Modeling and Visualization of Geomagnetic Storms at the CCMC

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SM53B-07, 2023 AGU Fall Meeting, Dec. 15, 2023

Covering 20+ Years of Geomagnetic Activity

Motivation: *Strong need in community for quality-curated library of pre-made runs of geomagnetic storms. Such library could advance science by providing standardized and repeatable simulations*.

Started by identifying strongest storms in each year:

- Dst: Minimum <= -150
- weaker storms to follow: -150 to -100, >= -100
- Event categorization by maximum Kp: >=7, 6, 5 possible as well

Runs prepared with comparisons automatically performed:

- Magnetic Perturbations deltaB (deltaB/dt) on the ground (SuperMag stations),
- Kp, Dst, (AU, AL, AE)
- Satellites tracked and observations compared with in-situ MHD results:
  - GOES, THEMIS, MMS, …
- Run configuration designed so the model captures required parameters

Building a Storm Event Simulation Library

- Started by covering strongest storms (1-2 per year)
- Defined naming convention for storm event runs:

  PRESET-YYYY-MM_TP-NN_REQUEST-DATE_M

  - **PRESET**: model name and setting number, e.g. SWMF-01
  - **YYYY-MM:** year and month of start day of time period
  - **TP:** short for Time Period – a few days of storm activity each month
  - **NN**: ID of time period selected in each month
  - **REQUEST-DATE:** 6-digit mmddyy date when request was submitted
  - **M**: run repetition number (usually 1; 2, …, 9 if rerun(s) were done)
- Growing event coverage exposing issues:
  - Low Mach solar wind occurs often, requiring grid extension upstream

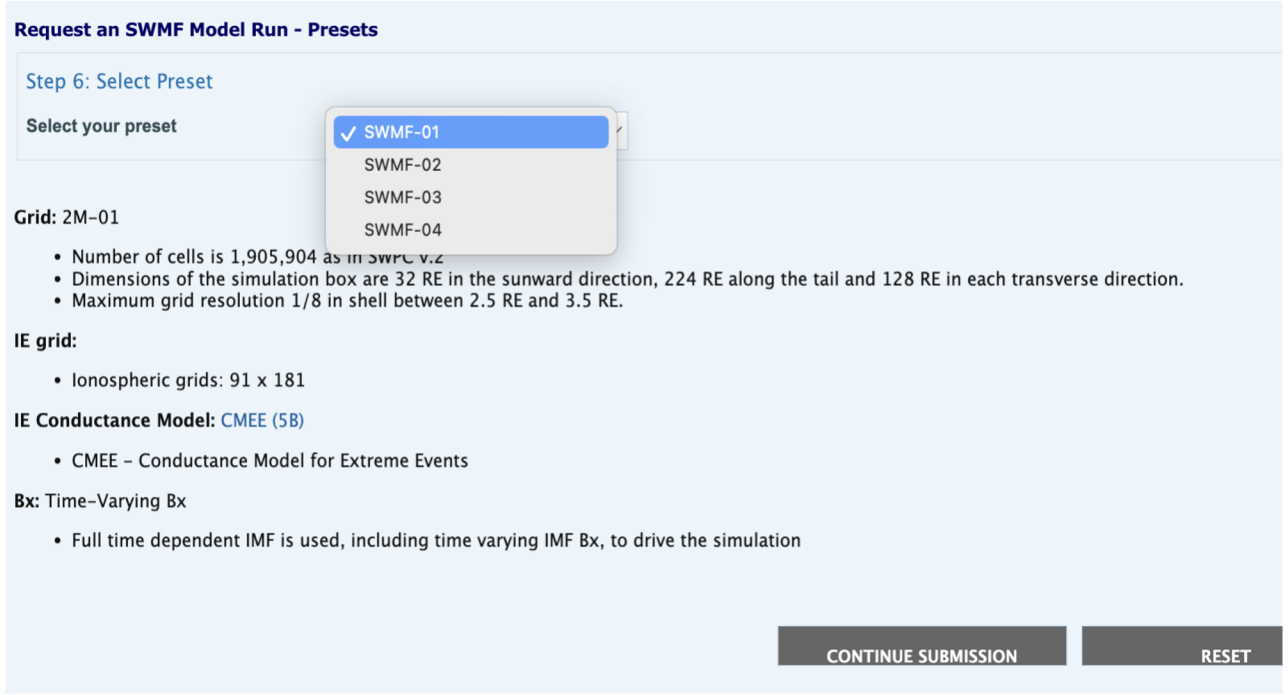
Redesigned Run Submission

2023 version of SWMF framework

- BATSRUS+RCM magnetosphere
- New conductance models in Ionosphere Electrodynamics Solver:
  - *Conductance Model for Extreme Events* (CMEE, A. Mukhopadhyay 2020)
  - *Conductance Model based on PFISR And SWARM Satellite* (COMPASS, Wang and Zou, 2022)
  - *Asymmetric Pedersen Conductance* (ASYM) set SigmaP differently for North and South
  - *AMPERE-Derived Electrodynamic Parameters of the High Latitude Ionosphere* (ADELPHI, Robinson et al., 2020)

Redesigned submission interface

- 4 run configurations
  - 2 based on SWPC version 2 real time configuration
  - 2 with higher resolution grid



SWMF 2023 presets

real time resolution

SWMF-01:

Grid 2M-01:

- Number of cells is **1,905,904** as in version 2 real time simulation used by NOAA SWPC
- Dimensions of the simulation box are 32 R_E in the sunward direction, 224 R_E along the tail and 128 R_E in each transverse direction.
- Maximum grid resolution 1/8 in shell between 2.5 R_E and 3.5 R_E.

IE grid:

- Ionospheric grids: 91 x 181
- Conductance Model**:**
  CMEE - Conductance Model for Extreme Events

Bx: Time-Varying Bx

- Full time dependent IMF is used, including time varying IMF Bx, to drive the simulation

SWMF-03 differs from SWMF-01 by:

Bx: Constant Bx set to 0

higher resolution

SWMF-02:

Grid: 5M-01

- Number of cells **4,873,456** storm setting optimized by University of Michigan
- Dimensions of the simulation box are 32 R_E in the sunward direction, 224 R_E along the tail and 128 R_E in each transverse direction.
- Maximum grid resolution 1/8 in shell between 2.5 R_E and 8.0 R_E.

IE grid:

- Ionospheric grids: 91 x 181
- **Conductance Model:**
  CMEE - Conductance Model for Extreme Events

Bx: Time-Varying Bx

- Full time dependent IMF is used, including time varying IMF Bx, to drive the simulation’

SWMF-04 differs from SWMF-02 by:

Bx: Constant Bx set to 0

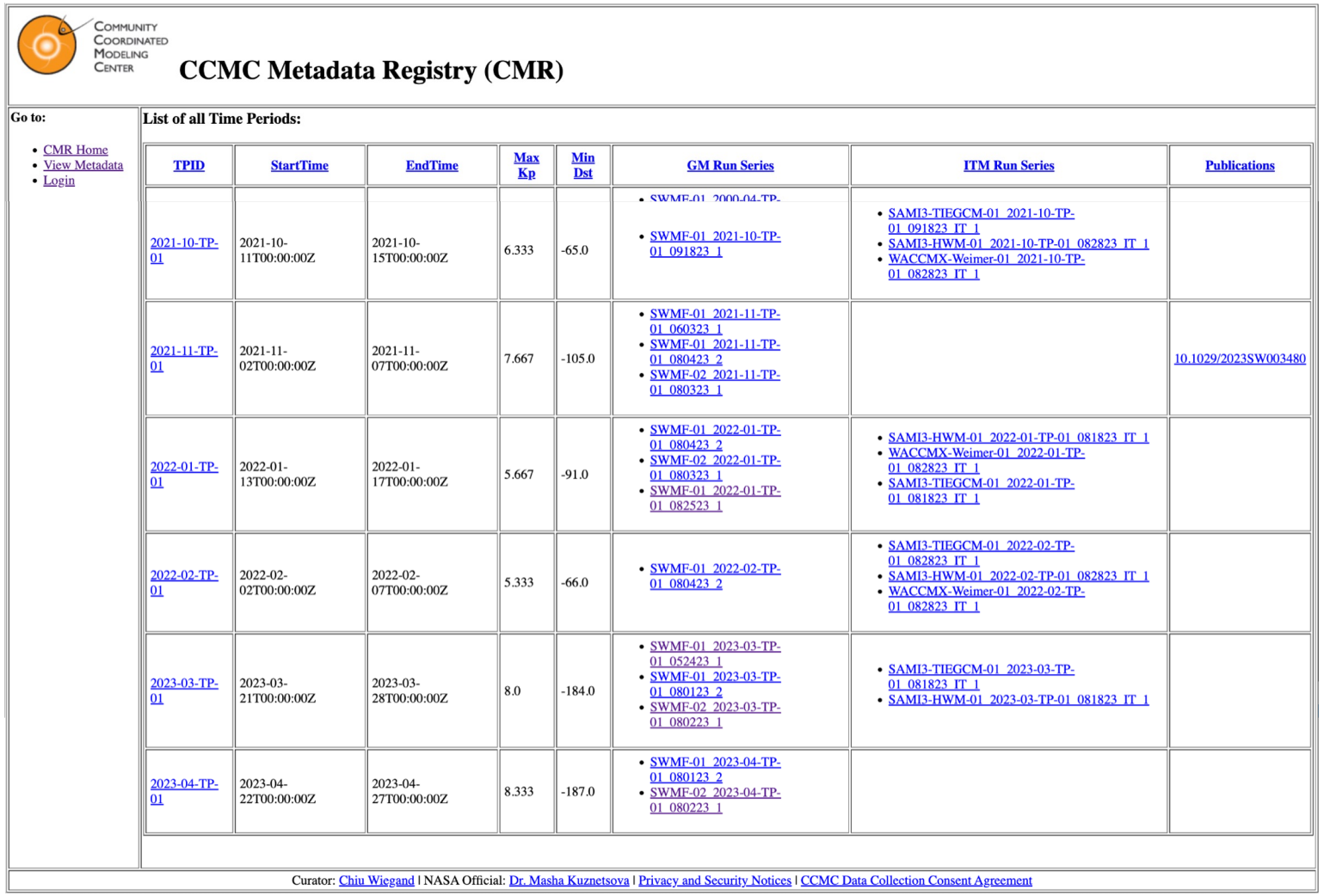
Current Event Coverage

https://kauai.ccmc.gsfc.nasa.gov/CMR/TimeInterval/viewAllTI

- About 40 of the strongest storms covered so far
- 2000 – 2023
- About 50 runs using SWMF-01 and SWMF-02

New runs added:

- About 6 new runs are executed at a time
- 3 weeks from start to publication for each run
- Time Periods added soon after storms occur



COMMUNITY COORDINATED MODELING CENTER

CCMC Metadata Registry (CMR)

Go to:

- CMR Home
- View Metadata
- Login

List of all Time Periods:

TPID	StartTime	EndTime	Max Kp	Min Dst	GM Run Series	ITM Run Series	Publications
2021-10-TP-01	2021-10-11T00:00:00Z	2021-10-15T00:00:00Z	6.333	-65.0	• SWMF-01_2021-10-TP-01_091823_1	• SAMI3-TIEGCM-01_2021-10-TP-01_091823_IT_1 • SAMI3-HWM-01_2021-10-TP-01_082823_IT_1 • WACCMX-Weimer-01_2021-10-TP-01_082823_IT_1	
2021-11-TP-01	2021-11-02T00:00:00Z	2021-11-07T00:00:00Z	7.667	-105.0	• SWMF-01_2021-11-TP-01_060323_1 • SWMF-01_2021-11-TP-01_080423_2 • SWMF-02_2021-11-TP-01_080323_1		10.1029/2023SW003480
2022-01-TP-01	2022-01-13T00:00:00Z	2022-01-17T00:00:00Z	5.667	-91.0	• SWMF-01_2022-01-TP-01_080423_2 • SWMF-02_2022-01-TP-01_080323_1 • SWMF-01_2022-01-TP-01_082523_1	• SAMI3-HWM-01_2022-01-TP-01_081823_IT_1 • WACCMX-Weimer-01_2022-01-TP-01_082823_IT_1 • SAMI3-TIEGCM-01_2022-01-TP-01_081823_IT_1	
2022-02-TP-01	2022-02-02T00:00:00Z	2022-02-07T00:00:00Z	5.333	-66.0	• SWMF-01_2022-02-TP-01_080423_2	• SAMI3-TIEGCM-01_2022-02-TP-01_082823_IT_1 • SAMI3-HWM-01_2022-02-TP-01_082823_IT_1 • WACCMX-Weimer-01_2022-02-TP-01_082823_IT_1	
2023-03-TP-01	2023-03-21T00:00:00Z	2023-03-28T00:00:00Z	8.0	-184.0	• SWMF-01_2023-03-TP-01_052423_1 • SWMF-01_2023-03-TP-01_080123_2 • SWMF-02_2023-03-TP-01_080223_1	• SAMI3-TIEGCM-01_2023-03-TP-01_081823_IT_1 • SAMI3-HWM-01_2023-03-TP-01_081823_IT_1	
2023-04-TP-01	2023-04-22T00:00:00Z	2023-04-27T00:00:00Z	8.333	-187.0	• SWMF-01_2023-04-TP-01_080123_2 • SWMF-02_2023-04-TP-01_080223_1		

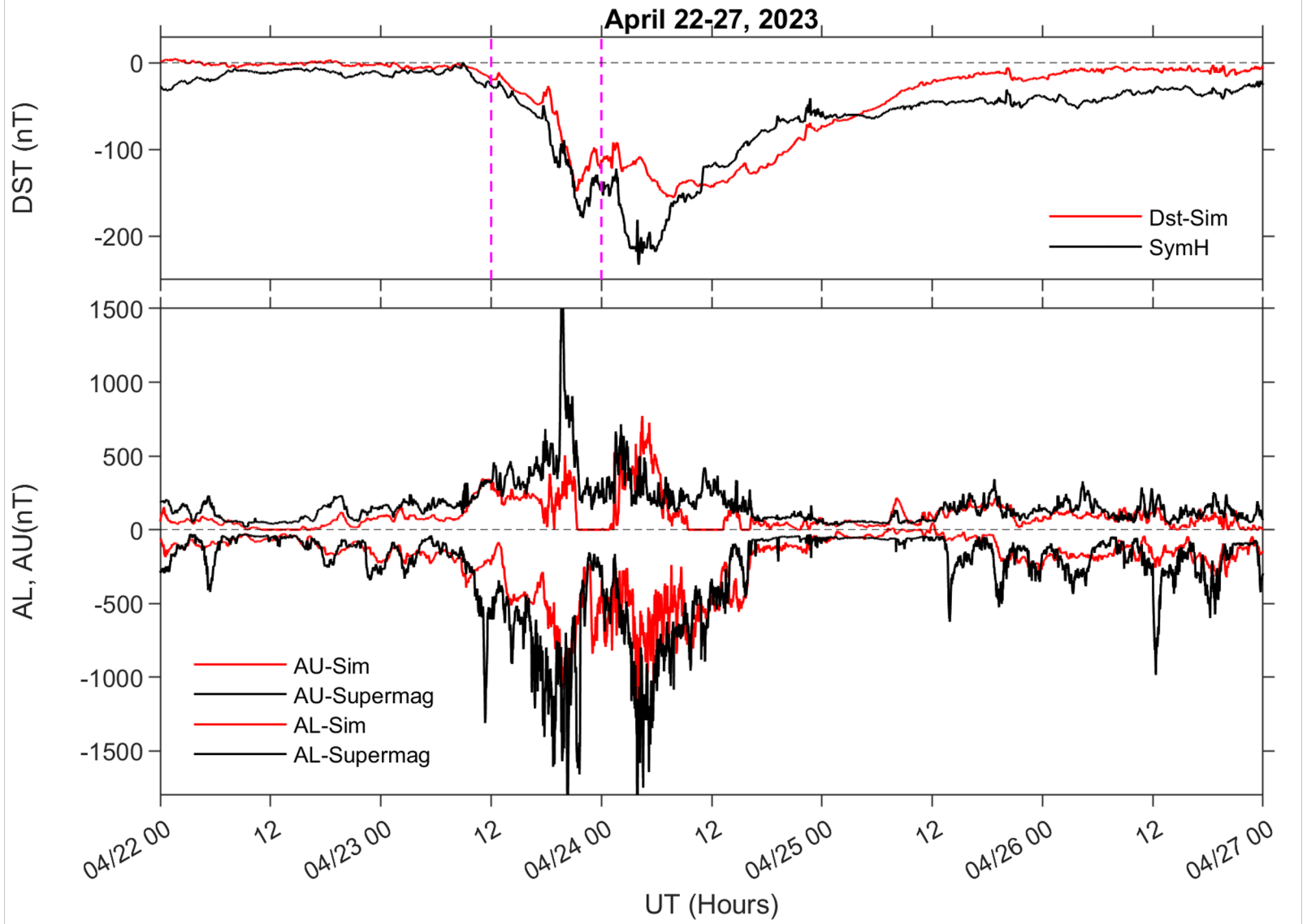
Curator: Chiu Wiegand | NASA Official: Dr. Masha Kuznetsova | Privacy and Security Notices | CCMC Data Collection Consent Agreement

SWMF-02_2023-04-TP-01: April 22-27 2023

Storm run done with SWMF-02 (5M-01 (4.87 million cell grid, 1/8 R_E within 8 R_E)

- **Top**:
  SymH: Observed and **simulated** (with less dynamic range in this case)

- **Bottom:**
  AU, AL: Observed
  Supermag Auroral indices and **simulated indices** (mostly closer to zero and with fewer spikes)



SWMF-02_2023-04-TP-01_110623_2

Run Status: Run Complete (status updated at 2023-11-28T15:26:38+0000)

SWMF-02_2023-04-TP-01

Run Metadata

Metadata Record:	View Full Run Metadata in the CCMC Metadata Registry (CMR)
Metadata as JSON:	View Full Run Metadata as JSON
Model Domain:	GM
Model Name:	SWMF
Model Version:	v20230424
Key Word:	Storm low Mach number
Run type:	Real event simulation
Inflow Boundary Conditions:	Time-dependent
Start Time:	2023/04/22 00:00
End Time:	2023/04/27 00:00
Dipole Tilt at Start in X-Z Plane:	10.26 °
Dipole Tilt in Y-Z GSE Plane:	29.38 °
Dipole Update With Time:	no
Ionospheric Conductance:	auroral
Radio Flux 10.7 cm:	-1
Co-rotation:	No corotation velocity is applied at the inner boundary.
Grid:	4,873,456 cells, 1/8 resolution at inner boundary
Coordinate System for the Output:	GSM
Solar wind input source:	OMNI
Ring current model:	RCM

Registered Metadata in SPASE

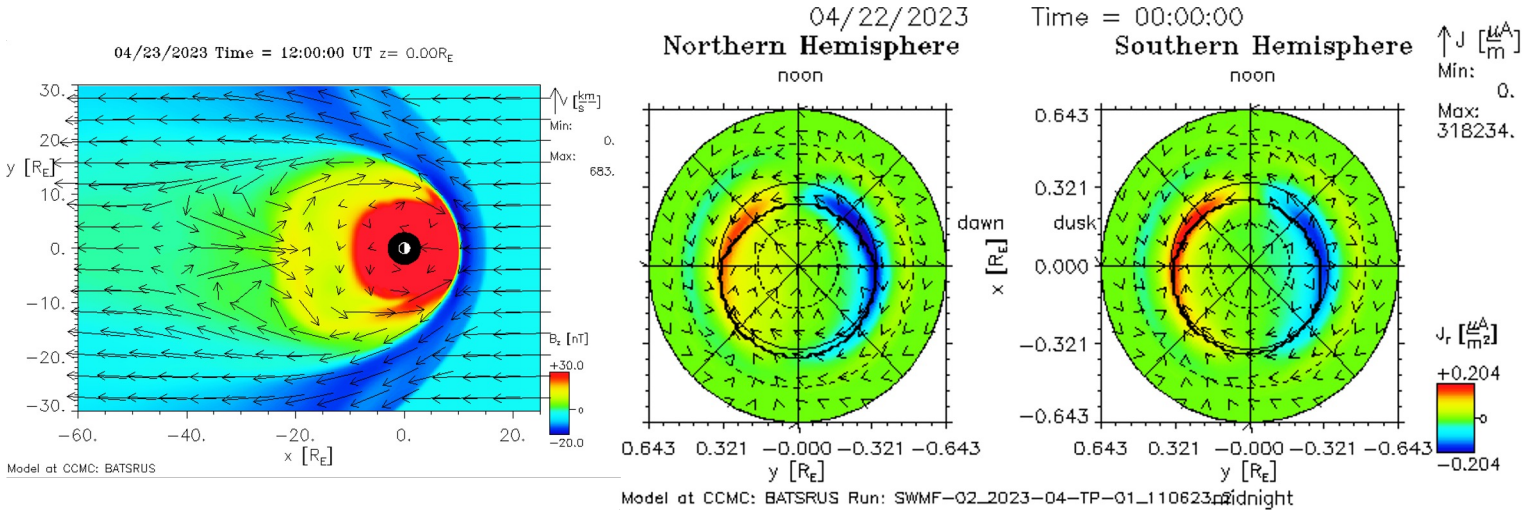
Initial Solar Wind (SW) Parameters in GSM Coordinates:

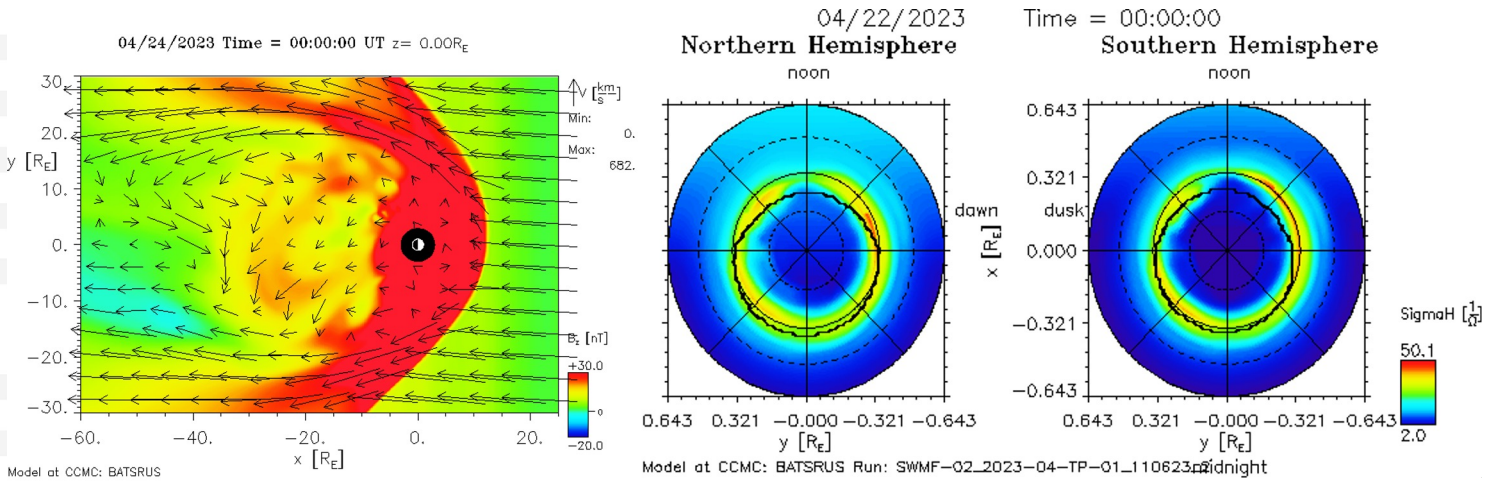
SW Density:	5.46000 n/cc
SW Temperature:	47839.00000 Kelvin
X Component of SW Velocity:	-368.80000 km/s
Y Component of SW Velocity:	14.30300 km/s
Z Component of SW Velocity:	-17.31600 km/s
IMF Bx:	0.90900 nT
IMF By:	1.74600 nT
IMF Bz:	-5.54500 nT
IMF IBI:	5.81000 nT
IMF Clock Angle:	162.52000 °

Magnetosphere Run Parameters:

GM solver:	Rusanov
GM limiter name:	mc3
GM limiter beta:	1
GM implicit:	explicit
GM Boris clight factor:	0.01

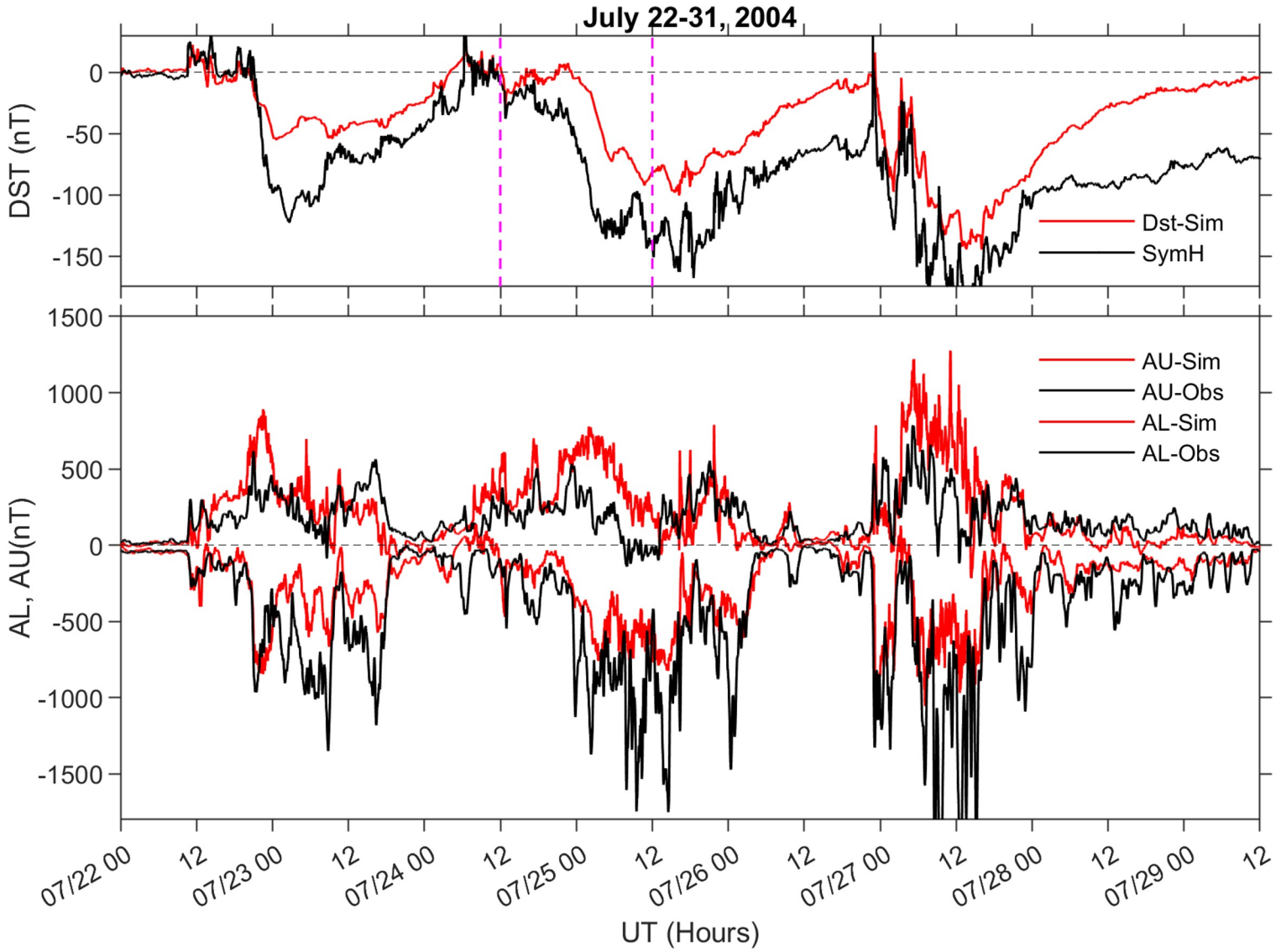
Sample Visualizations





SWMF-02_2004-07-TP-1: July 22-31, 2004

- **SymH: Observed** and **simulated** (tracking above observations in this case)
- **AU, AL: Observed** Supermag Auroral indices and **simulated indices** (mostly higher AU and weaker AL)



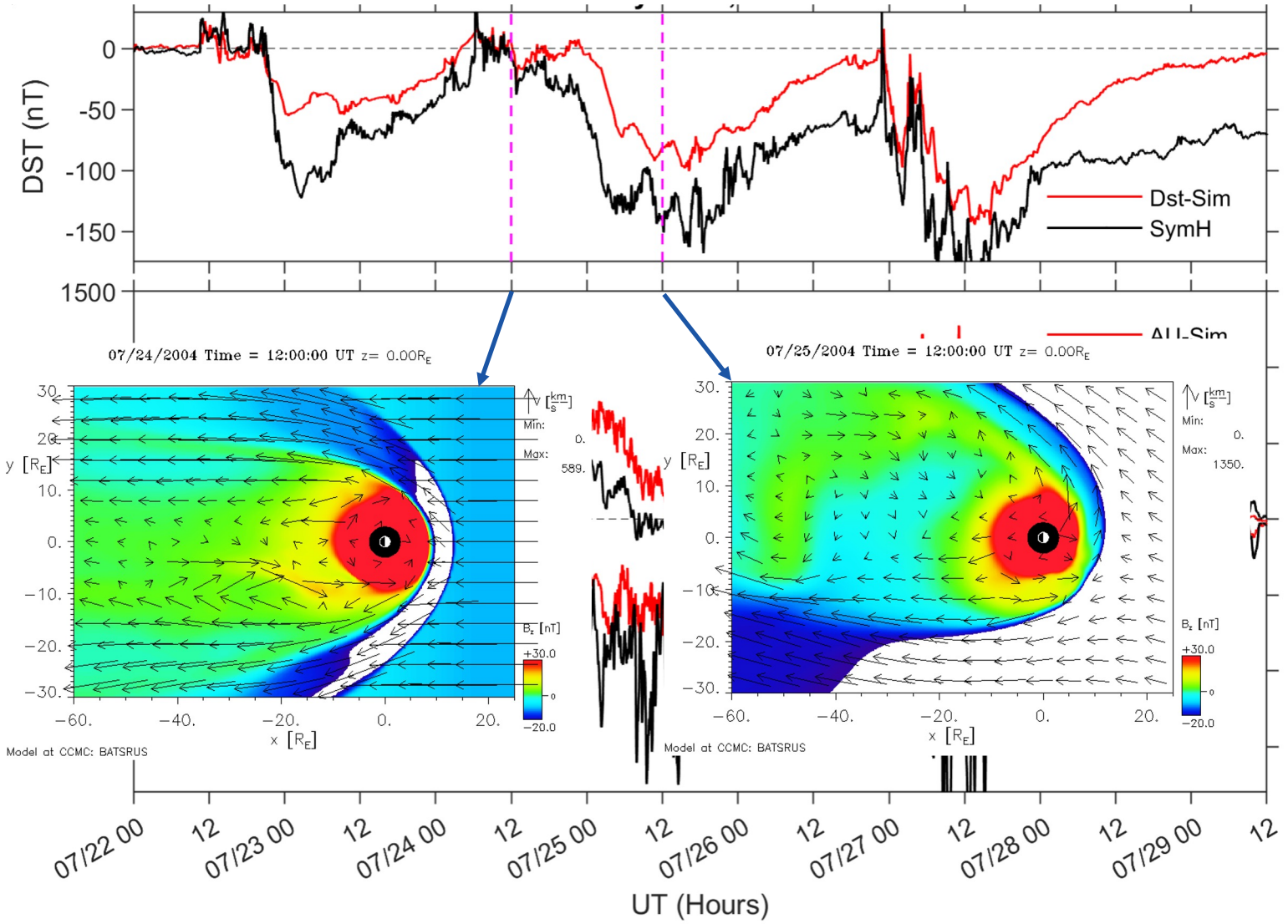
SWMF-02_2004-07-TP-1 (in preparation)

Low Mach event

- Testing modification of grid setup

Multi-storm events:

- How to define Storm onset, Main Phase and Recovery Phase for targeted model-data evaluation and skill scoring



Comprehensive Analysis of Models and Events based on Library Tools (CAMEL)

Goals of connecting event run library with CAMEL:

- Standardize model-data comparison studies by building applications in CAMEL
- Make comparisons available for anyone to review
- Easily extend model-data comparisons:
  - adding time periods using standardized simulation runs
  - add simulation of other models using similar standardized settings

Data Acquisition

- Began work on acquiring SuperMag data:
  - checking precision, value ranges, data errors
  - calculate time derivatives

CAMEL User Experience:

- Workflows for **single-event analysis** and **multi-event skill scoring** are being developed and implemented
- DeltaB (North, East, Down components)
- Time derivative (d/dt) of each component, magnitude of horizontal d/dt

Plans

- **Advanced visualization for model outputs:**
  - Present DeltaB results beyond lon-lat map of each component or time series for each separate station (-> CAMEL)
  - Efficient quick look movies for large magnetosphere runs (1000s of output times)
  - Kamodo (CCMC's Python data access and visualization library) support: RCM and Magnetometer outputs
- **Model driving:**
  - SWMF-IE -> GITM, (TIEGCM, WACCM-X, …)
- **More global magnetosphere models:**
  - MAGE 0.75 = GAMERA+REMIX+RCM has been delivered to the CCMC.
    The modelers are continuing to make improvements and
    we are testing the ROR interface, as well as post-processing of the results.
    We expect the model to be available to the community soon.
  - GUMICS-5 – install the MPI version of the model
- **Extend computational resources**