NOAA Space Weather Prediction Center: Operational Models

George Millward NOAA/SWPC, CU/CIRES

SWPC relies on forecasts from 3 large-scale time-dependent 3D computational models running operationally on NWS supercomputer WCOSS2

WSA-Enlil: 3D MHD model of the Heliosphere: 5 day forecast of Solar Wind at Earth (especially CMEs)
Key input to WSA-Enlil is CME direction and speed from operational coronagraphs

Three models providing short-term forecasts - driven directly by in-situ solar wind parameters measured at L1:

WAM-IPE: Whole Atmosphere Ionosphere Plasmasphere Electrodynamics Model:
Forecast of Thermospheric density and winds (satellite drag) and Ionospheric Electron Density (radio communication, GPS)

Geospace (SWMF): UMICH Space Weather Modeling Framework: MHD model of Earth's Geospace environment
Forecast of Geomagnetic activity (Kp and DST), Regional K, Regional ground magnetic disturbance (dB), induced ground geoelectric fields (GICs) – in development

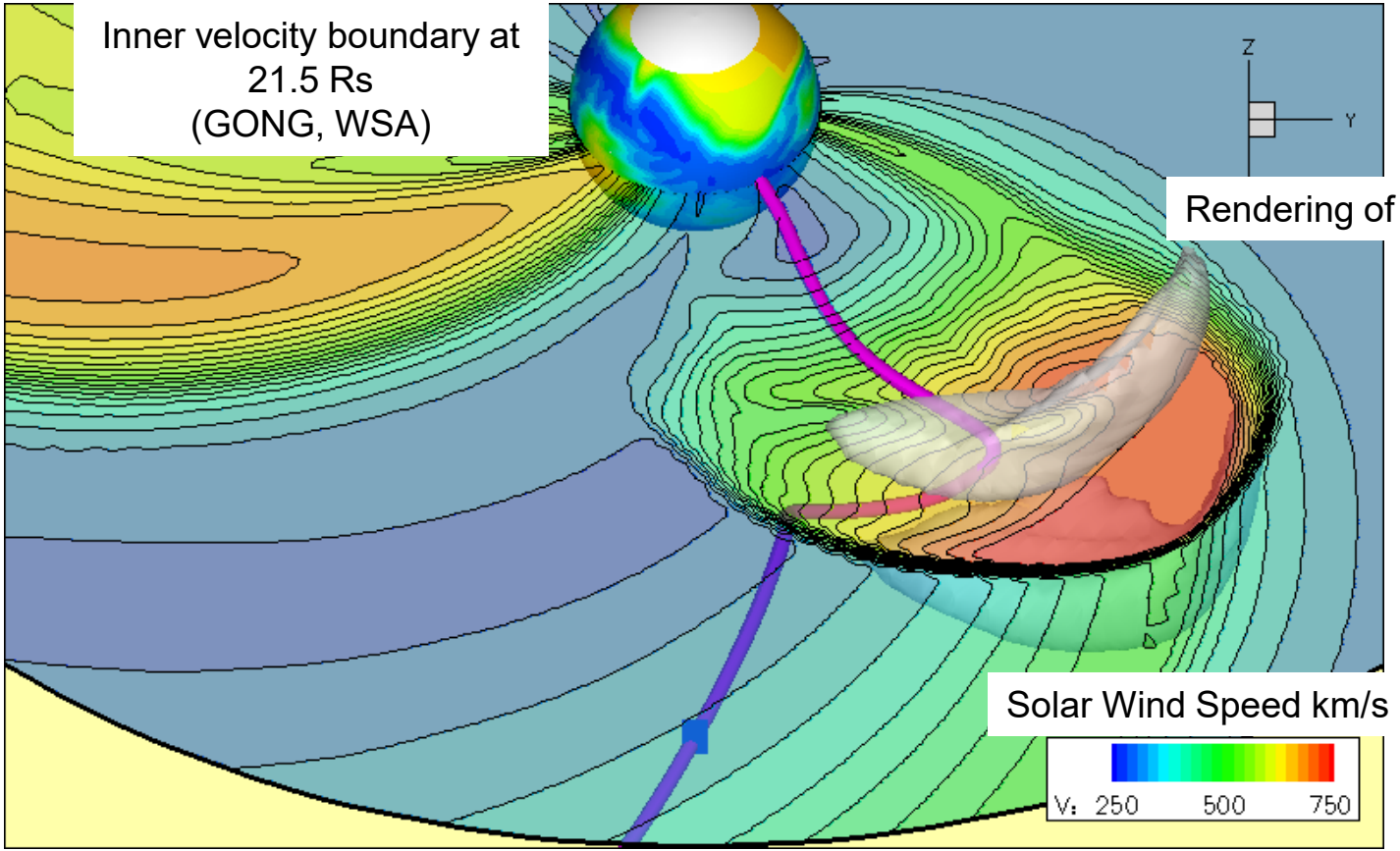
Ovation Model: Aurora Forecast:
Forecast of probability of being able to see Aurora (runs locally at SWPC)

Relativistic Electron Forecast Model (REFM): *uses ACE SWEPAM and GOES energetic electron measurements*

WSA-Enlil: 3D MHD model of the Heliosphere: 5 day forecast of Solar Wind at Earth (especially CMEs)

Key input to WSA-Enlil is CME direction and speed from operational coronagraphs

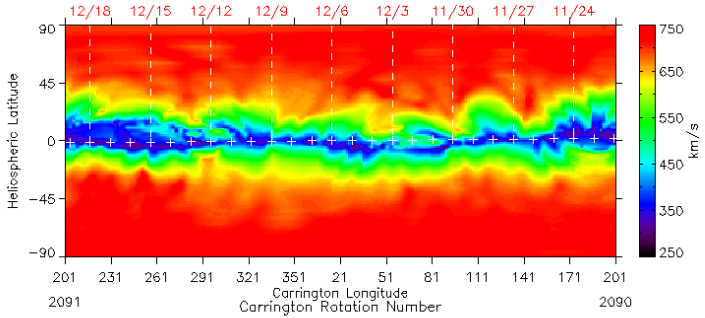
WSA-Enlil 3D MHD model of the Heliosphere



Enlil Model Inputs

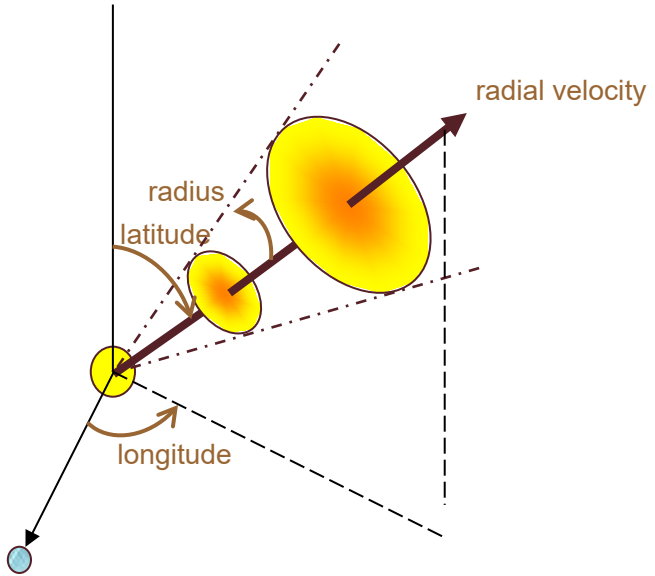
Solar Photospheric Magnetic Field (NSO, GONG)

WSA

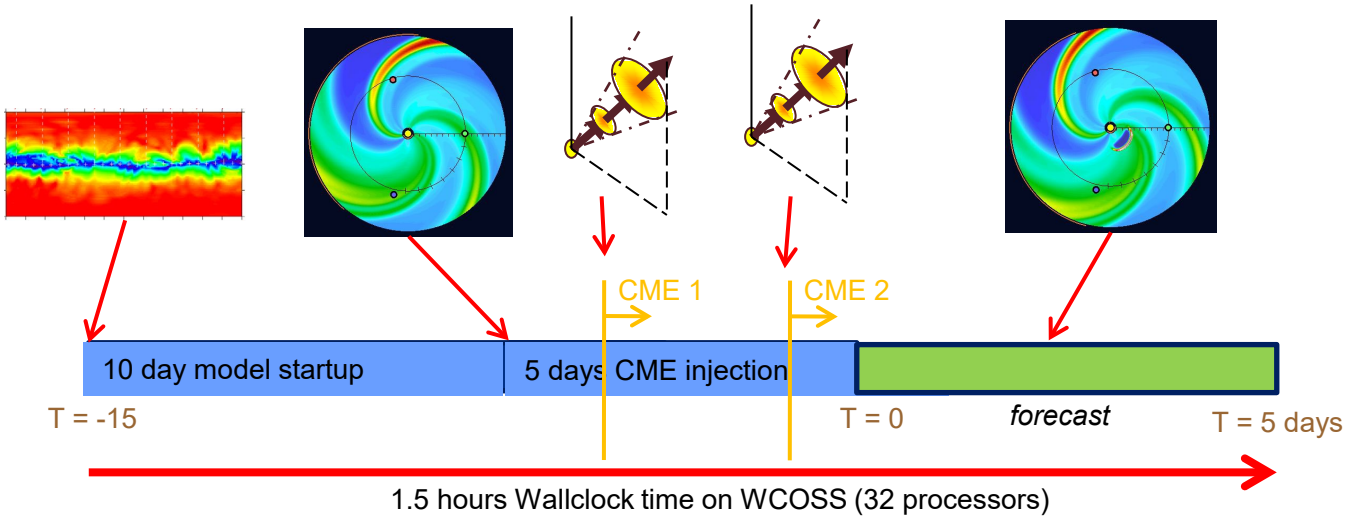


Global velocity and magnetic polarity. Steady, Co-rotating, Background Flow at 21.5Rs

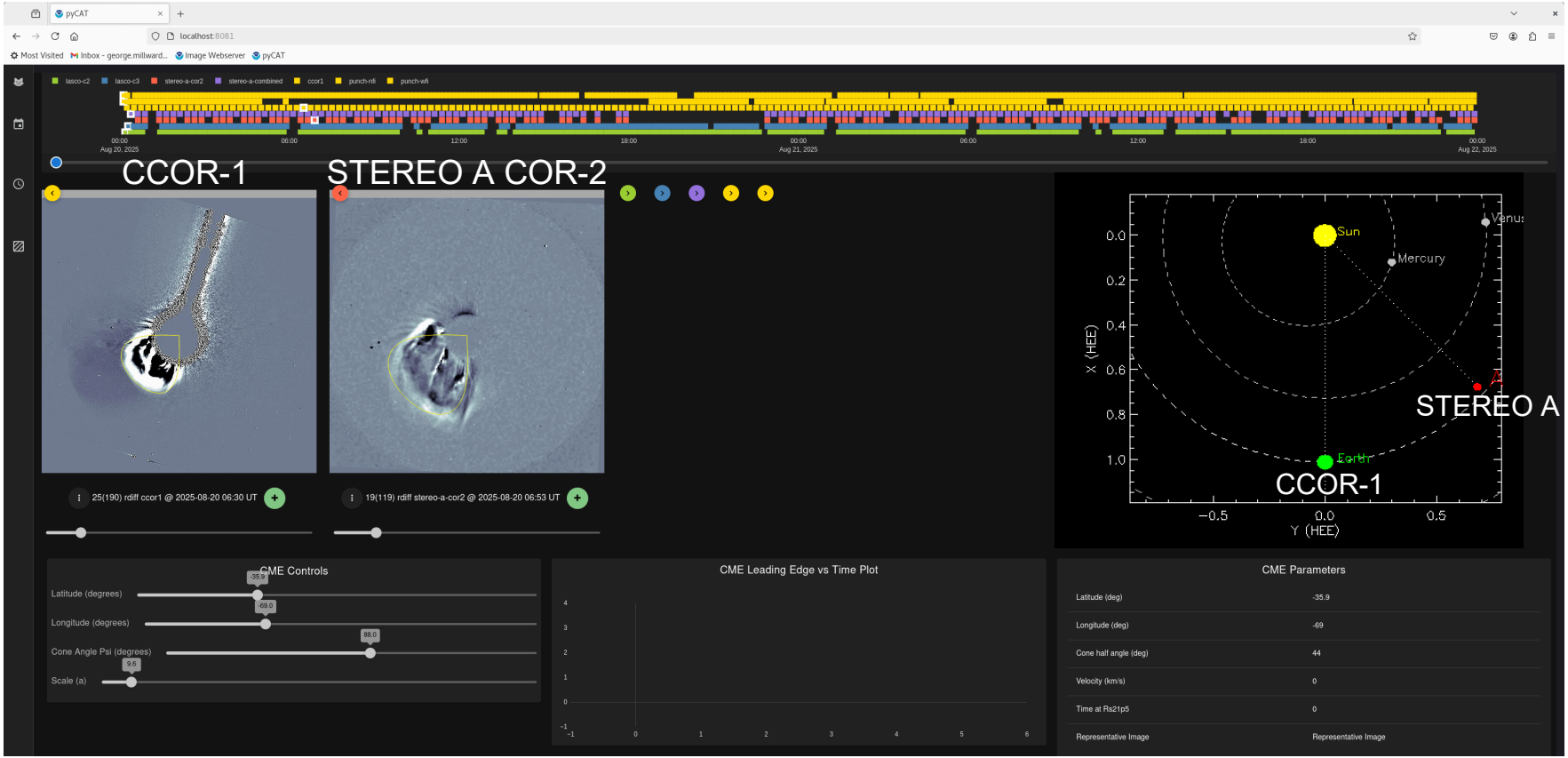
CME Parameterization

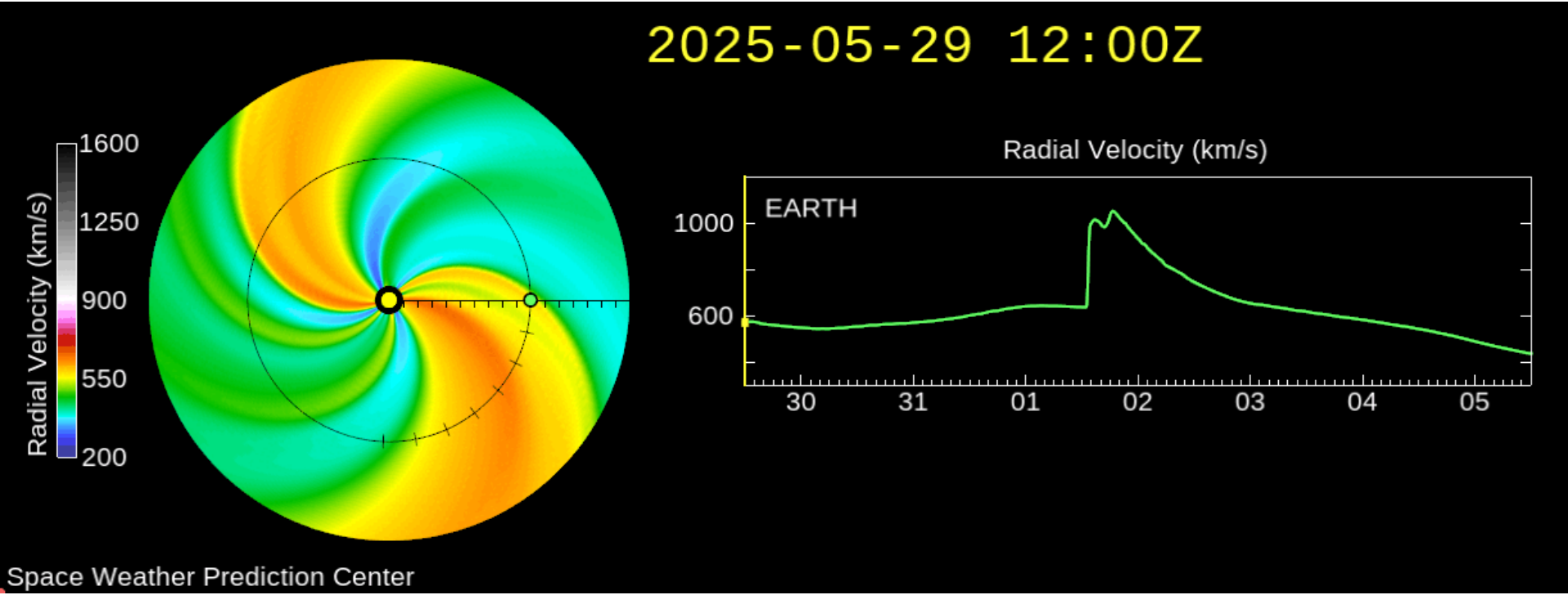


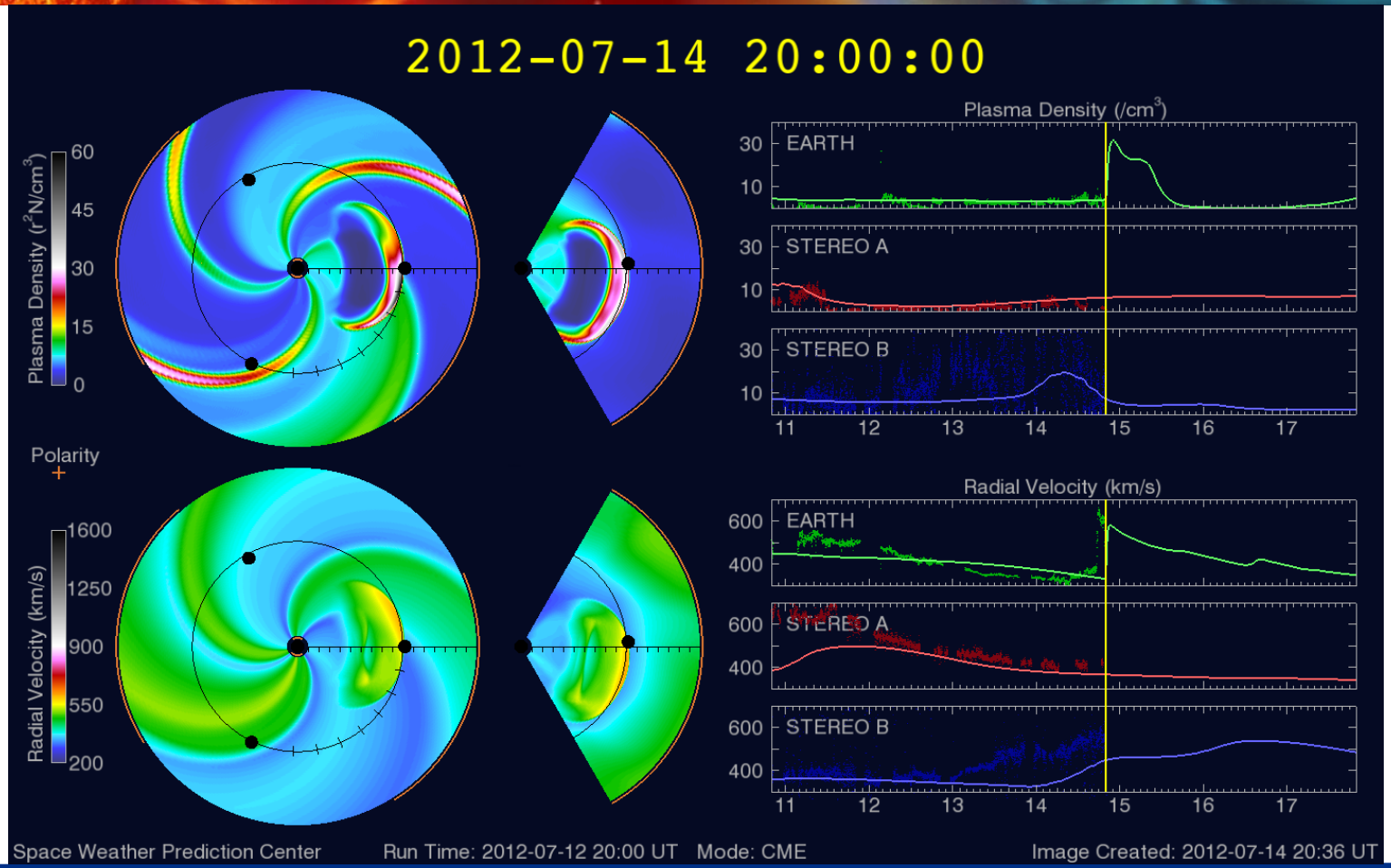
WSA-Enlil Run Schematic



CME Analysis Tool: PyCAT



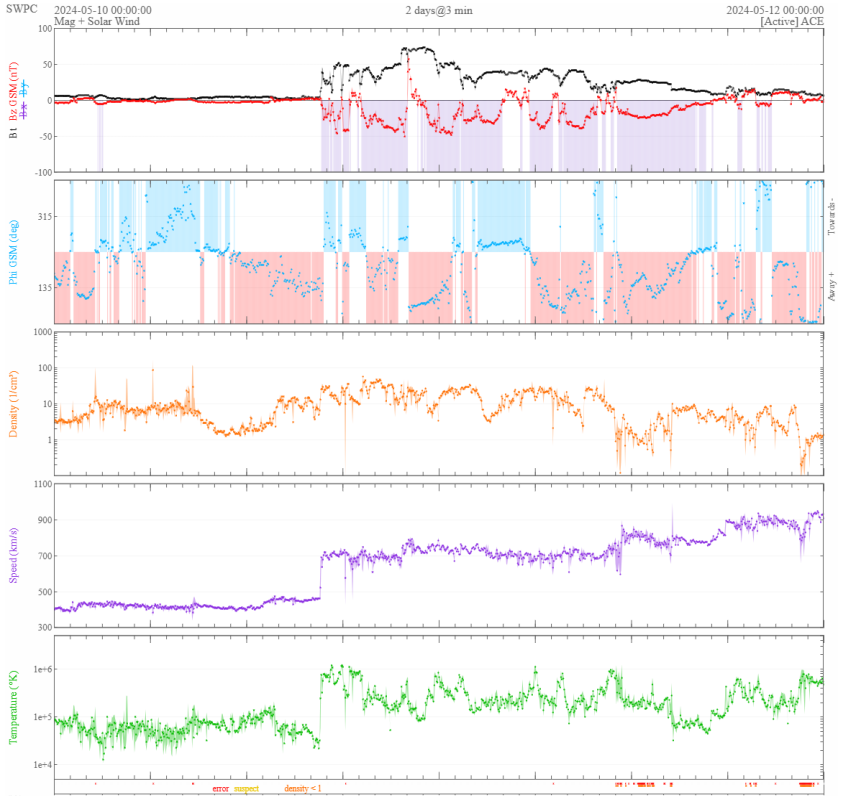

2025-05-29 12:00Z
Radial Velocity (km/s)
1600
1250
900
550
200
Radial Velocity (km/s)
EARTH
1000
600
30
31
01
02
03
04
05
Space Weather Prediction Center


2012-07-14 20:00:00
Plasma Density (r²N/cm³)
60
45
30
15
0
Plasma Density (/cm³)
EARTH
STEREO A
STEREO B
30
10
11
12
13
14
15
16
17
Polarity
+
Radial Velocity (km/s)
1600
1250
900
550
200
600
400
Space Weather Prediction Center
Run Time: 2012-07-12 20:00 UT
Mode: CME
Image Created: 2012-07-14 20:36 UT

WAM-IPE: Whole Atmosphere Ionosphere Plasmasphere Electrodynamics Model:

Forecast of Thermospheric density and winds (satellite drag) and Ionospheric Electron Density (radio communication, GPS)

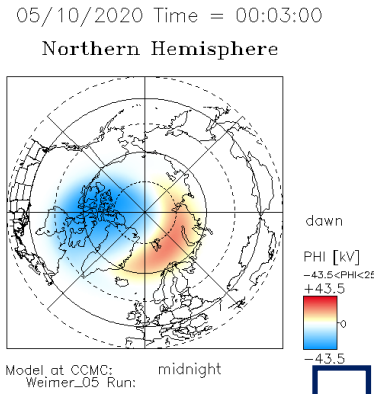
Real-time Solar Wind at L1 (ACE/DSCOVR)



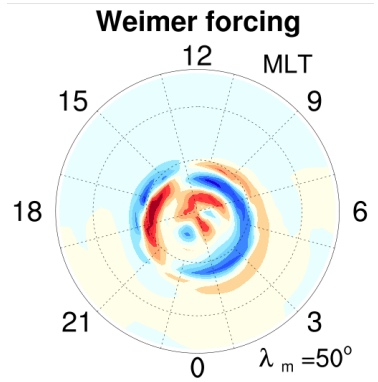
L1 data propagated forward in time (ballistic) ~ 40 minutes

Driver at Earth … Weimer empirical model

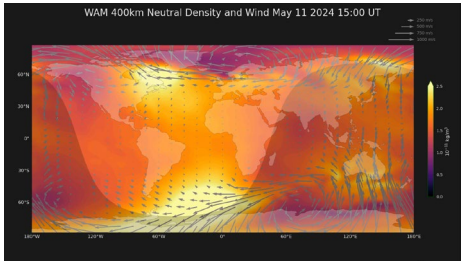
Electric Potential



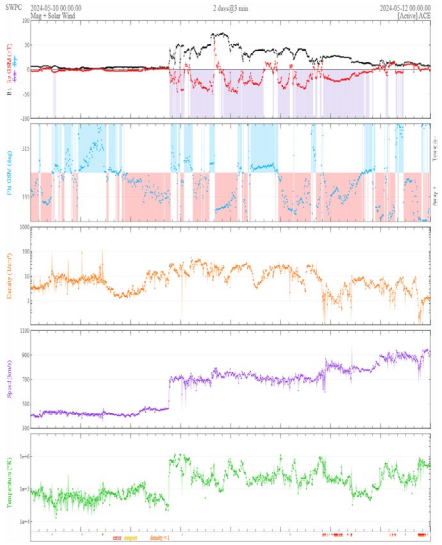
Radial Current Density

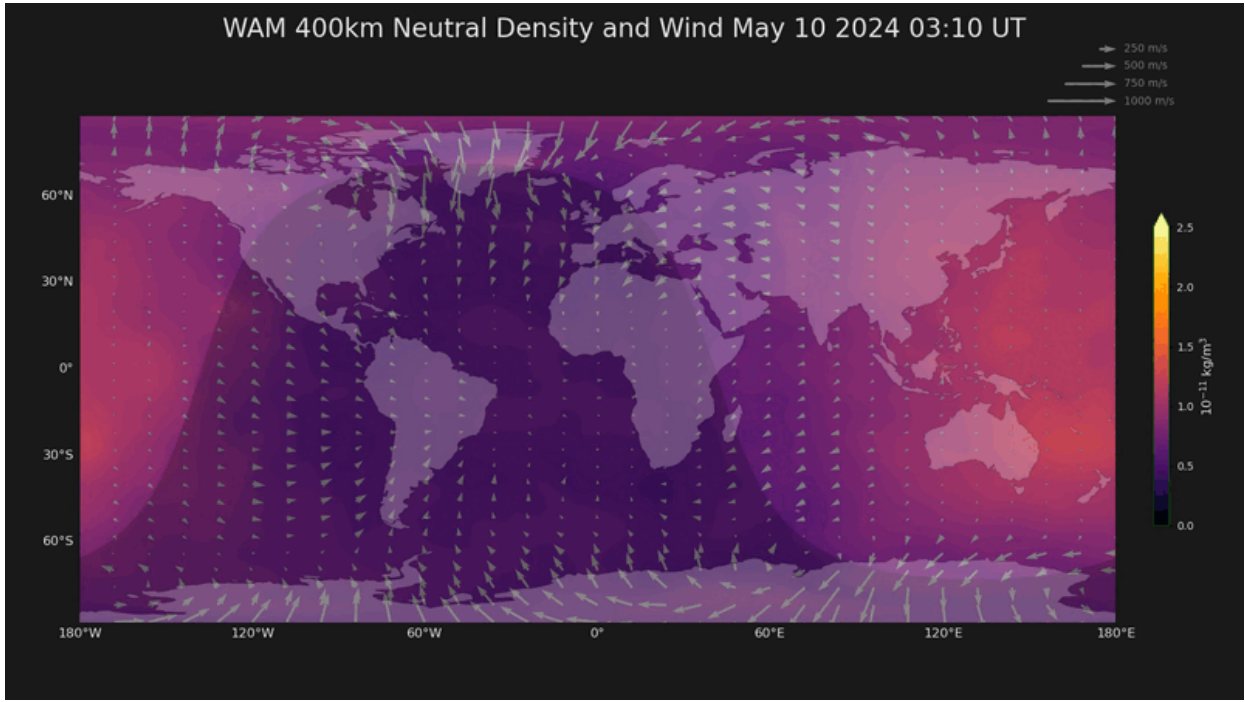


Whole Atmosphere – Ionosphere Plasmasphere Electrodynamics model (WAM-IPE)

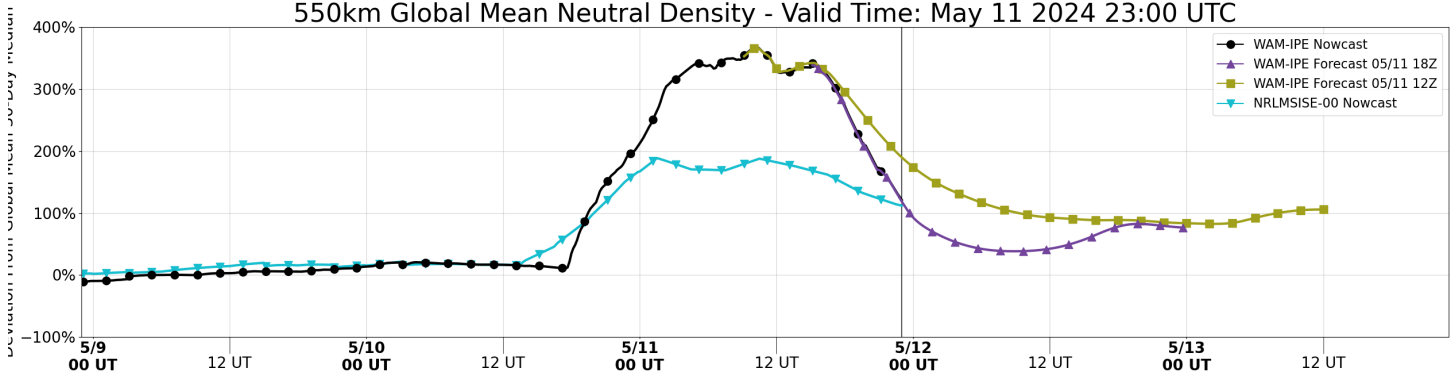


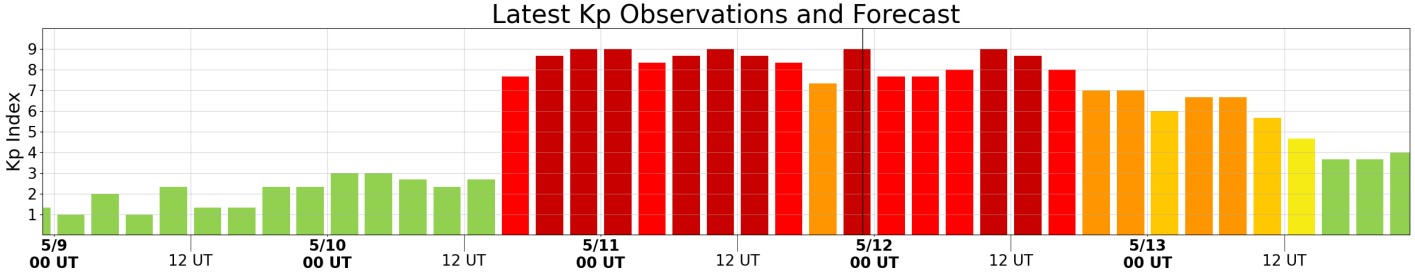
WAM-IPE (Whole Atmosphere and Ionosphere Plasmasphere Electrodynamics Model) – Short-term Thermospheric Forecast

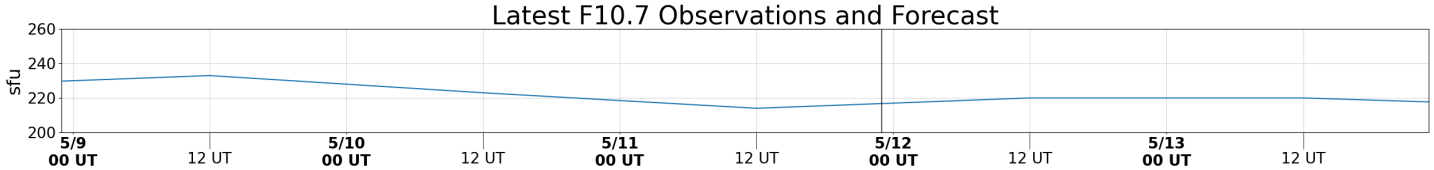




https://www.swpc.noaa.gov/products/wam-ipe

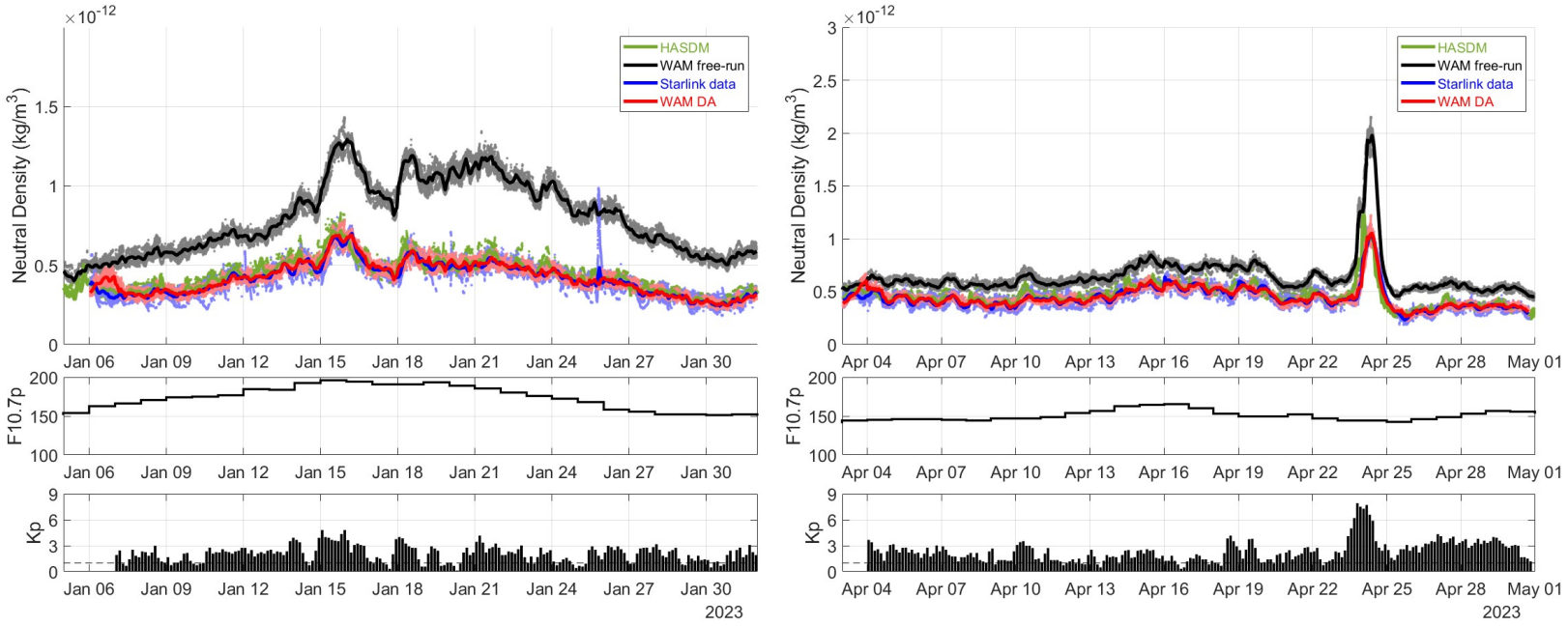






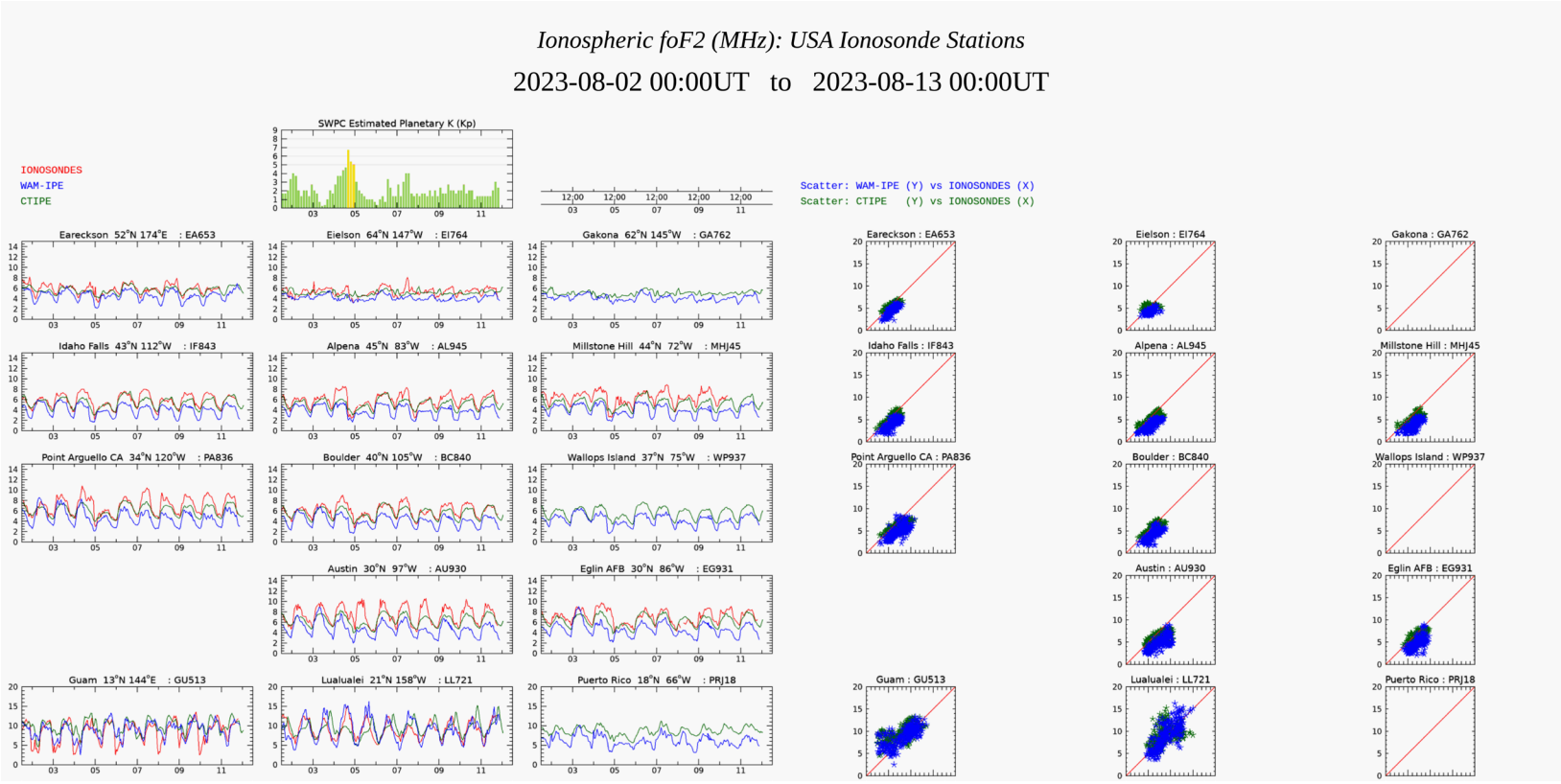
Space Weather Prediction Center - EXPERIMENTAL PRODUCT

WAM with data assimilation – comparison with SpaceX Starlink



WAM-IPE - Short-term Ionospheric forecast:

Ionospheric foF2/MHz (Peak electron density) at USA Ionosonde Stations – foF2 denotes the maximum frequency for “over the horizon” radio communication (ie, Transatlantic commercial aircraft, Military etc.)



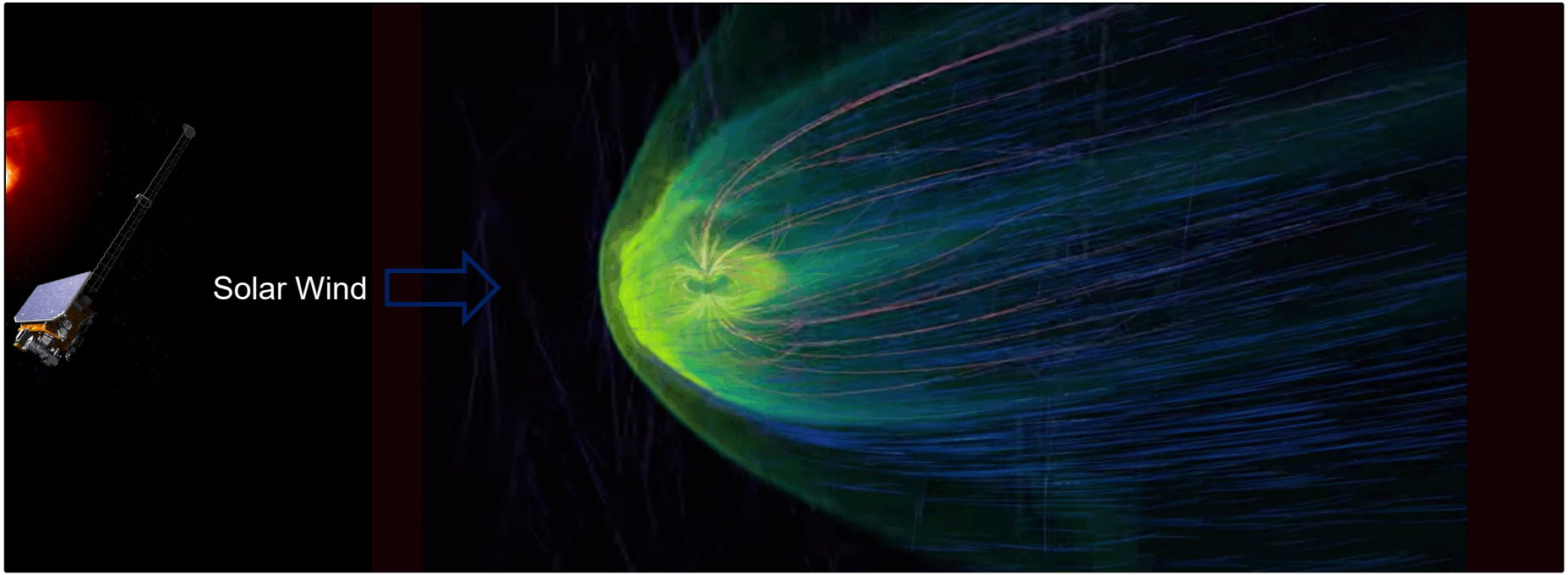
Geospace (SWMF): UMICH Space Weather Modeling Framework: MHD model of Earth's Geospace environment

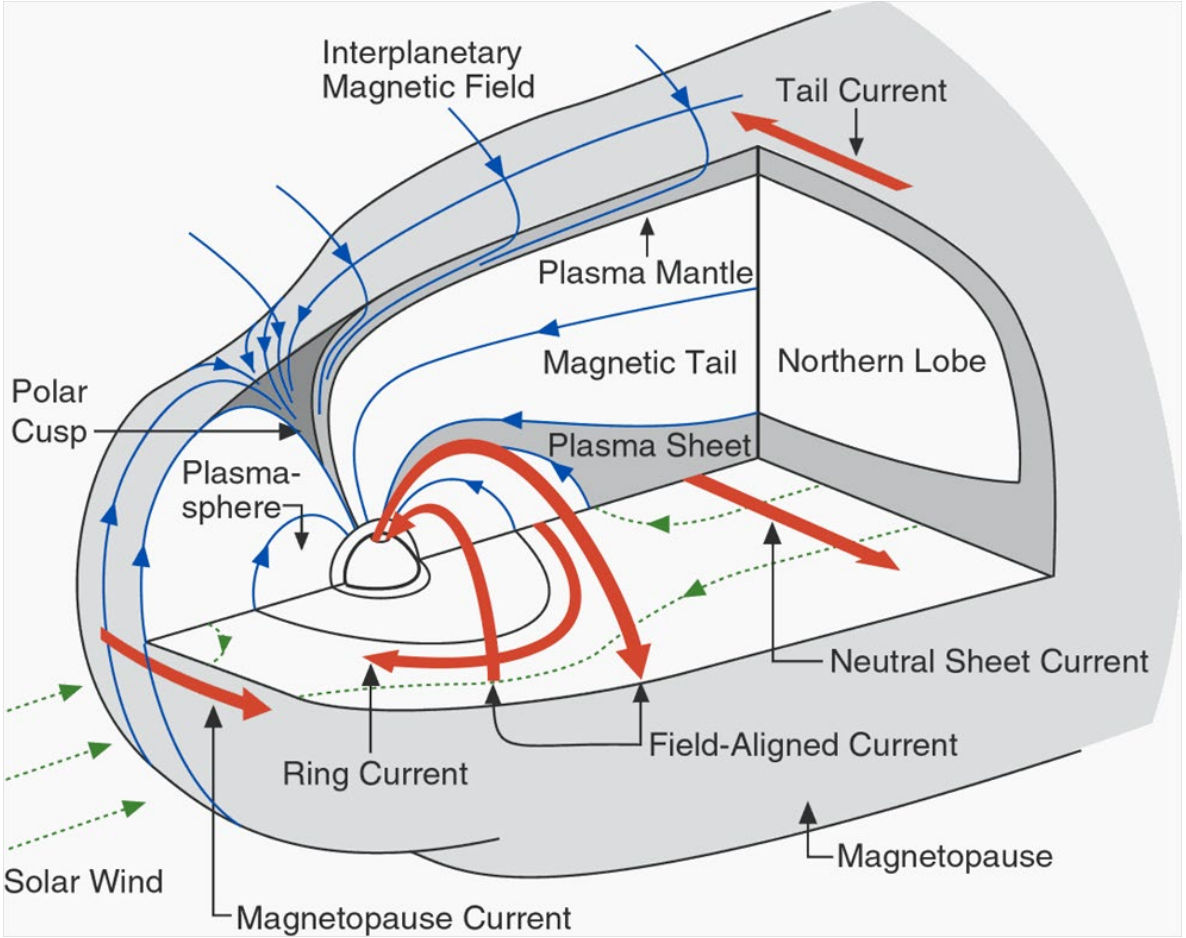
Forecast of Geomagnetic activity (Kp and DST), Regional K, Regional ground magnetic disturbance (dB), induced ground geoelectric fields (GICs) – in development

What is Geospace? …

the environment around the Earth where the Solar Wind interacts with Earth's magnetic field.

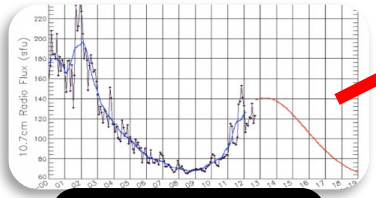
(render from the SWFO-L1 promotional movie)



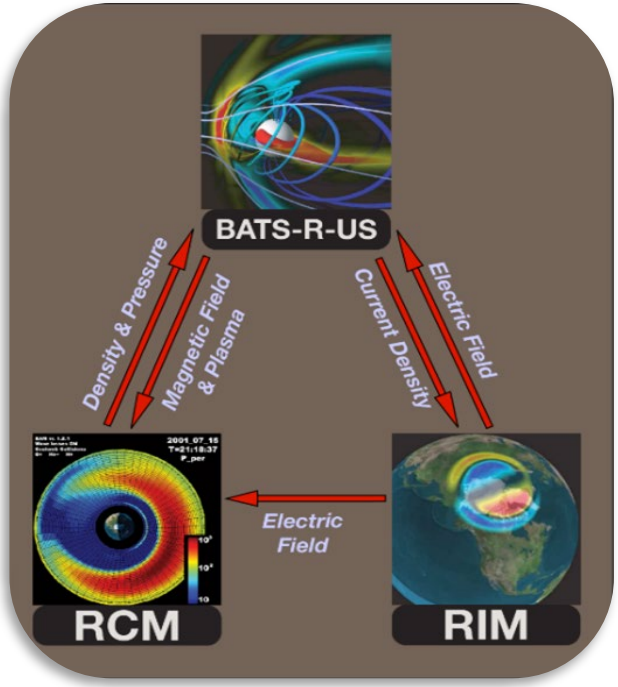

Interplanetary
Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Northern Lobe
Polar
Cusp
Plasma Sheet
Plasma-
sphere
Neutral Sheet Current
Field-Aligned Current
Ring Current
Magnetopause
Solar Wind
Magnetopause Current

Operational SWMF

Solar Wind Data: V, n, T, B



F10.7 Radio Flux



Forecast Products

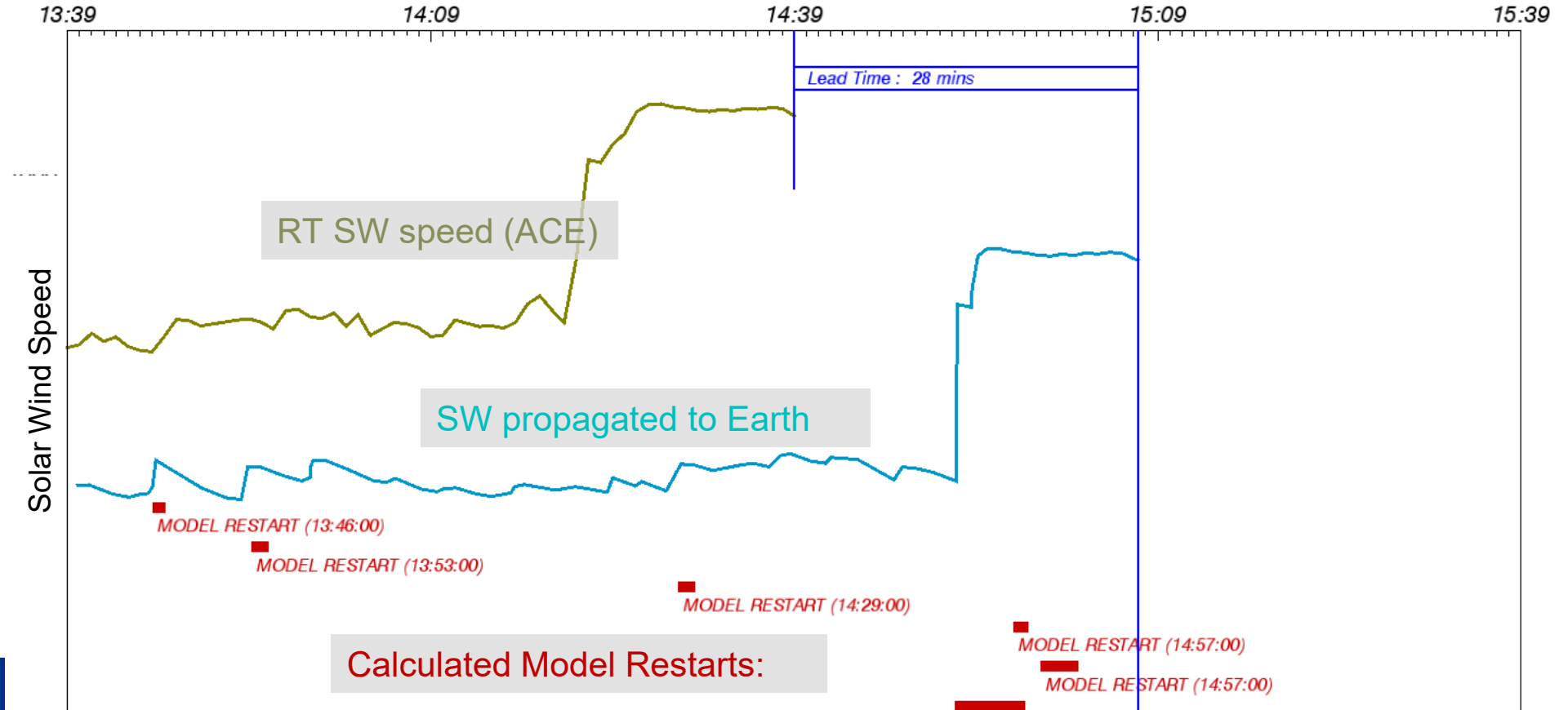
Delta B and dB/dt

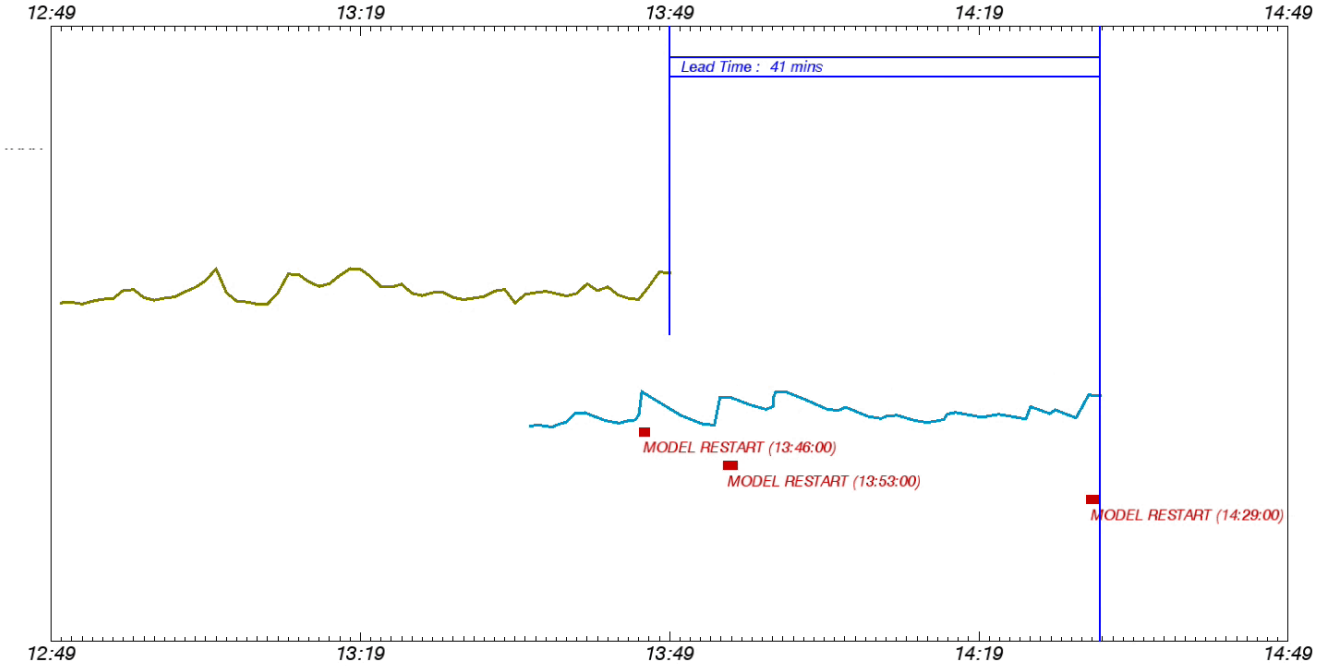
Regional K

Magnetosphere visualization

Params for input into Geoelectric model and Ionospheric models

Real-time input data [t] and SWMF Control Script

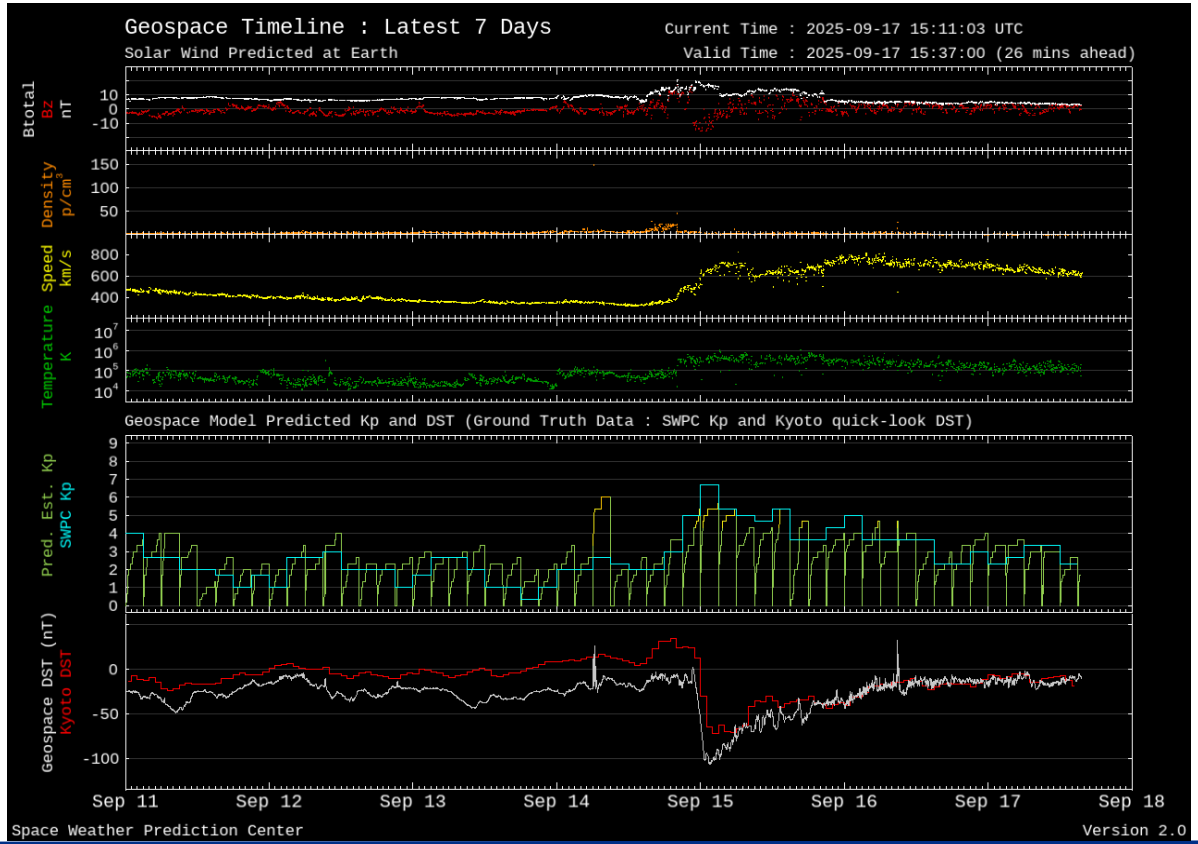





```
Wallclock  : 13:49:00
Propagated : 14:30:46
SWMF : NORMAL (SOLARWIND DECREASING)
Model Run from 14:29:39 to 14:30:46 (Timestep :  66 s)
SW speed (t-1) -> (t) :   600.20 ->   598.53
```

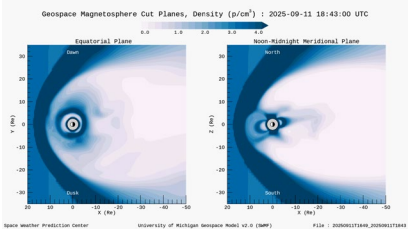
Geospace (SWMF): Real-time solar wind input, Model forecast of Kp and DST

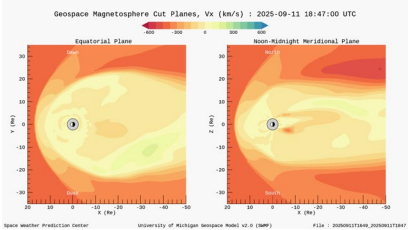
Solar Wind parameters propagated forwards in time to provide ~ 45 minutes forecast lead time

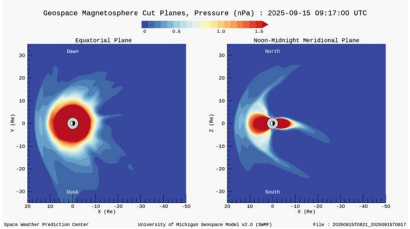


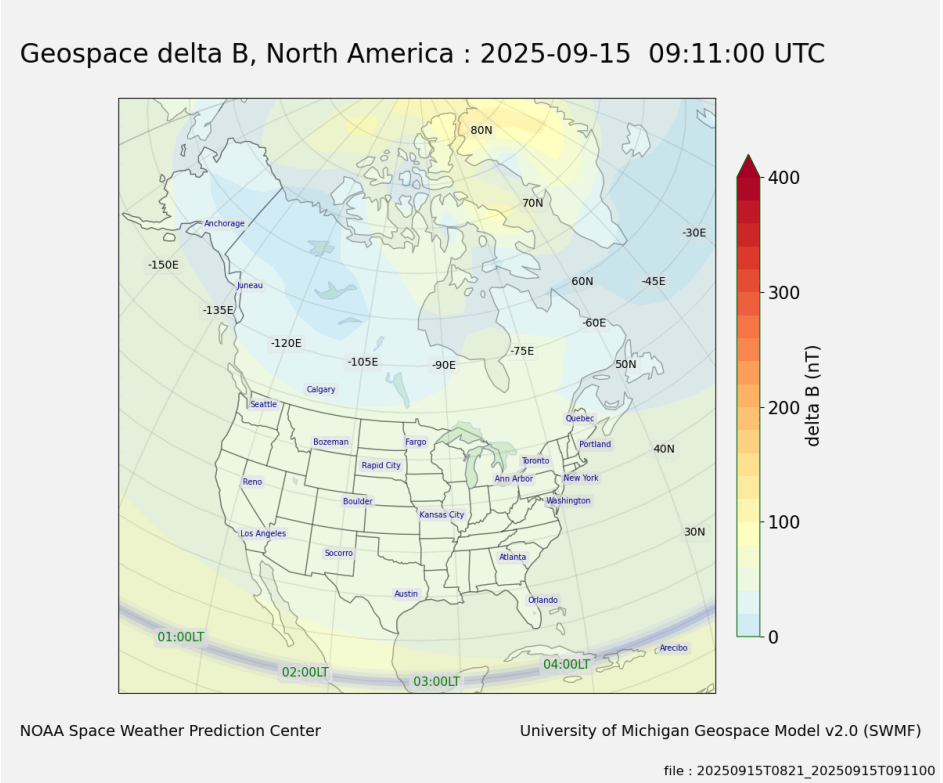
Geospace (SWMF): Magnetospheric cut-planes, Ground magnetic perturbation (dB) over North America

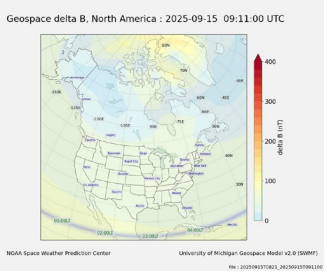
Mild to moderate Geomagnetic storming last weekend

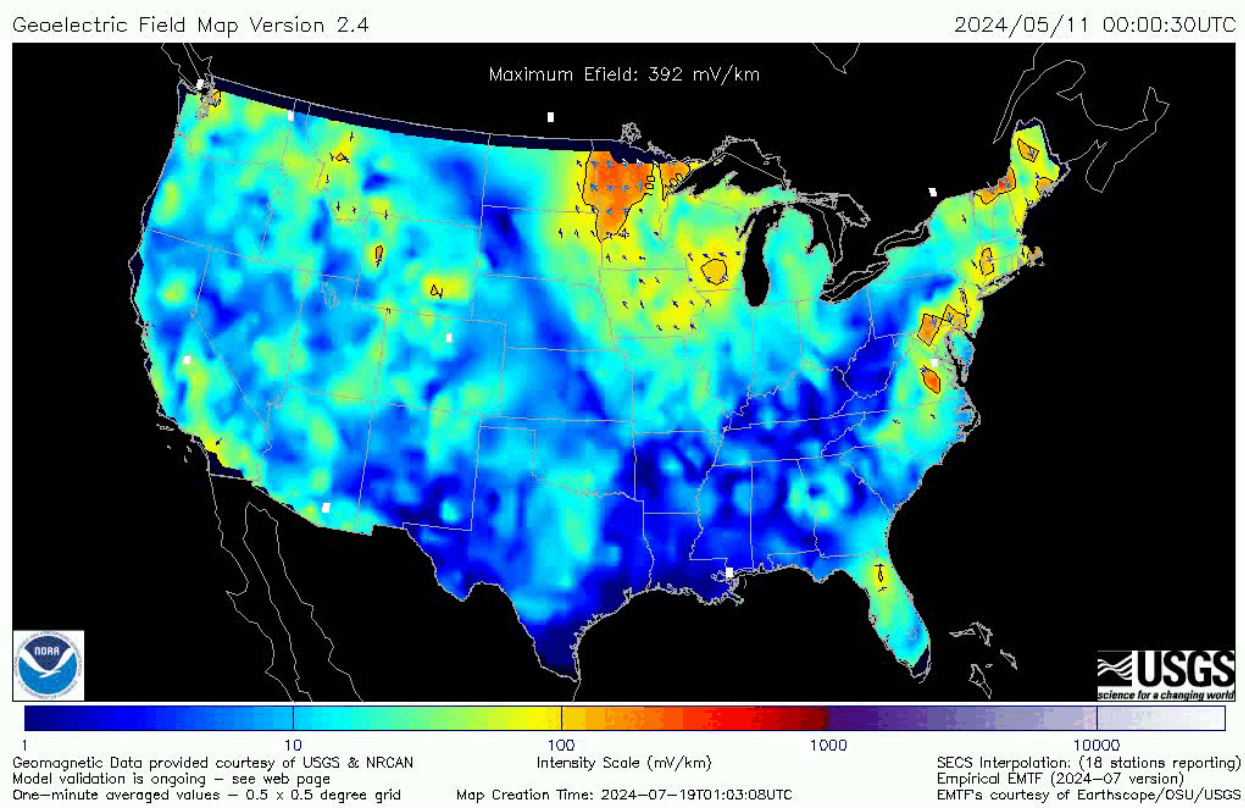




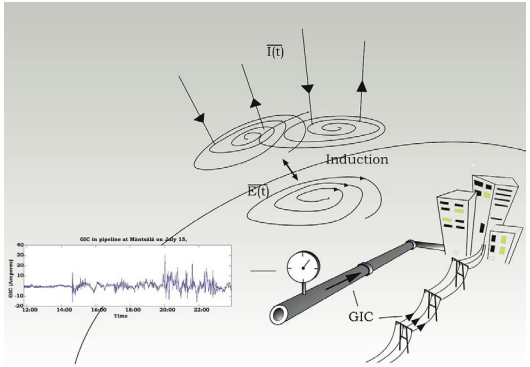


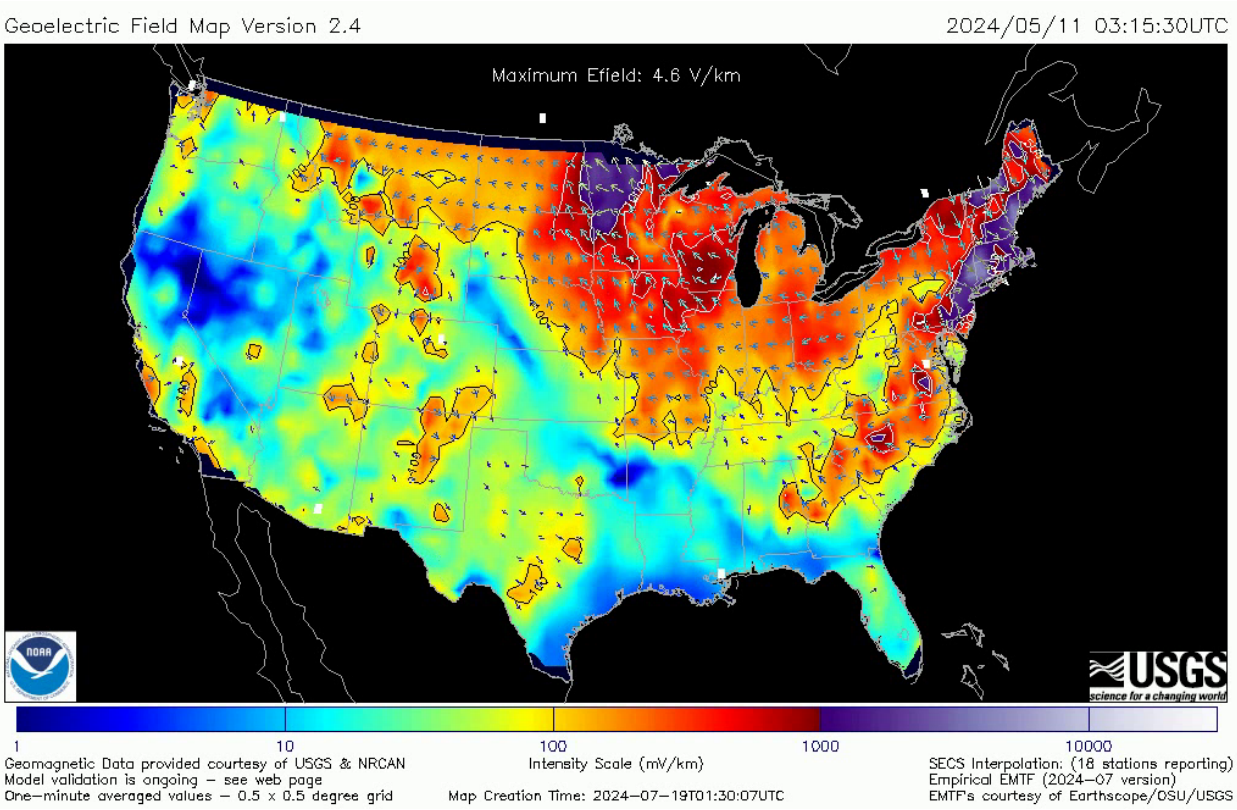



Geospace delta B, North America : 2025-09-15 09:11:00 UTC
400
300
200
100
0
delta B (nT)
NOAA Space Weather Prediction Center
University of Michigan Geospace Model v2.0 (SWMF)


Geoelectric Field Map Version 2.4
2024/05/11 00:00:30UTC
Maximum Efield: 392 mV/km
NOAA
USGS
science for a changing world
1
10
100
1000
10000
Geomagnetic Data provided courtesy of USGS & NRCAN
Model validation is ongoing – see web page
One-minute averaged values – 0.5 x 0.5 degree grid
Intensity Scale (mV/km)
Map Creation Time: 2024-07-19T01:03:08UTC
SECS Interpolation: (18 stations reporting)
Empirical EMTF (2024-07 version)
EMTF's courtesy of Earthscope/OSU/USGS

Ground Induced Currents (GICs)



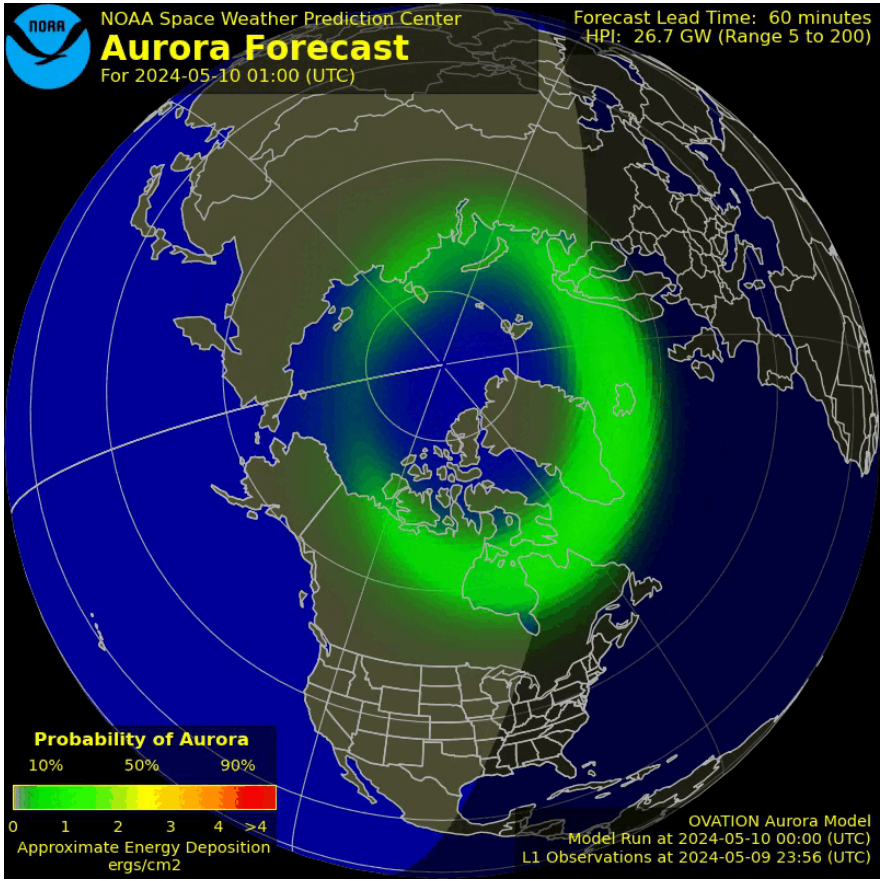


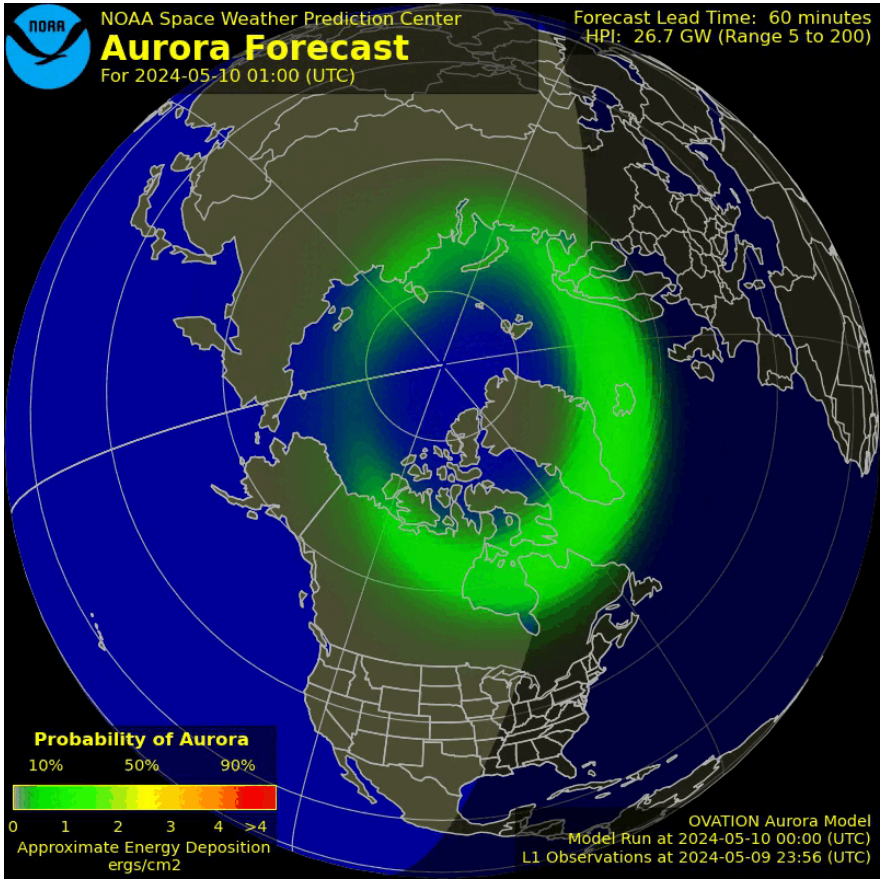
Ovation Model: Aurora Forecast:

Forecast of probability of being able to see Aurora (runs locally at SWPC)

OVATION Aurora Forecast

- Empirical auroral intensity model developed at Johns Hopkins University Applied Physics Laboratory.
- Takes input from solar wind velocity and the interplanetary magnetic field (IMF), measured at L1
- Calculates three types of electron precipitation and proton precipitation, which strongly correlate with auroral activity
- 70% of the web-traffic to SWPC




NOAA Space Weather Prediction Center
Aurora Forecast
For 2024-05-10 01:00 (UTC)
Forecast Lead Time: 60 minutes
HPI: 26.7 GW (Range 5 to 200)
Probability of Aurora
10%
50%
90%
0
1
2
3
4
>4
Approximate Energy Deposition
ergs/cm2
OVATION Aurora Model
Model Run at 2024-05-10 00:00 (UTC)
L1 Observations at 2024-05-09 23:56 (UTC)

The End