Statistical study of substorm onset times in MHD and observations

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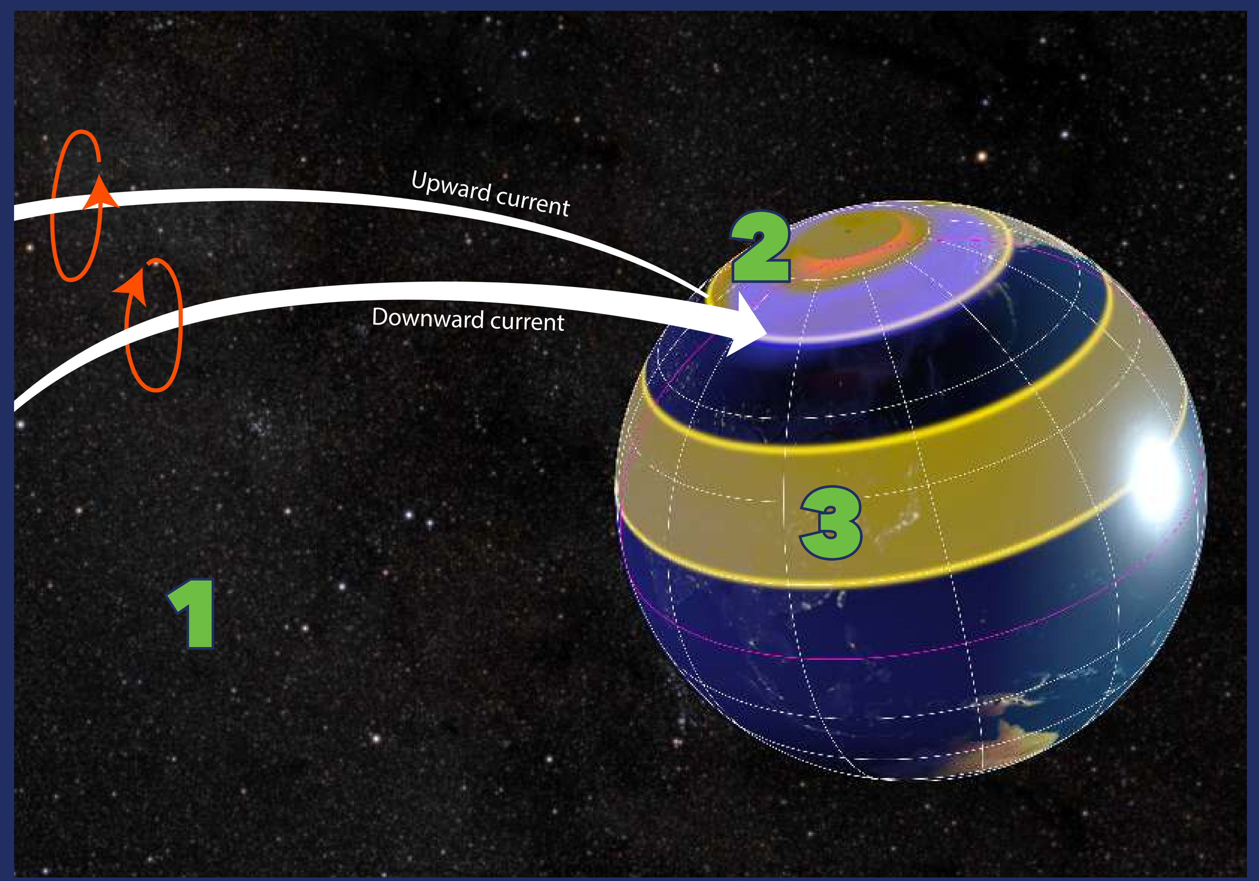
Abstract

Magnetospheric substorms release stored energy from the magnetotail into the auroral zone. They cause magnetic perturbations at the surface, which generate potentially harmful currents in power grids. In order to investigate the effectiveness of magnetohydrodynamic (MHD) models in capturing substorms, we simulate a one-month period and make statistical comparisons with observations.

Substorm signatures



A substorm produces field-aligned currents which connect the auroral zone to the magnetotail, generating magnetic field perturbations in the magnetotail, auroral zone, and mid-latitudes. Field data in region (1) can be detected by satellites, field data in region (2) is used to calculate the AE index, while the fields in region (3) are averaged in latitude to produce a mid-latitude map.

Models

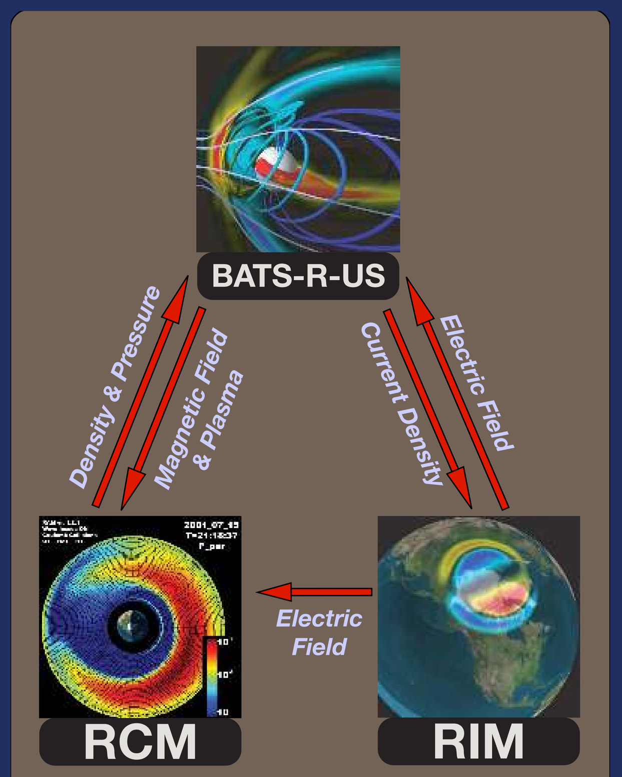
Space Weather Modeling Framework (SWMF) coupled model

- BATS-R-US MHD model
- Ridley ionosphere model (RIM)
- Rice Convection Model (RCM)

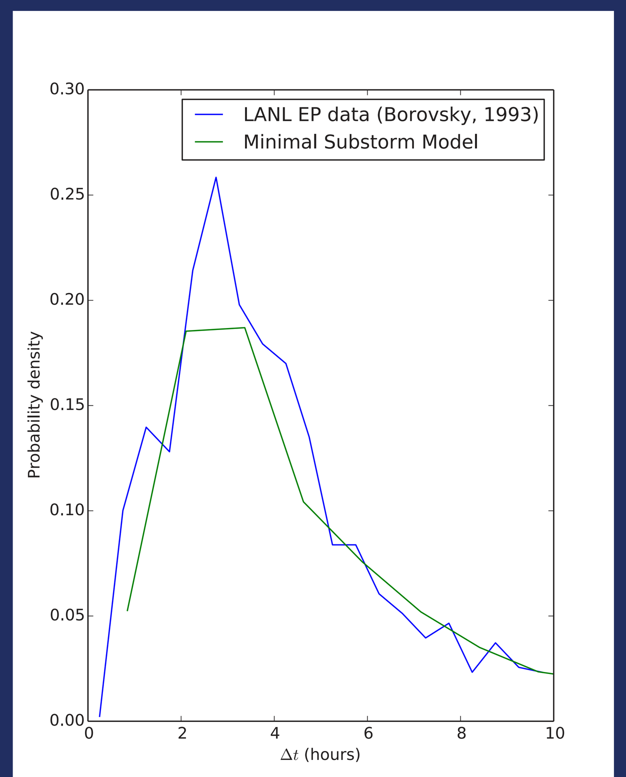
Minimal Substorm Model (MSM)

- Solves an energy balance equation for the state of the magnetotail
- Reproduces the observed distribution of inter-substorm intervals

Both models are driven by solar wind observations from L1.



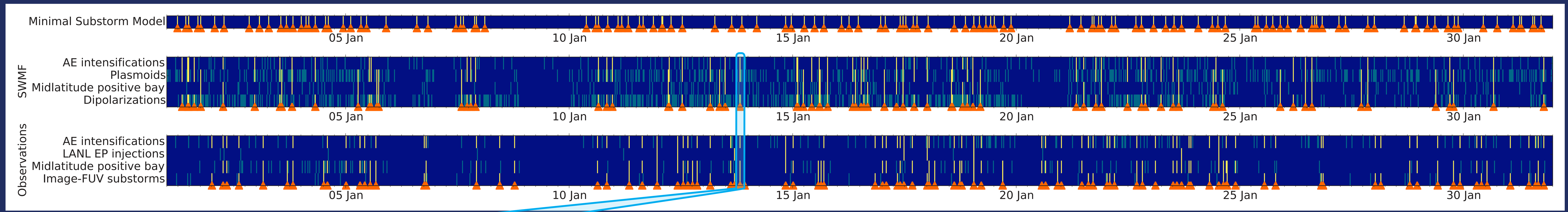
SWMF components: Models included in the SWMF run configuration.

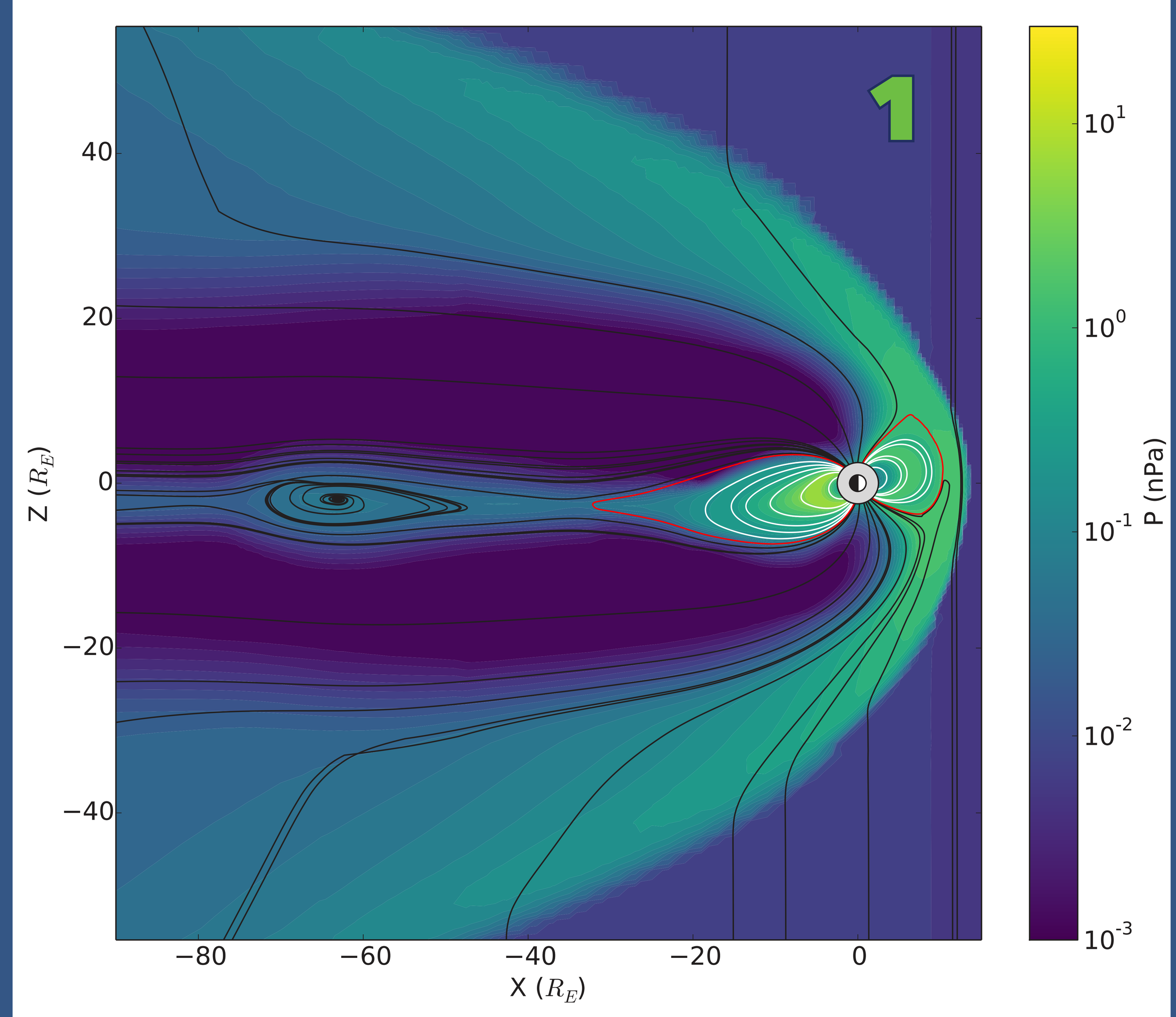


Timing: Inter-substorm timing distribution calculated by MSM agrees with observations

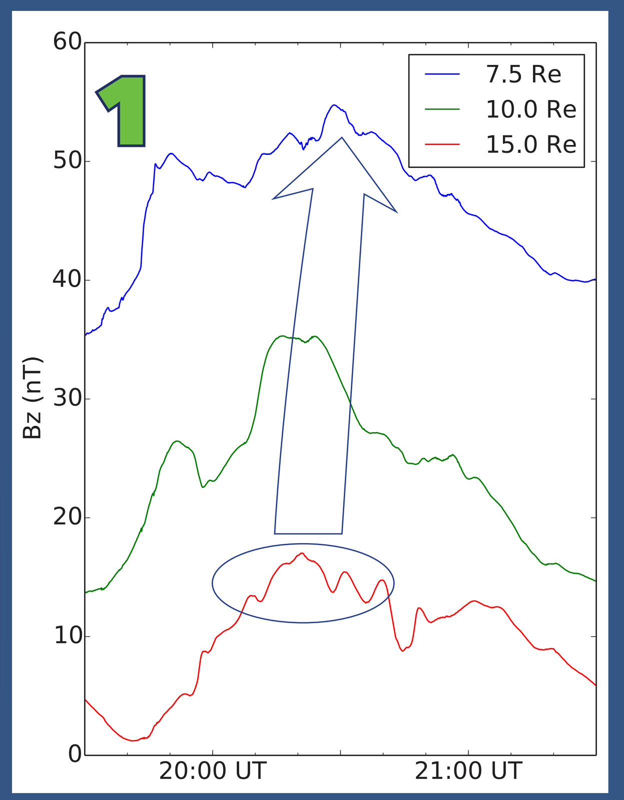
Substorm identification

Identified substorm signatures: The timeseries shows substorm signatures identified by each method. Simultaneous detection by multiple signatures (2 in observations, 3 in SWMF output) within a 30-minute period is identified as a substorm and highlighted on the graph. Counts of these events are used to calculate the forecast metrics in the results section. Individual signatures for a representative event on January 13, 2005 are shown in the figures in the cyan box.

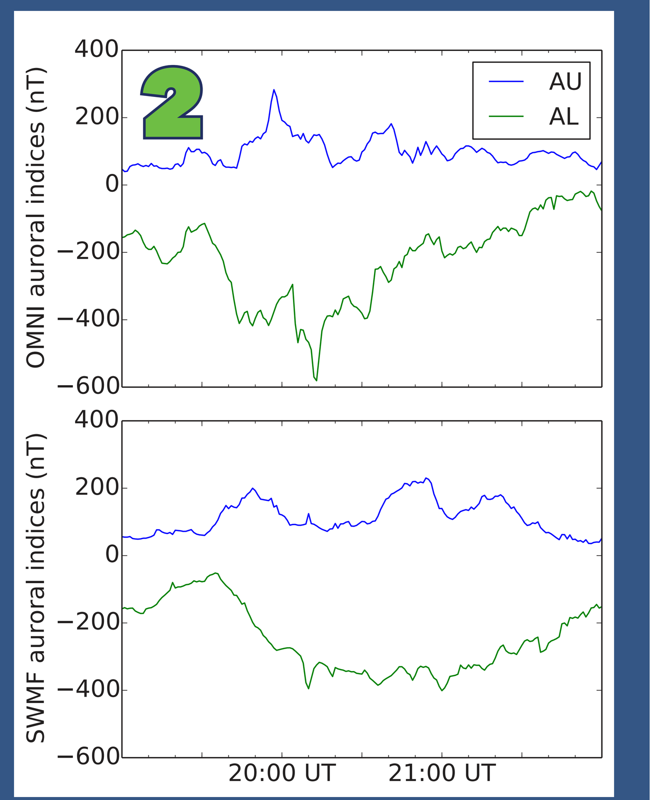




Plasmoid release in SWMF: Cut-plane of thermal pressure and magnetic field lines from the SWMF output at 20:45 UT on January 13, 2005. A plasmoid release is evident in both the pressure distribution and the magnetic field structure.

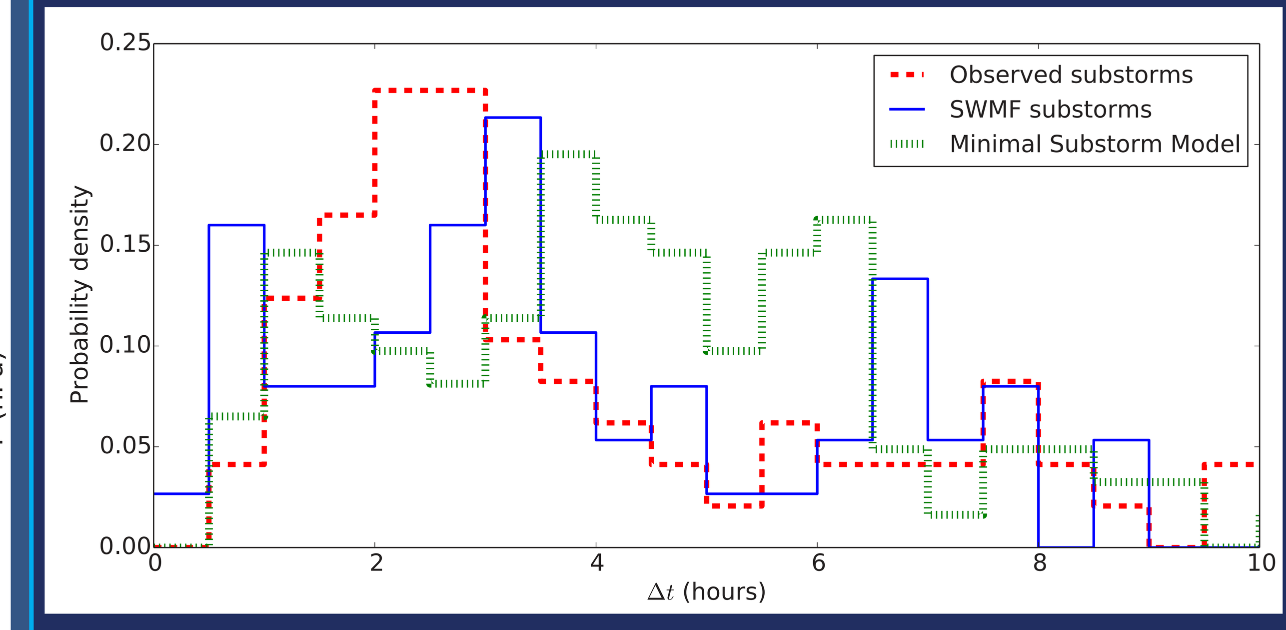


Dipolarization: Z-component of magnetic field on January 13, 2005, for 3 points directly antisunward of the Earth. A dipolarization signature can be seen beginning around 19:45 at 15 Re and propagating inward, indicative of a plasmoid release.

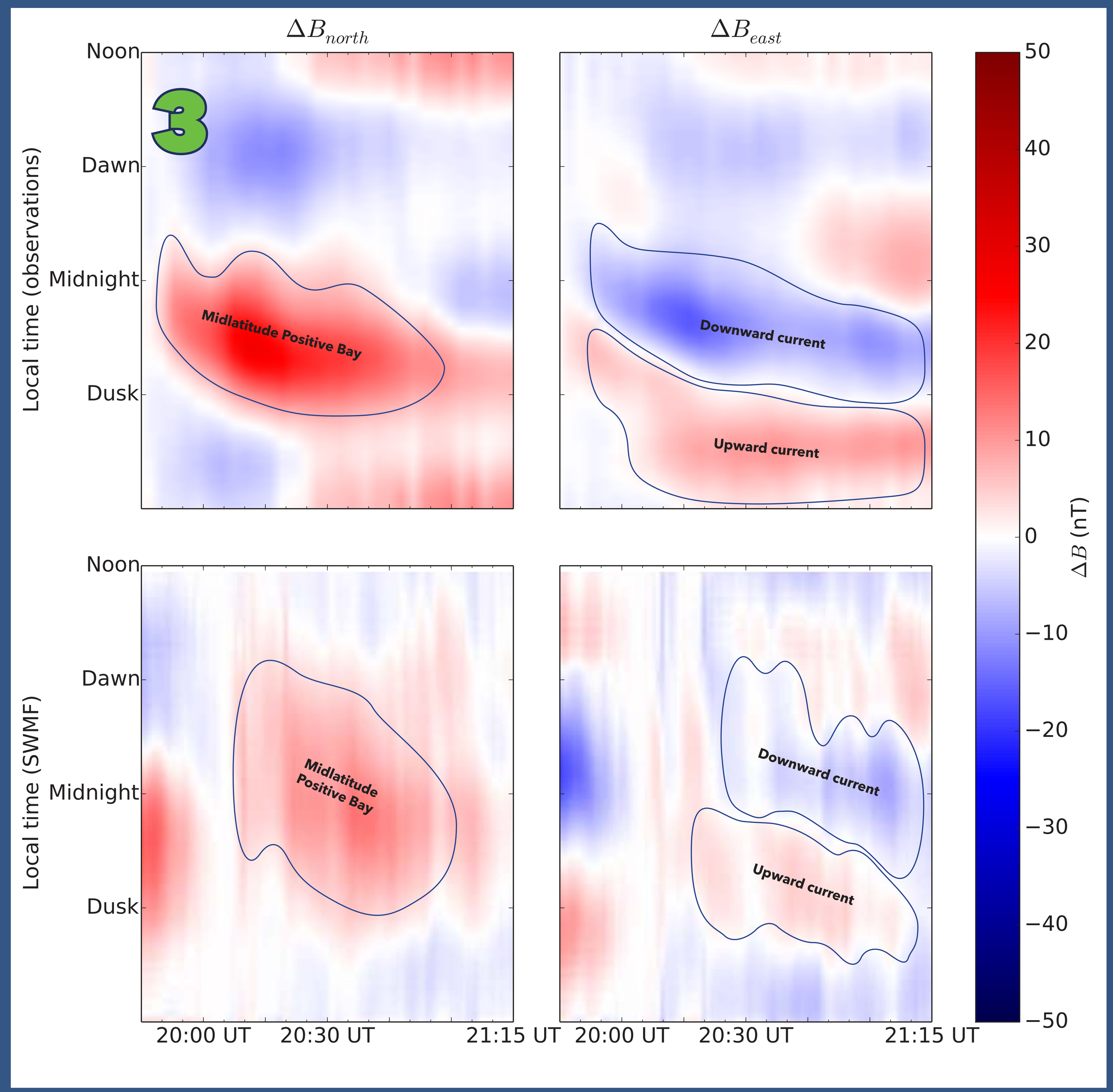


AE intensification: Auroral upper (AU) and auroral lower (AL) indices from observations (above) and SWMF output (below) for January 13, 2005. The model intensification is weaker, but onset occurs within a few minutes of the observed onset.

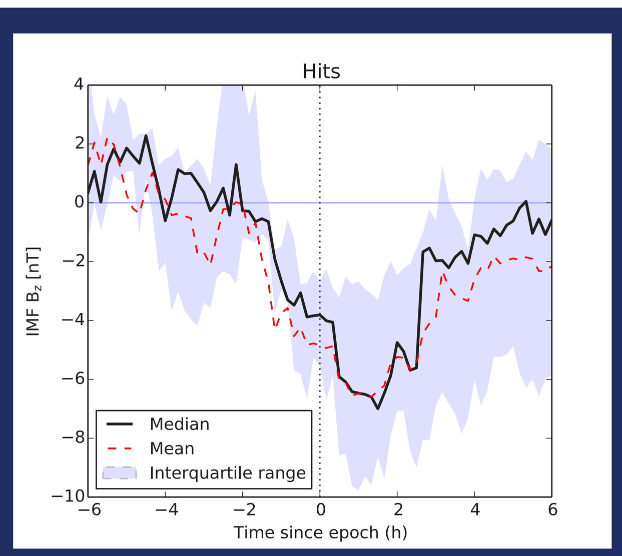
Results

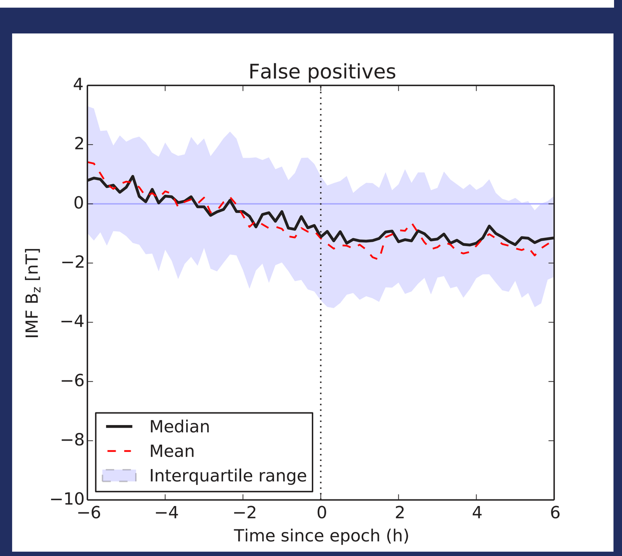


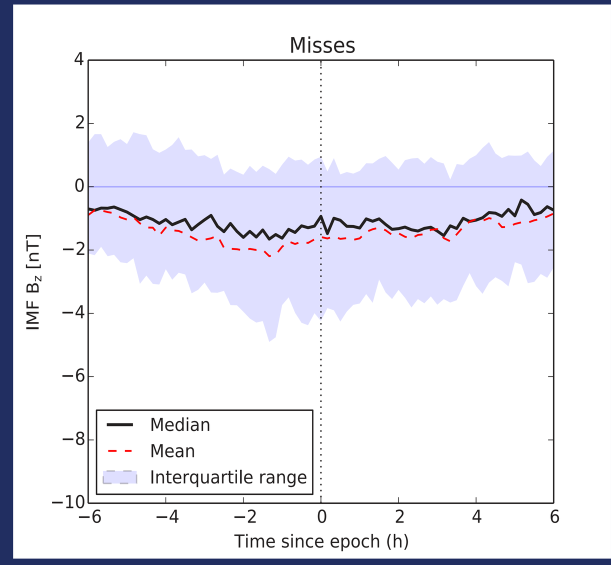
Timing distribution: Inter-substorm timing distribution for January, 2005. MHD and MSM both produce a distribution similar to that found in observations.



Midlatitude Positive Bay (MPB): Mid-latitude map of northward (left column) and eastward (right column) magnetic field perturbations for January 13, 2005. The upper row shows observations from ground-based magnetometers; the lower row shows SWMF output. An MPB is apparent in both the observations and the SWMF output. The field components from the onset time of the event have been subtracted from each plot.







		Observations Y	Observations N
SWMF	Y	8	69
SWMF	N	90	1321

Contingency table for SWMF (all signatures), using a 30 minute time window. The surrounding plots show a superposed epoch analysis of IMF for the events in this table. "Hits" are characterized by a northward IMF that turns southward.

	Predictive skill: Same signature	Predictive skill: All signatures	**Hit rate**	**False alarm rate**
Dipolarizations		0.041	0.500	0.368
Plasmoids		0.026	0.367	0.299
Midlatitude positive bay	-0.007	-0.006	0.122	0.131
AE intensifications	0.083	**0.036**	0.184	0.131
SWMF (all signatures)		**0.036**	0.082	0.050
Minimal Substorm Model		-0.002	0.082	0.083

Skill scores for individual detection methods, all detection methods combined, and Minimal Substorm Model. Combining detection methods produces a skill score similar to that of the AE intensifications but with a much lower false alarm rate. These metrics indicate a weak predictive skill with respect to the observed substorms.

Conclusions

- **MHD reproduces the observed timing ditribution**
- **Predictive skill for individual events is weak**
- **Combining multiple detection techniques reduces false positives**
- **Correct predictions by SWMF correspond with southward turning IMF**

Future work

- **Investigate effect of model tuning on results**
- **Further investigate common traits among hits and misses**
- **Test additional physics (Hall MHD, embedded PIC)**
- **Analyze substorm strength**