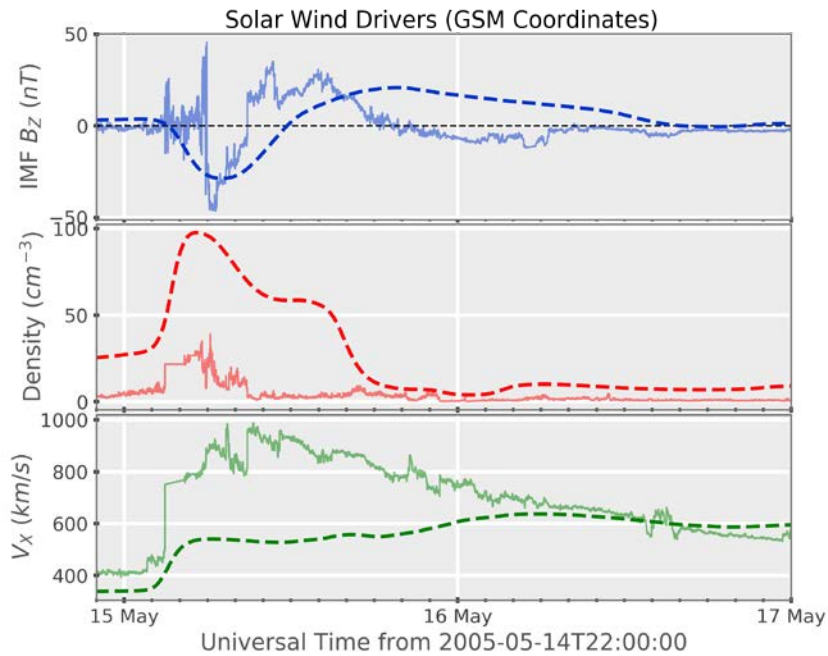


Threshold	POD	POFD	HSS
0.3 [nT/s]	0.865 (+0.171)	0.180 (+0.072)	0.677 (+0.080)
0.7 [nT/s]	0.732 (+0.164)	0.109 (+0.045)	0.618 (+0.069)
1.1 [nT/s]	0.613 (+0.126)	0.091 (+0.038)	0.518 (+0.033)
1.5 [nT/s]	0.523 (+0.111)	0.075 (+0.031)	0.445 (+0.023)

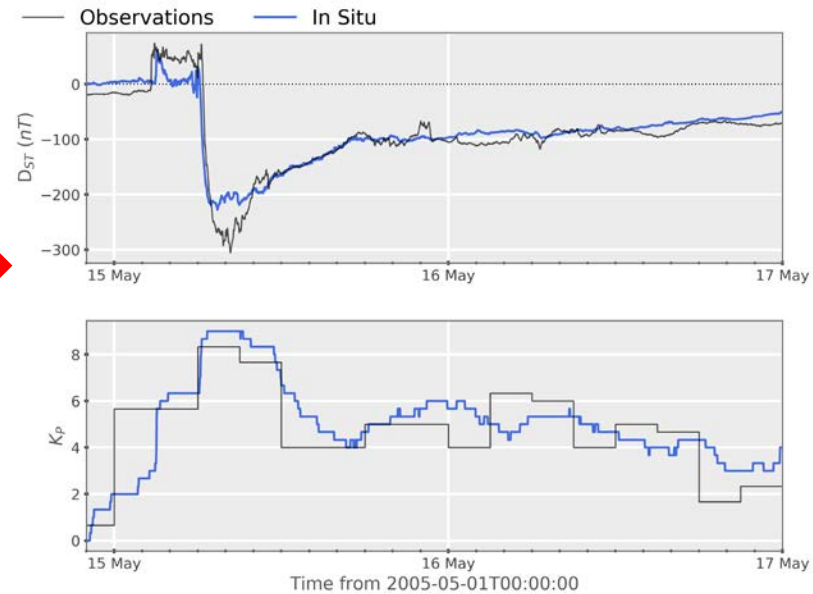
How to Increase the Forecast Time?



Corona/SW models get us to L1.

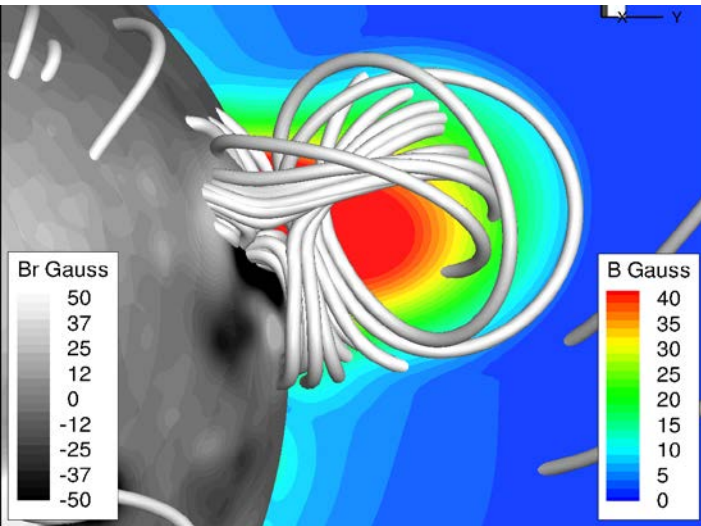


Magnetosphere models get us to the ground.



EEGGL to AWS☀M-R Forecasting

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



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

AWS☀M-R: Alfvén Wave Solar Model [Sokolov 2013, van der Holst+ (2014)]

m CCMC Run-on-Request

m AWSoM-R Corona:

🌐 5 hours simulated

m AWSoM Heliosphere:

🌐 8 days simulated

m Run Time:

🌐 6 days 7 hours on 144 CPUs

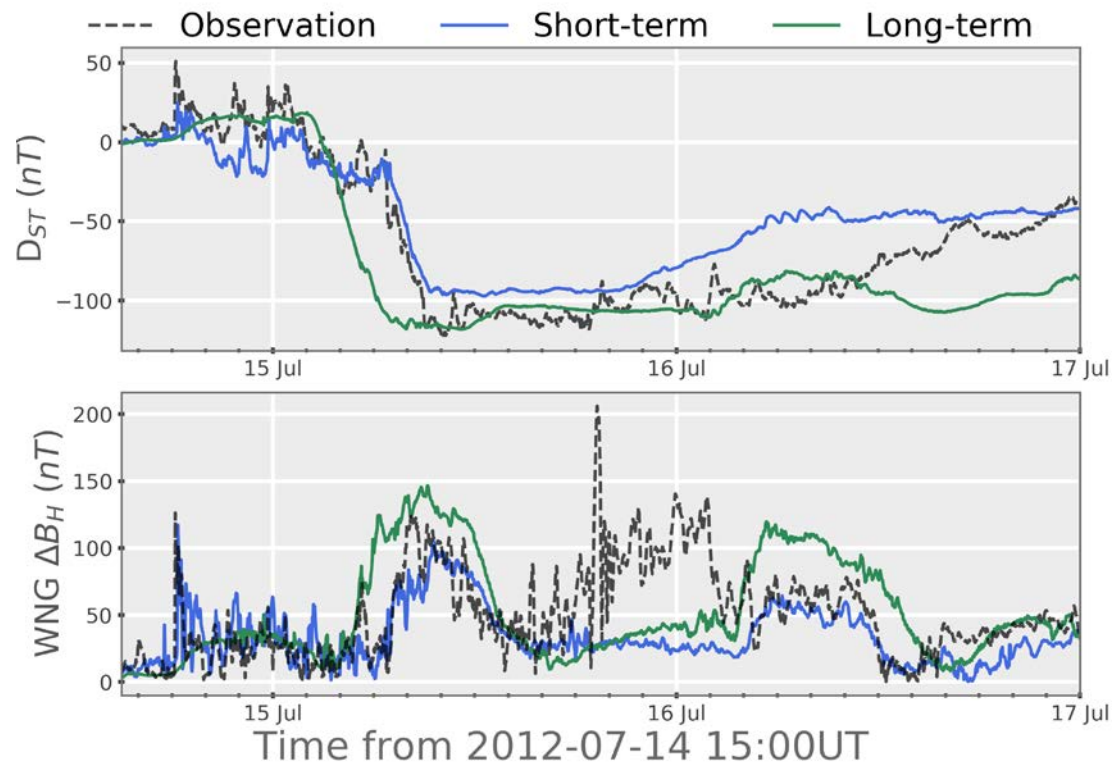
Recommended Parameters

GL Flux Rope Parameters

Longitude: 81.50°
Latitude: -15.50°
Orientation: 155.00°
Radius[Rs]: 0.54
Bstrength[Gs]: 15.77



Surface B Forecast & Metrics



AWSOM-EEGGL prediction of D_{ST} , 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

M Models cannot produce results without appropriate input data

M Observations at Earth

- 🌍 More real-time magnetometer stations for data assimilation
- 🌍 H⁺ and O⁺ observations for model improvement and data assimilation

M Observations at L1

- 🌍 Multiple L1 monitors (three would be ideal) to establish plane
 - 🔴 The data could be collected and sent to Earth by one of the satellites
- 🌍 More reliable L1 measurements without spikes and data gaps

M Observations beyond L1

- 🌍 Sub-L1 monitor would increase the forecast window without much decrease in accuracy

M Observations at the Sun

- 🌍 Synchronic magnetograms covering the whole sun including poles
- 🌍 Vector magnetograms with less noise and polarity ambiguity resolved

M Space Weather Modeling Framework

- 🌐 Different physics domains, different scales, different schemes.
- 🌐 Michigan Geospace Model is running 24/7 at NOAA SWPC, v2 coming.
- 🌐 We have been working with SWPC for 6 years to transition and improve
 - 🔴 **O2R is real**: our research and science capabilities have benefited a lot

M Improving forecast window and accuracy

- 🌐 Terrestrial, L1, sub-L1 and solar observations
- 🌐 Better physics for extreme events
 - 🔴 MHD-AEPIC (MHD with Adaptively Embedded PIC) INSPIRE, PRE-EVENTS
- 🌐 Machine Learning + physics based models
 - 🔴 SOLSTICE DRIVE Center (Gombosi)
- 🌐 Data assimilation & Uncertainty Quantification
 - 🔴 NextGen SWMF SWQU project

M Open Source community model using GPUs: **MSTEM-QUDA**

- 🌐 Michigan Sun-To-Earth Model with Quantified Uncertainty and Data Assimilation