Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting

Dusan Odstrcil (PI), Lan Jian (Co-I), and Janet G. Luhmann (Co-I)

supported by:
NASA/CCMC (L Mays, P. MacNeice, A. Taktakishvili)
collaboration with: NOAA/SWPC & EU/HELCATS

Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting

- Improvements in the WSA-ENLIL-Cone modeling system (*Dusan Odstrcil*)
- Verification and Validation of the updated WSA-ENLIL-Cone modeling system (*Lan Jian*)
- Modeling/predicting solar energetic particle (SEP) events using SEPMOD with ENLIL (*Janet Luhmann/Christina Lee*)
- Q & A

Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting: Improvements in the WSA-ENLIL-Cone Modeling System

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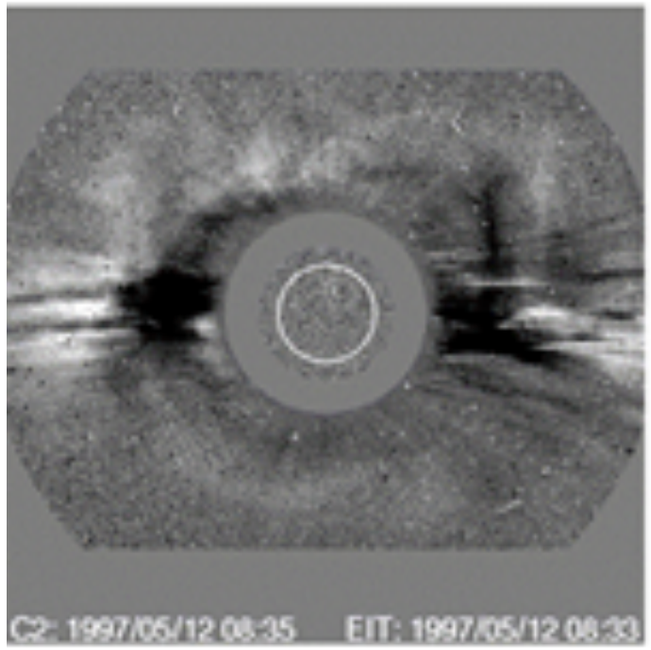
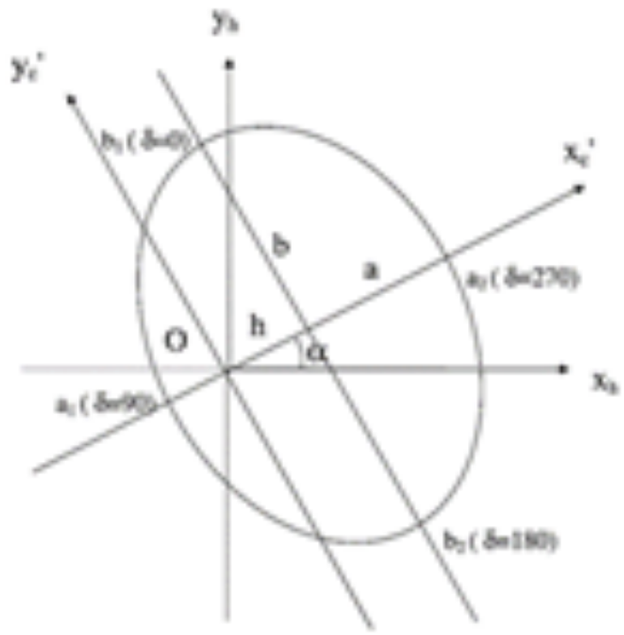
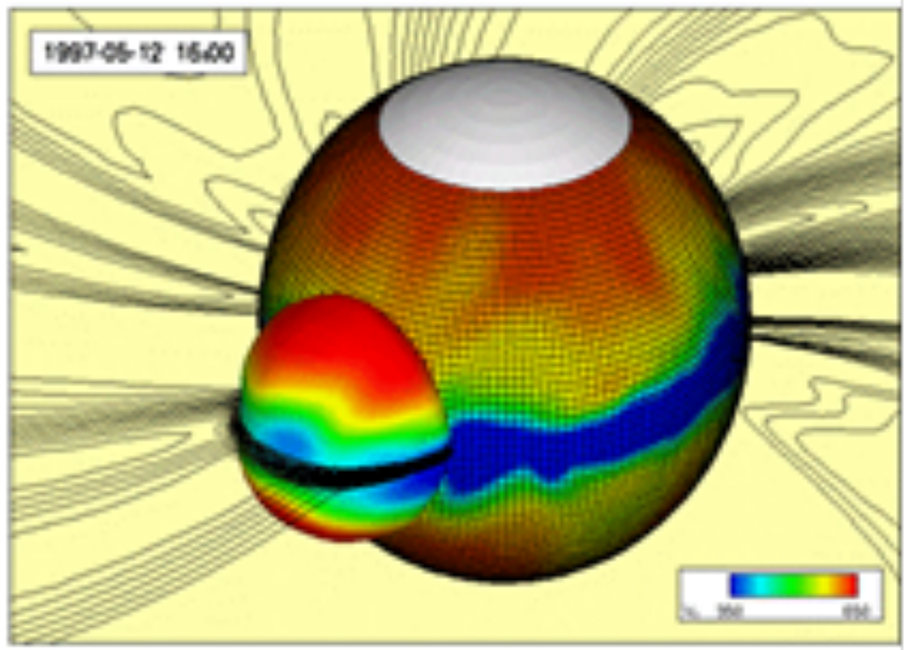
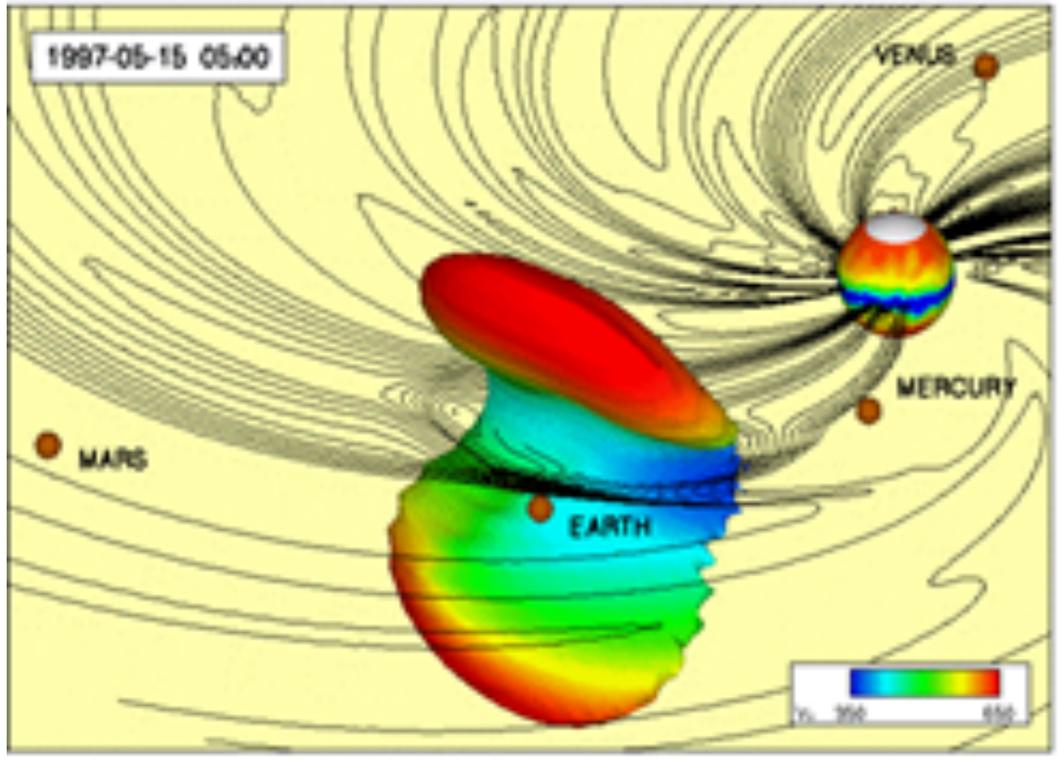
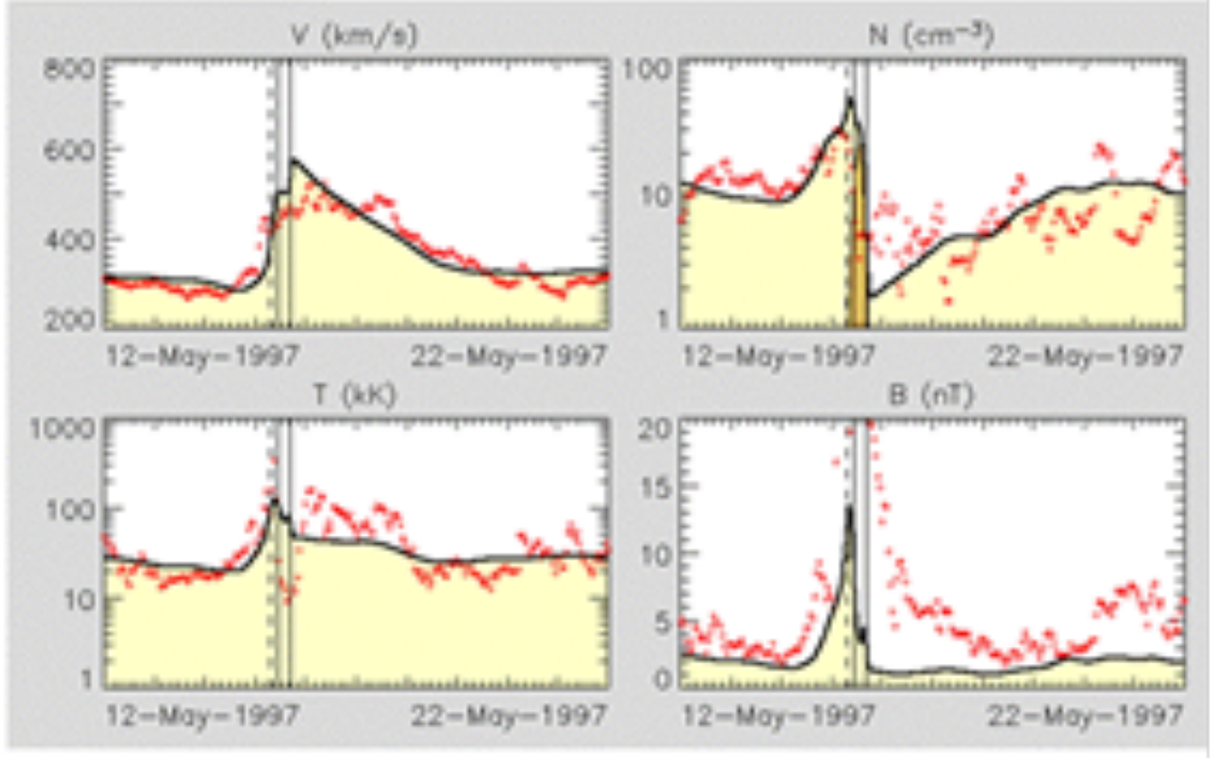
WSA-ENLIL-Cone Modeling System — Heliospheric Space Weather





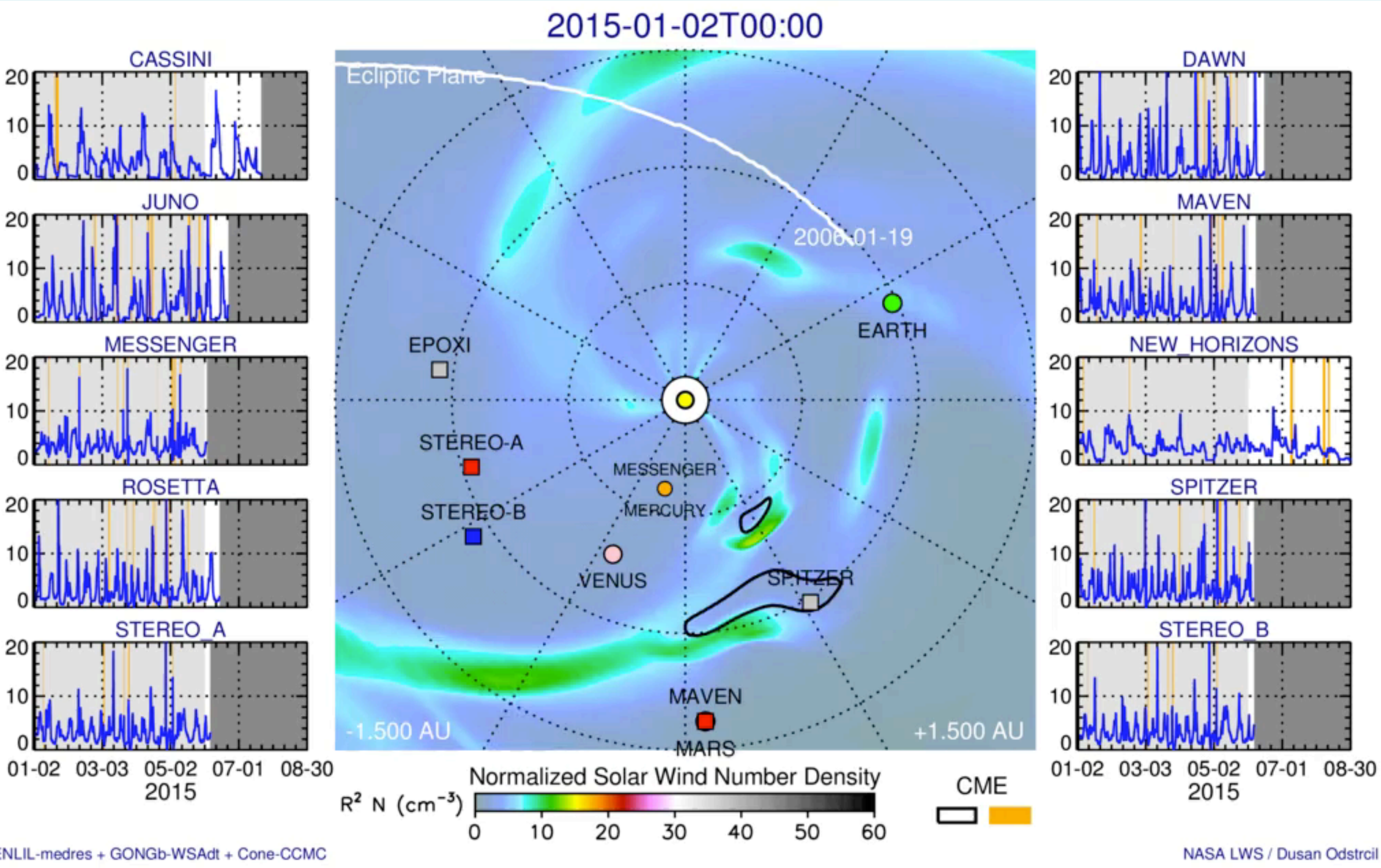






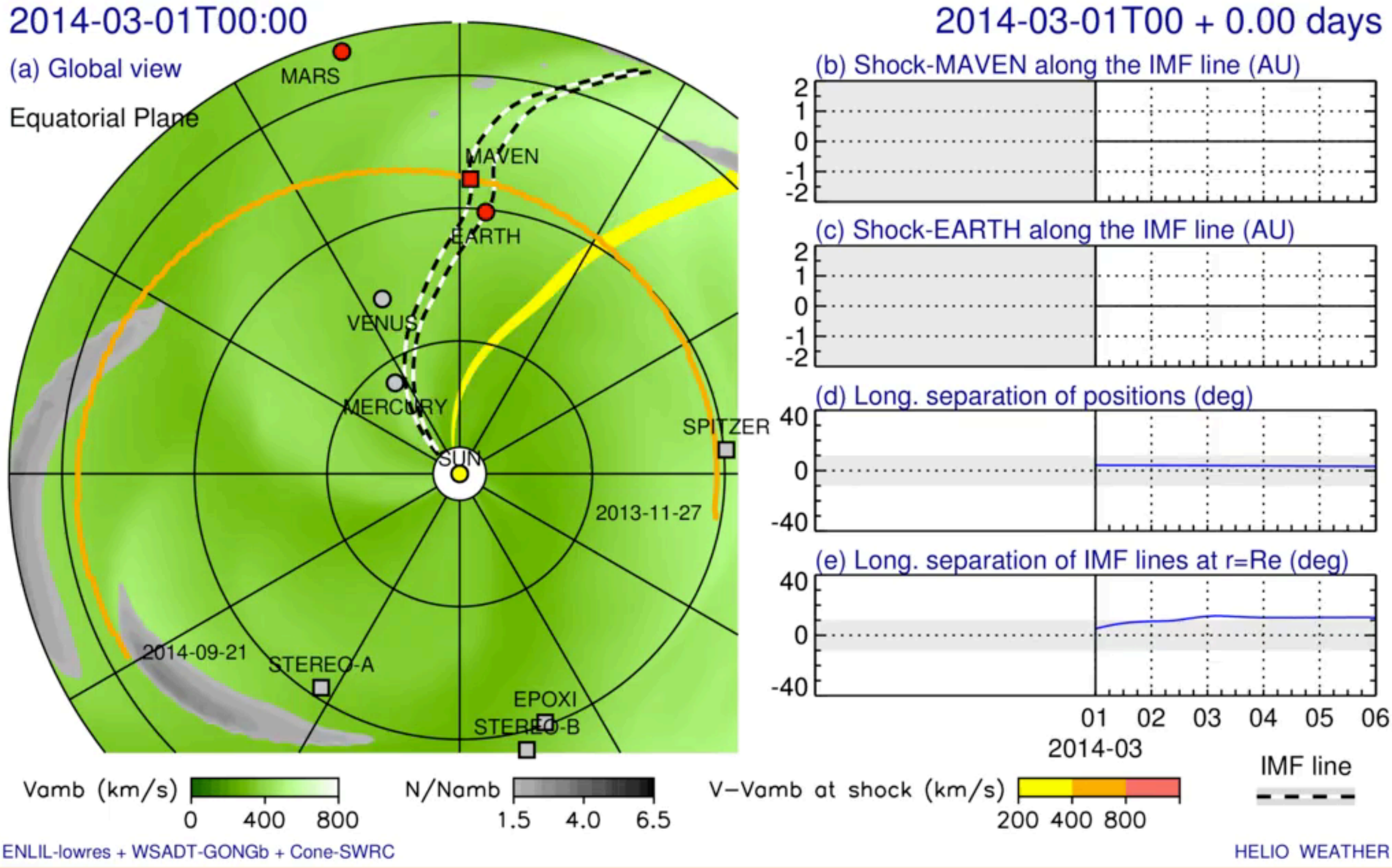
- Observationally driven, near-real time, “hybrid” modeling system for heliospheric space weather
- Routine simulation of co-rotating streams & CMEs, event-by-event, much faster than real-time
- Supported by NSF.CISN and implemented at NASA/CCMC & NOAA/SWPC

WSA-ENLIL-Cone — Heliospheric Predictions for NASA Missions



- All CMEs (>500 km/s) fitted by CCMC in past 8 months are used for 4-months prediction at NH
- History (light-grey background) and prediction (white background) for heliospheric missions
- Can be used for mission planning and operational support at NASA/CCMC

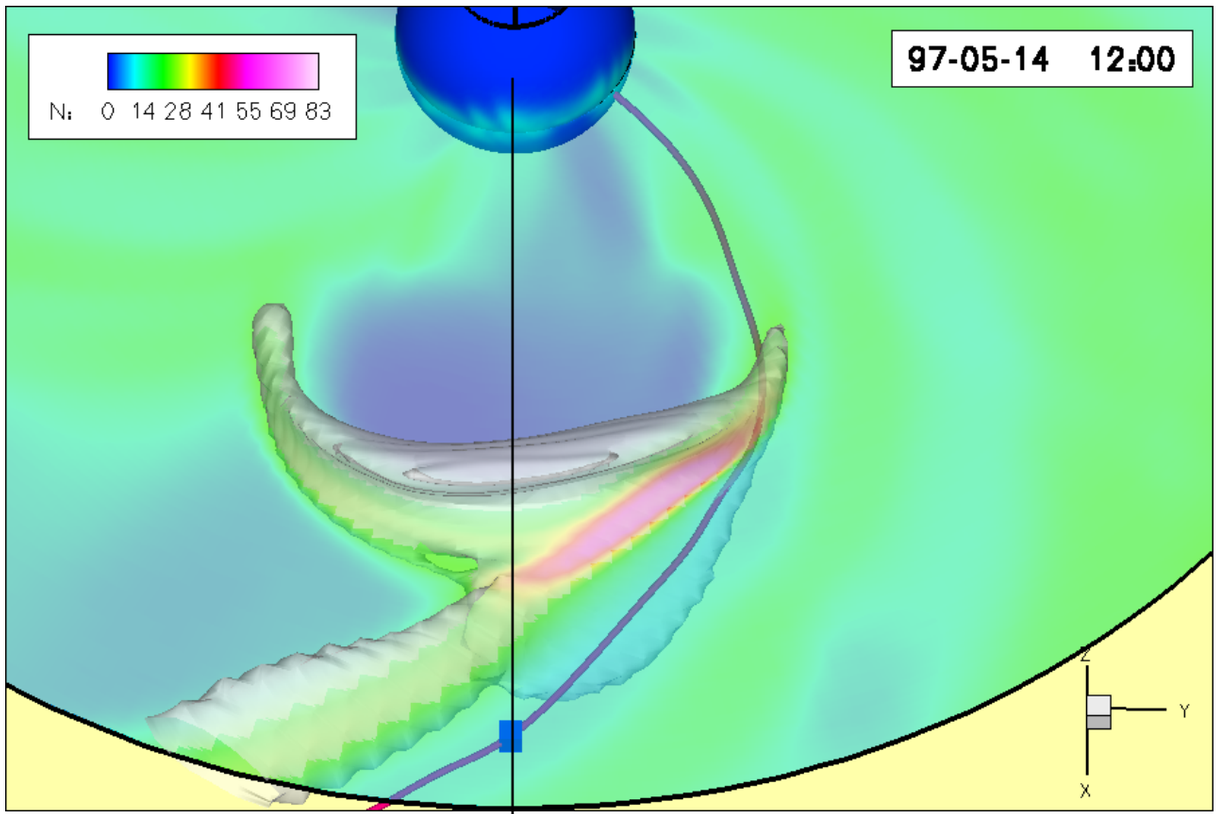
MAVEN Cruise to Mars — Predicted Shock-SEP Alerts



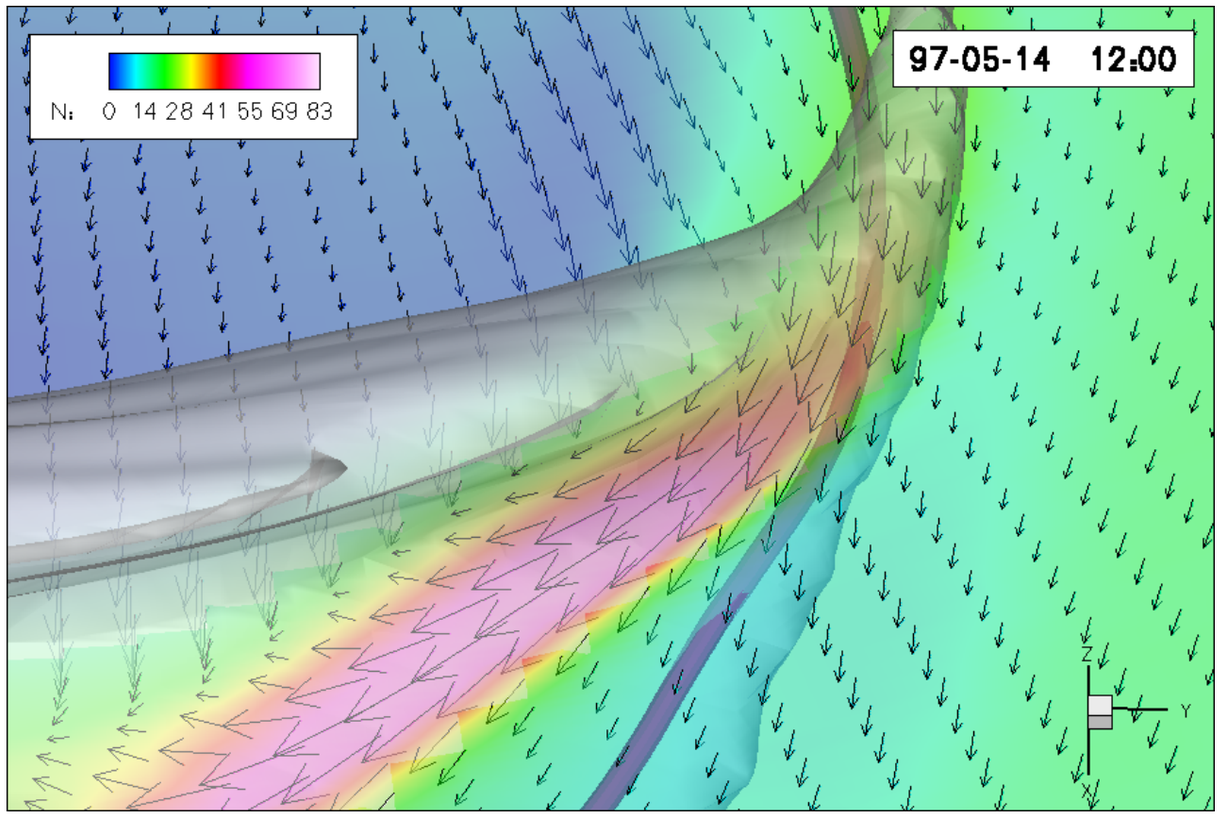
- All (“classical-propulsion”) missions to Mars follow the Hohmann trajectory
- Spacecraft close to IMF line passing through Earth with SEP measurements for alerts
- Simulations confirm Posner’s idea (*PSS, 2013)* except periods when IMF is disturbed by CMEs

Shock Detection Challenge

Global view

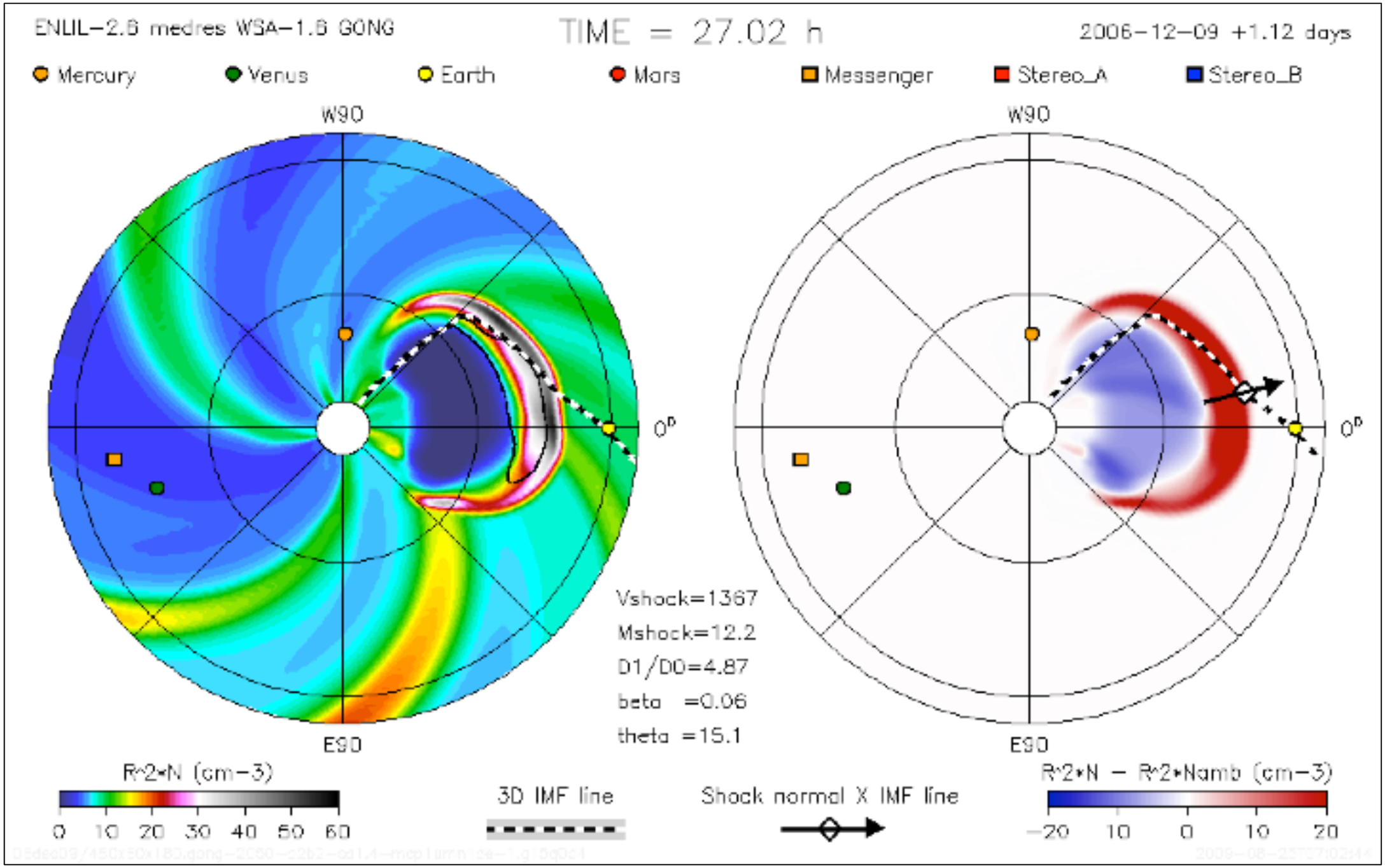


Detailed view



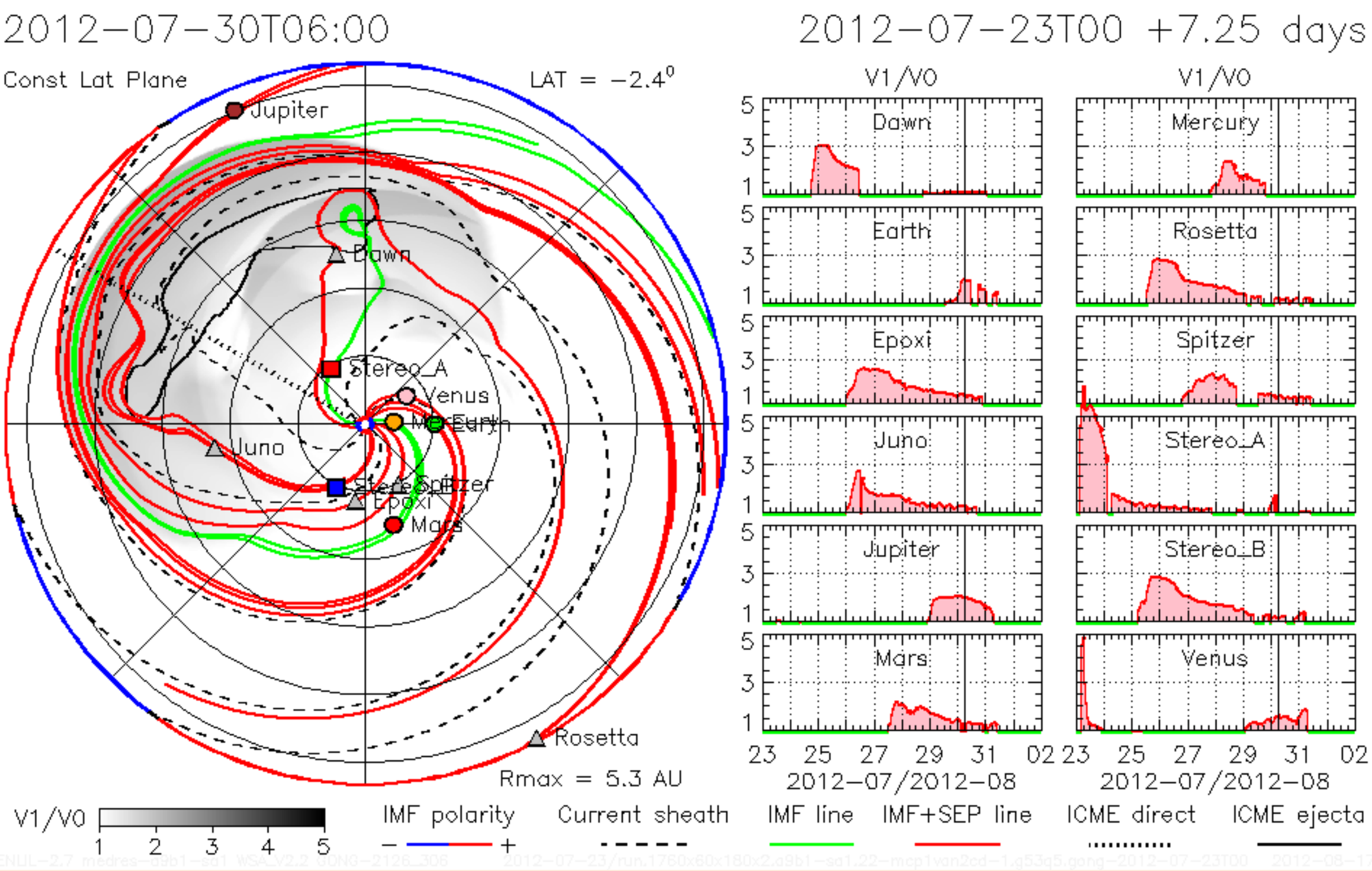
- IMF line connects geospace with an interplanetary shock under very large inclination angle because of: (1) spiraling IMF line and (2) bow-shaped shock front
- Thus determination of shock parameters from MHD values stored along the IMF line is very difficult because many numerical grid points are used across the shock structure and pre- and post-shock values are at different solar wind

Automatic Detection of CME-Driven Shocks



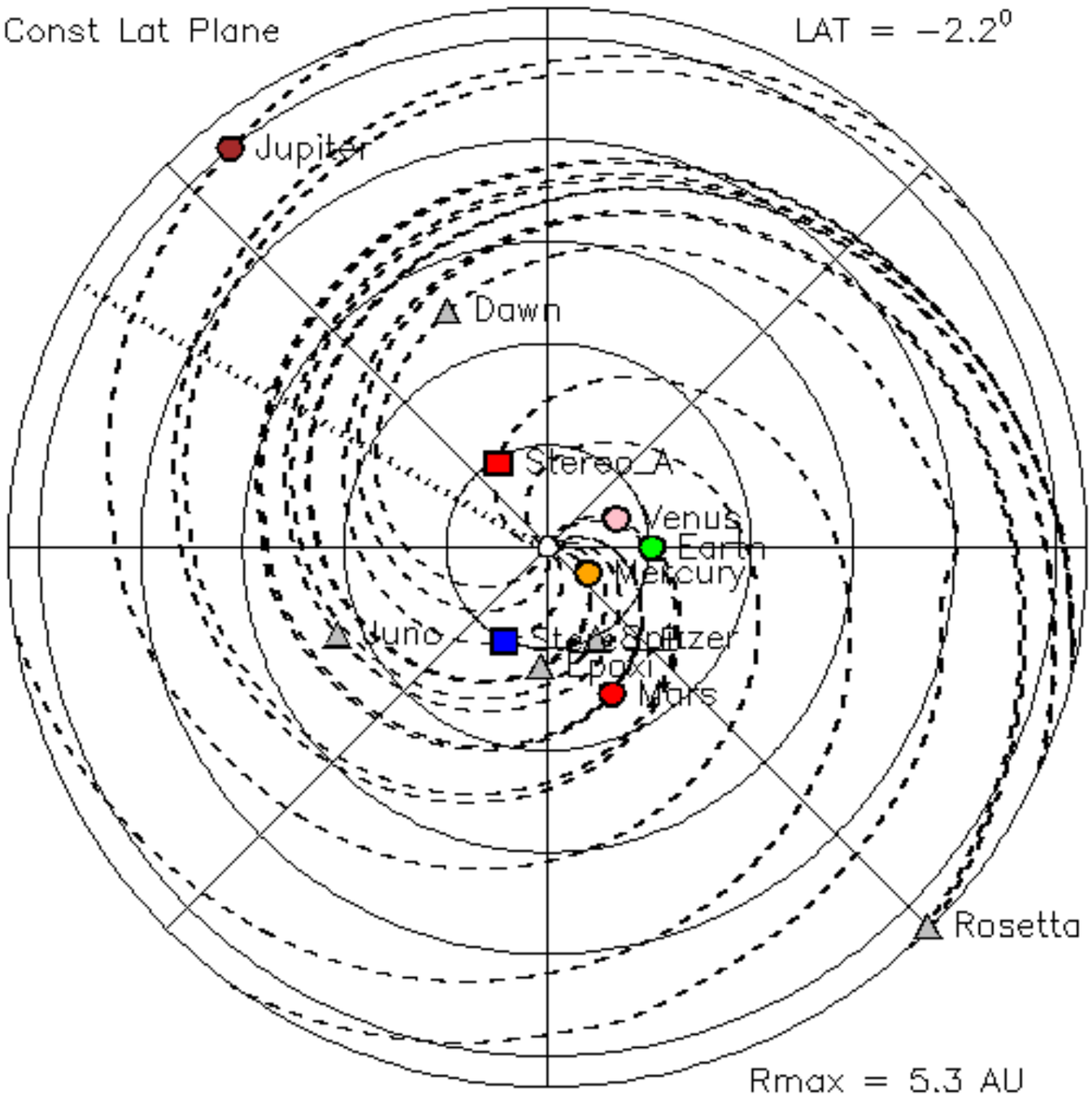
- Two simulations are used: one for background only and the other for background+transient
- Subtraction the two results to clearly identify an interplanetary shock leading edge along the observer connected IMF line

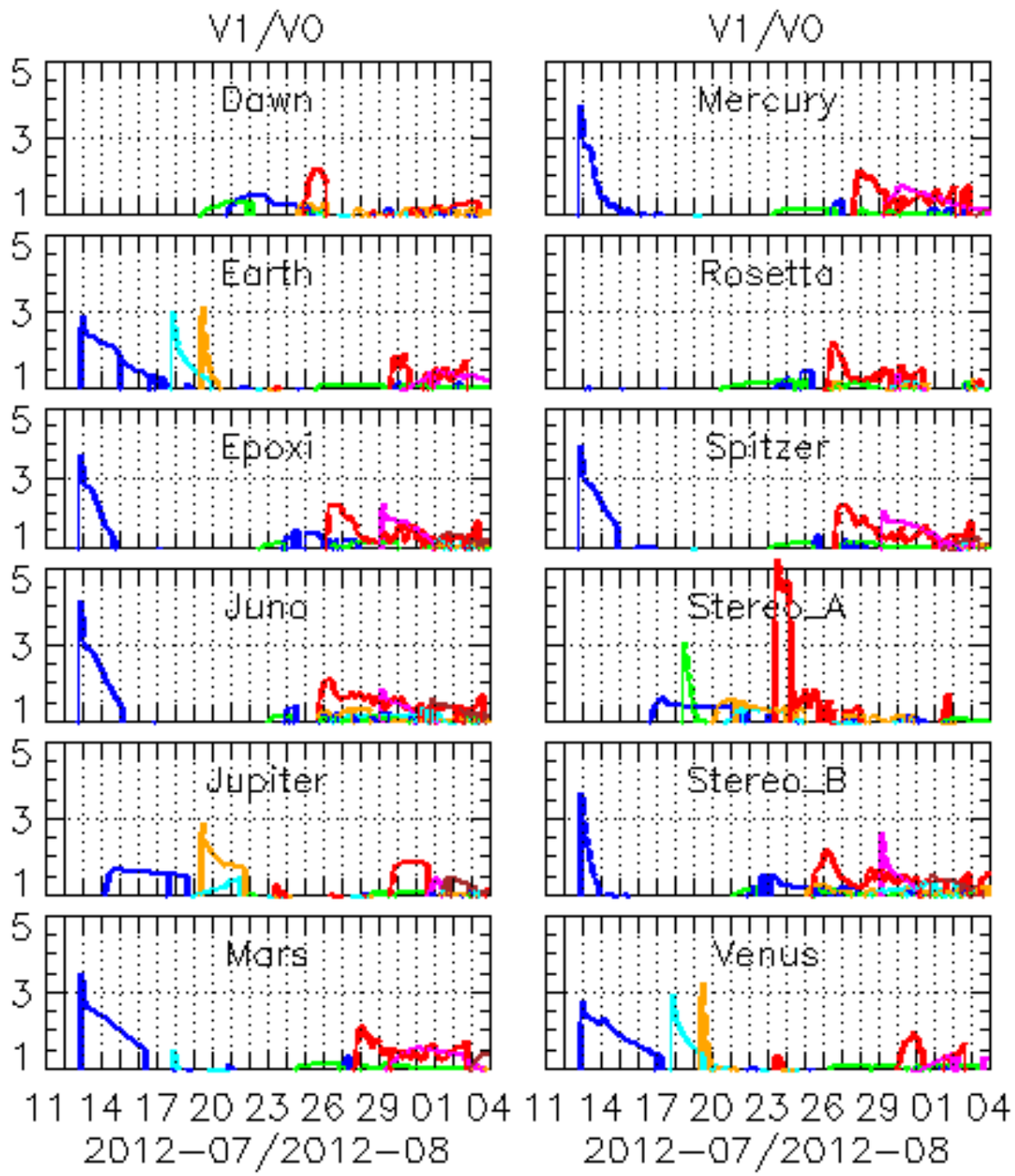
WSA-ENLIL-Cone Modeling System — Project Proposal



- Driven by evolving WSA maps & improved CME fittings — predictions in mid heliosphere
- Development of additional products and applications (SEP, white-light, etc.)
- Validation across the solar-activity cycle

Multi-CME Events — 2012 July





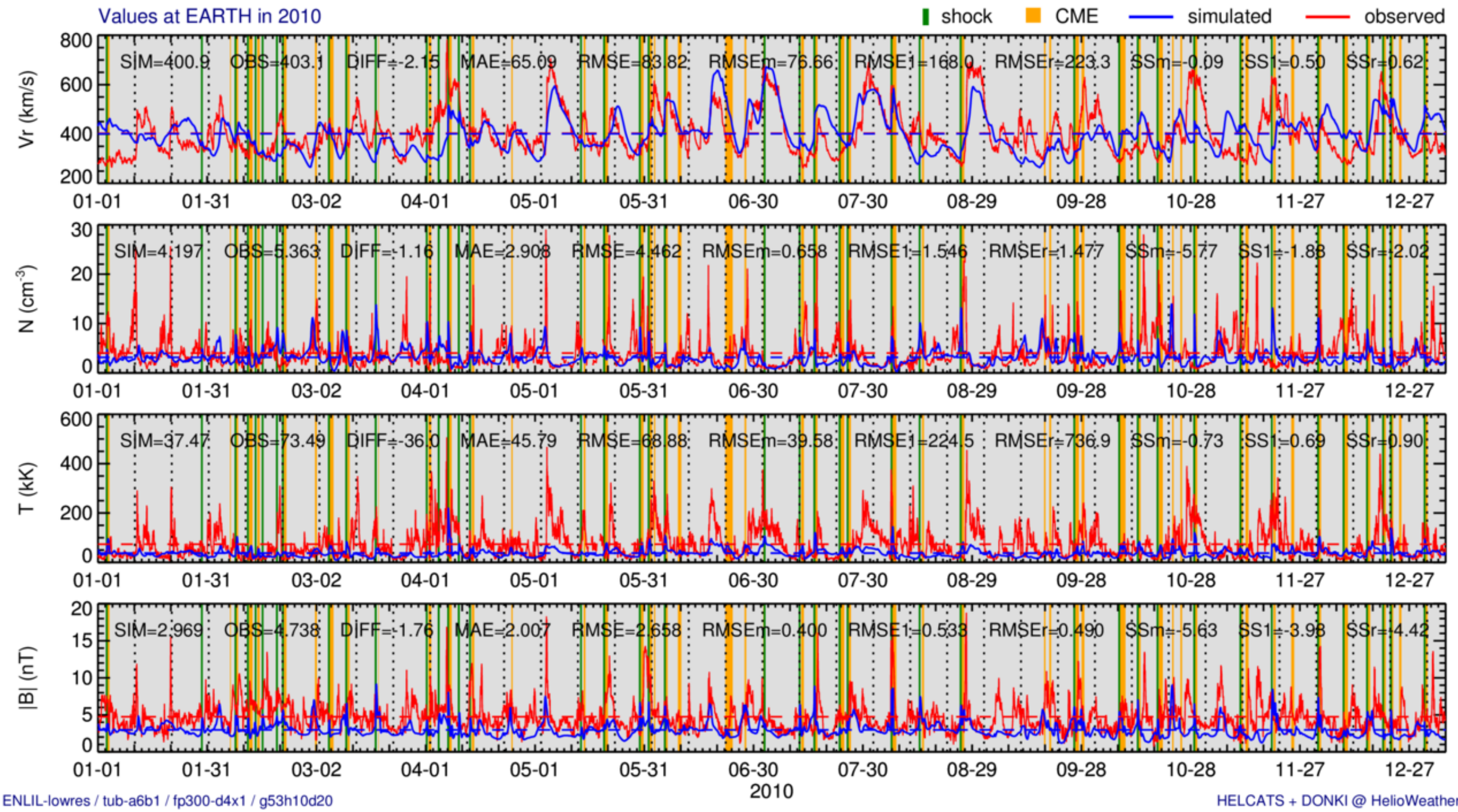
WSA-ENLIL-DONKI-HELCATS — Solar Wind and CMEs

http://helioweather.net/archive

Year	Month											
2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

- Simulations of all CMEs from 2007 (STEREO data available) until present:
  - evolving background using the WSA maps
  - hydrodynamic ejecta by DONKI and HELCATS fitting of CMEs > 300 km/s
- This covers basically the solar-activity cycle:
  - verification & validation during minimum and maximum solar activity
  - calibration of model free parameters

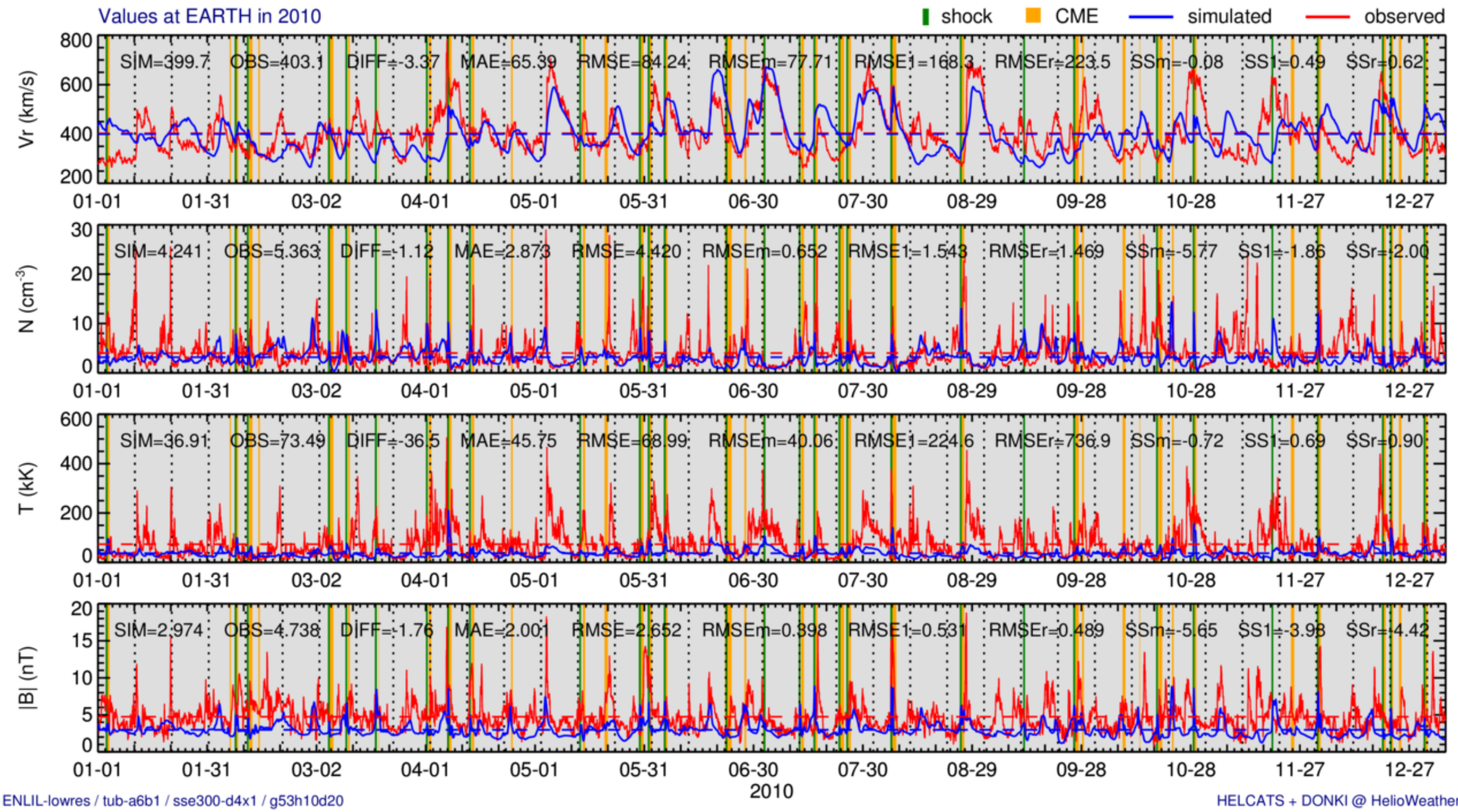
WSA-ENLIL-DONKI-HELCATS — CMEs > 300 km/s by FP in 2010



ENLIL-lowres / tub-a6b1 / fp300-d4x1 / g53h10d20

HELCATS + DONKI @ HelioWeather

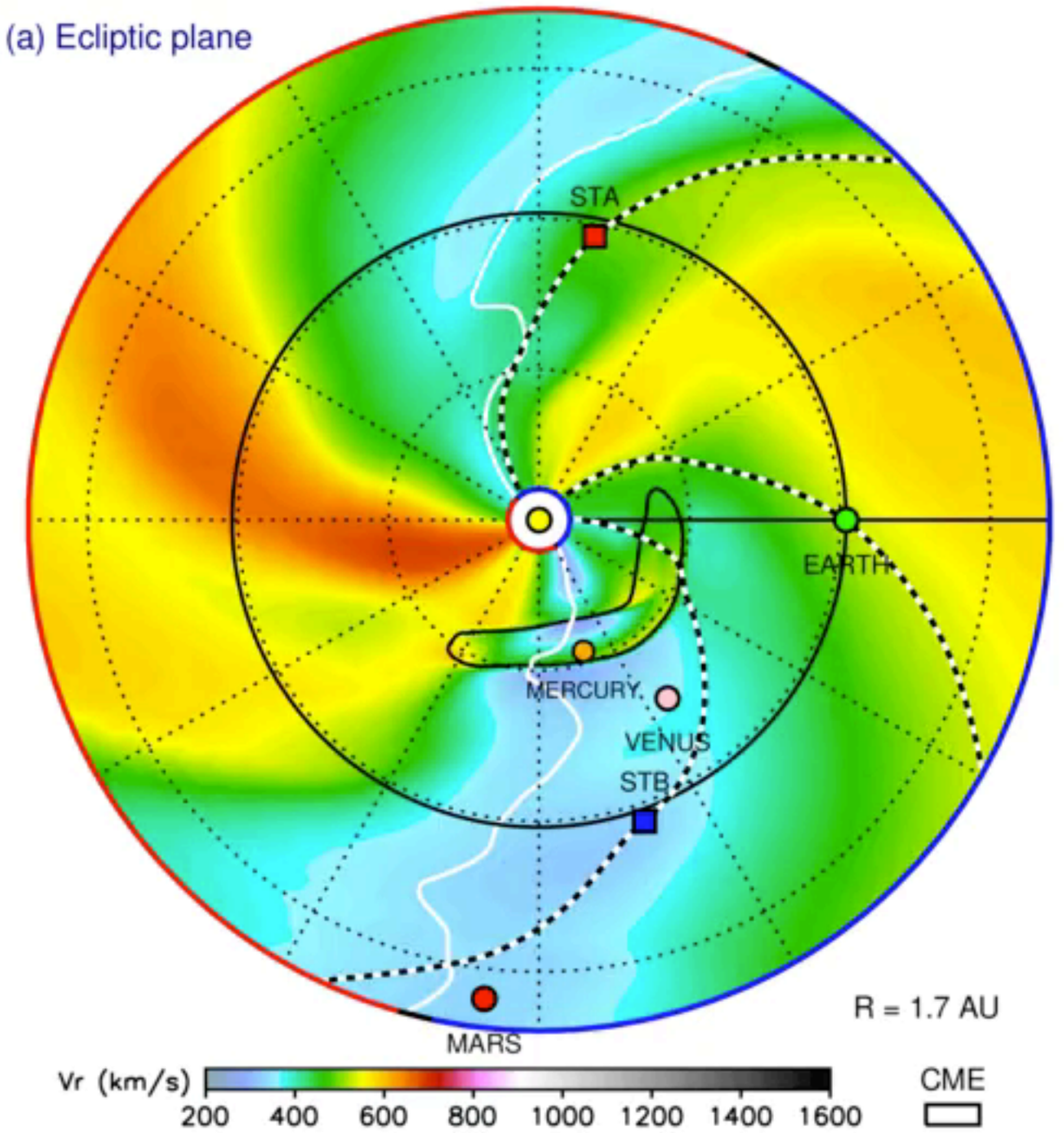
WSA-ENLIL-DONKI-HELCATS — CMEs > 300 km/s by SSE in 2010

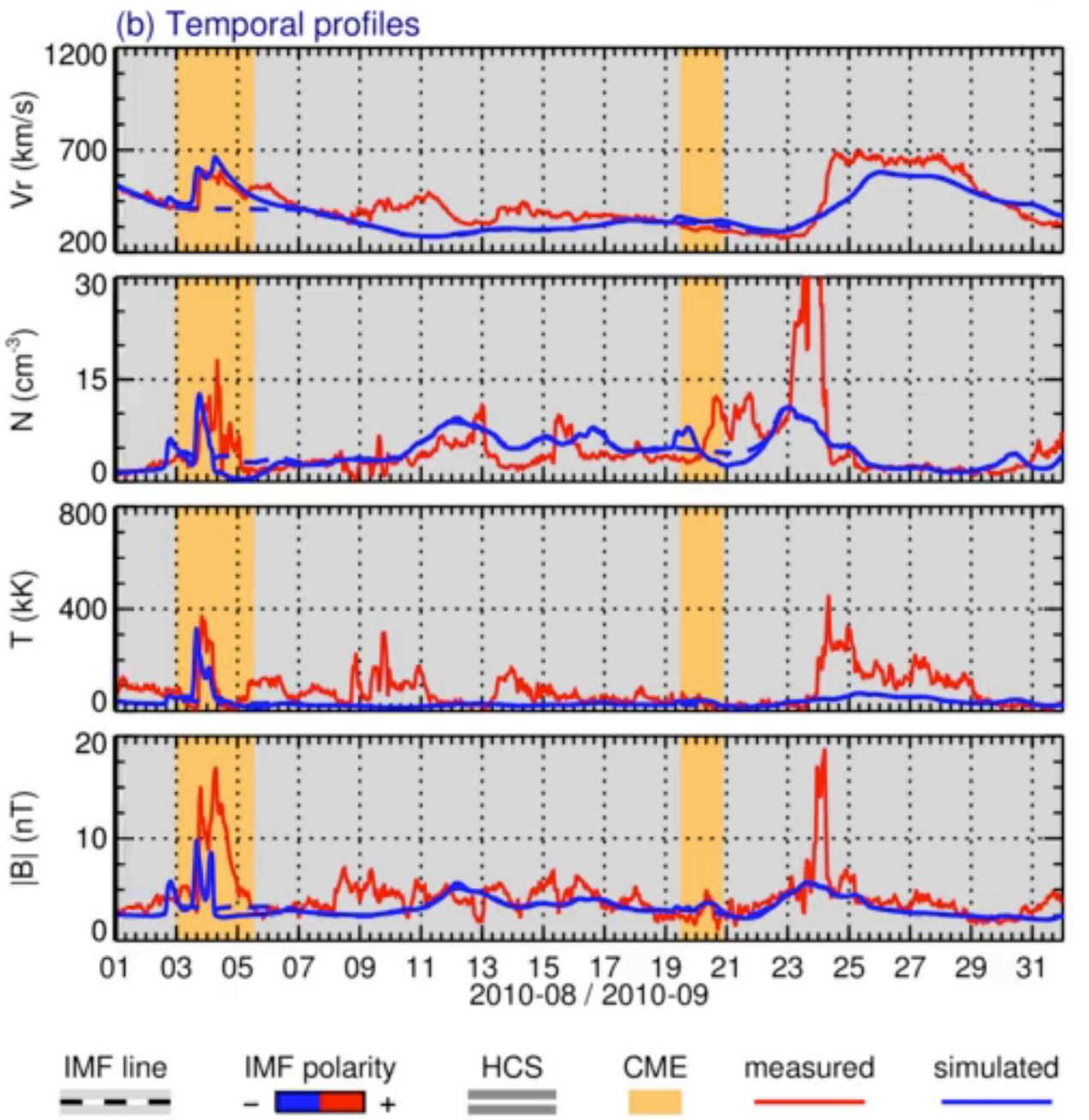


ENLIL-lowres / tub-a6b1 / sse300-d4x1 / g53h10d20

HELCATS + DONKI @ HelioWeather

WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03

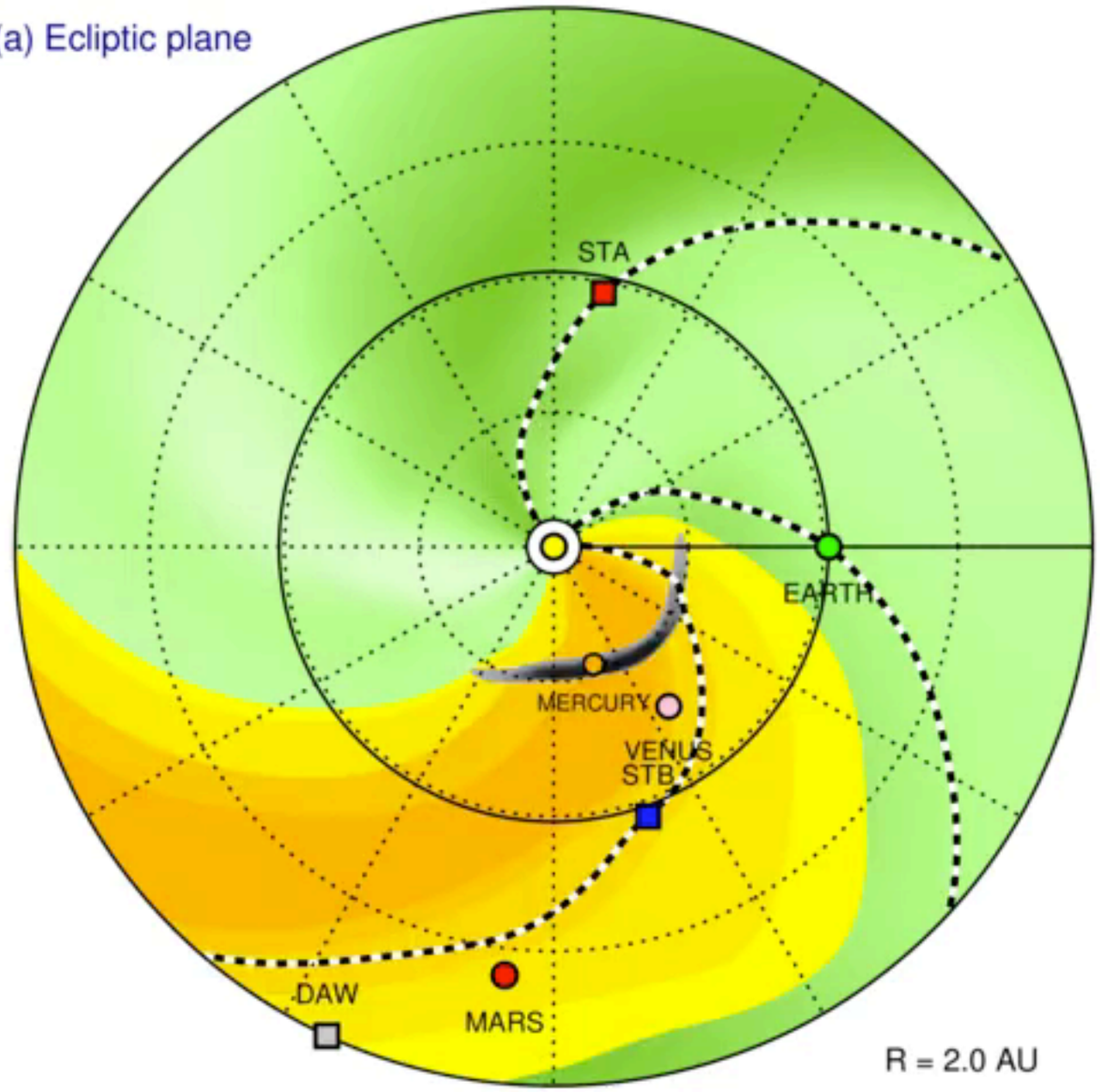




WSA-ENLIL-DONKI-HELCATS — Shock SEP Alerts

2010-08-01T00:00

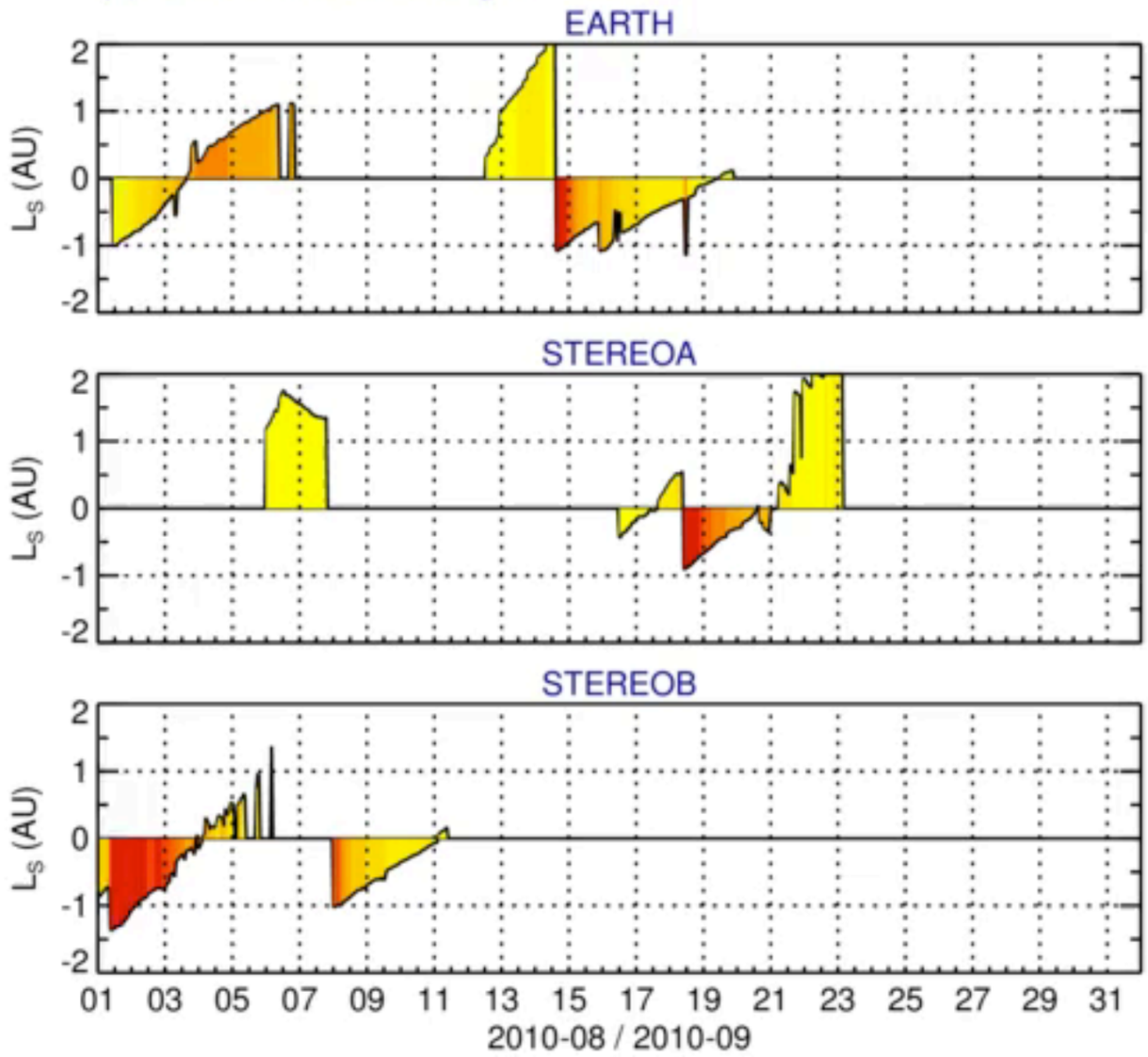
(a) Ecliptic plane



R = 2.0 AU

2010-08-01T00 + 0.000 days

(b) Shock distance along the IMF line



IMF line

Vamb (km/s) 0 400 800

N/Namb 1.5 4.0 6.5

V−Vamb at shock (km/s) 20 210 400

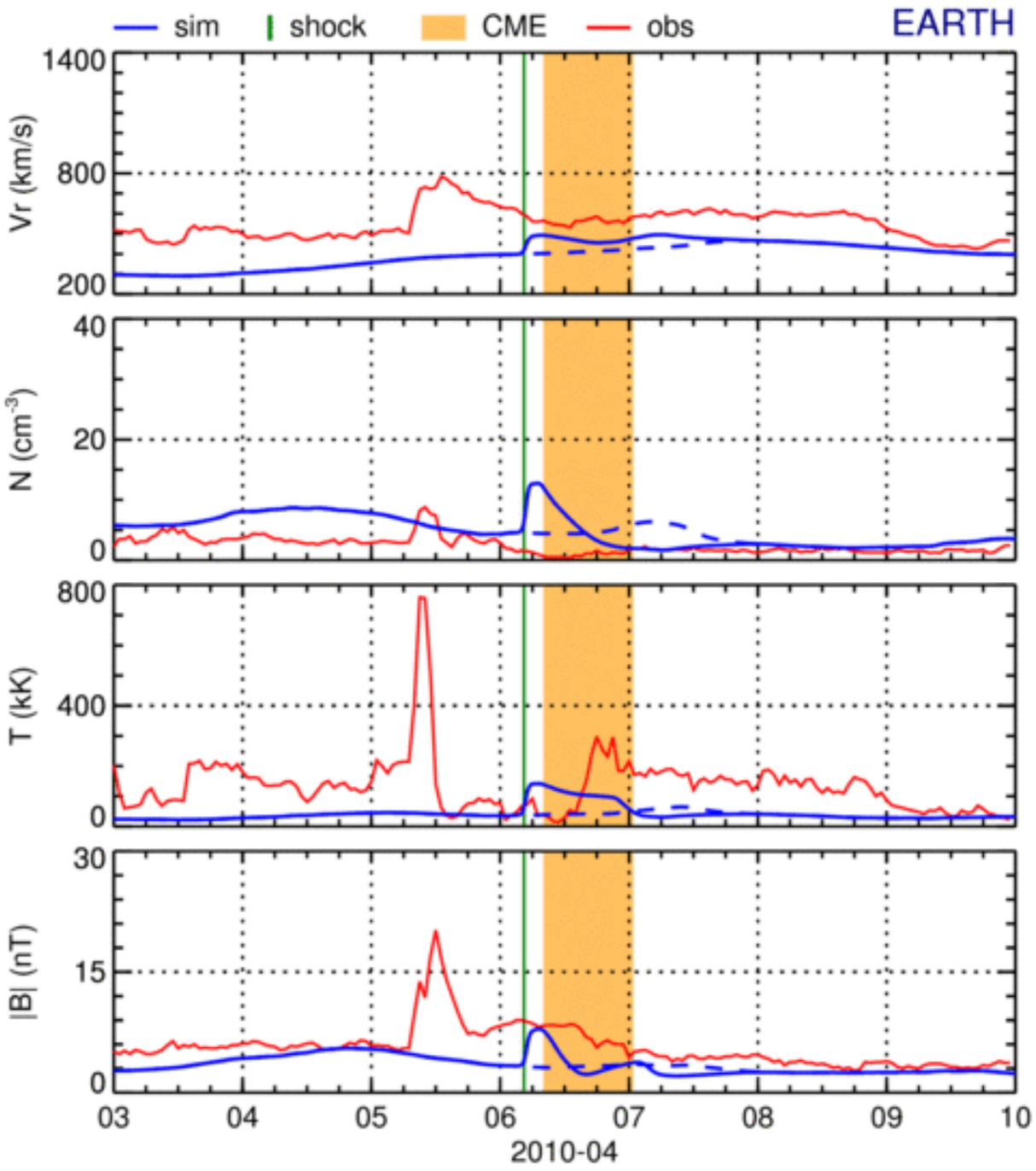
ENLIL-lowres + GONGb-WSAtu / fp400-d4x1 / g53h10

HELCATS + DONKI @ HelioWeather

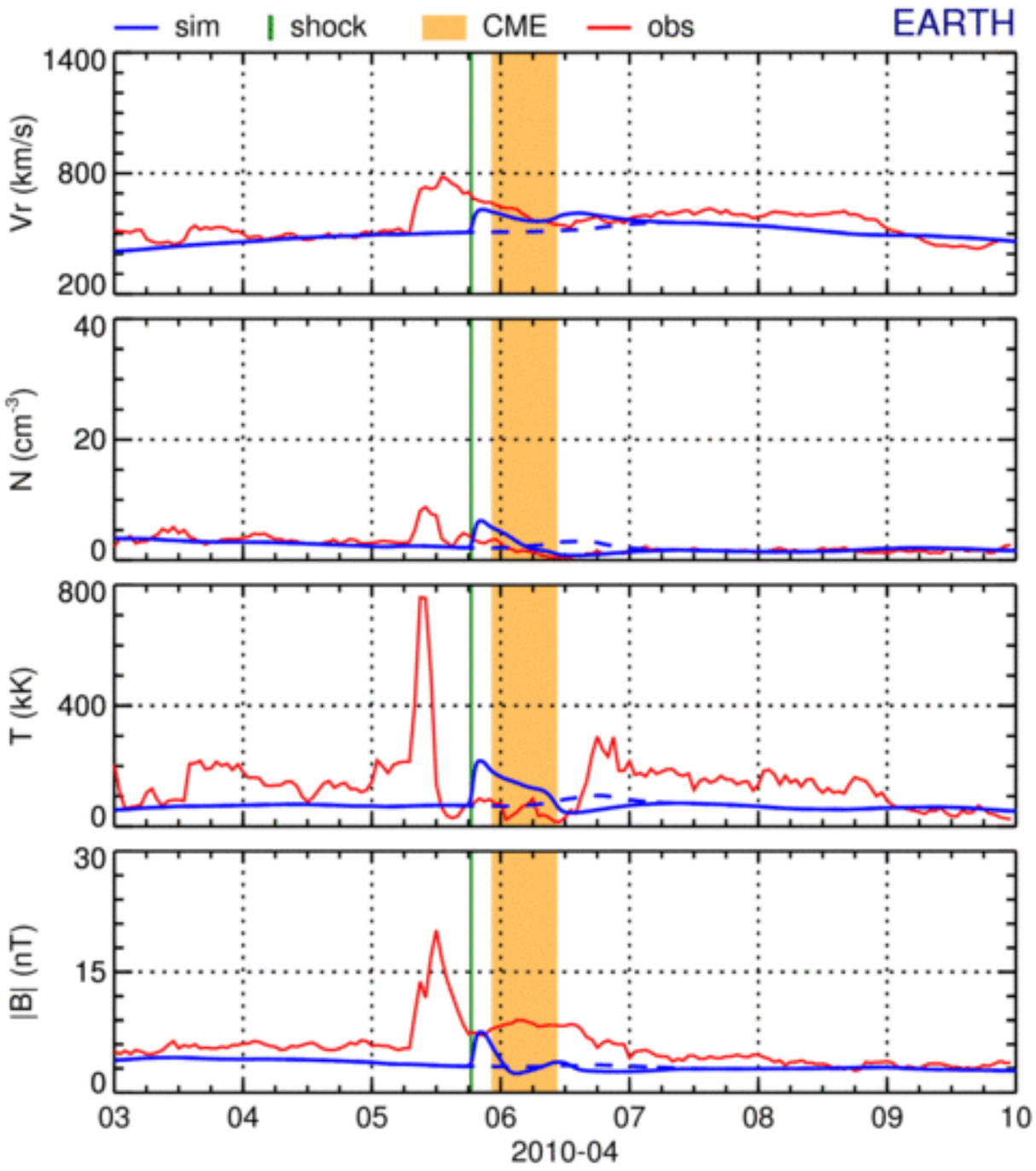
iCCMC Event “A” — CME 2010-04-03

observed arrival: 2010-04-05T08:26, predicted arrival: 2010-04-06T03:30 (19.07 h later)

- “ad hoc” solar wind — predicted arrival: 2010-04-06T04:27 (20.02 h later)
- “realistic” solar wind — predicted arrival: 2010-04-05T18:32 (10.09 h later)

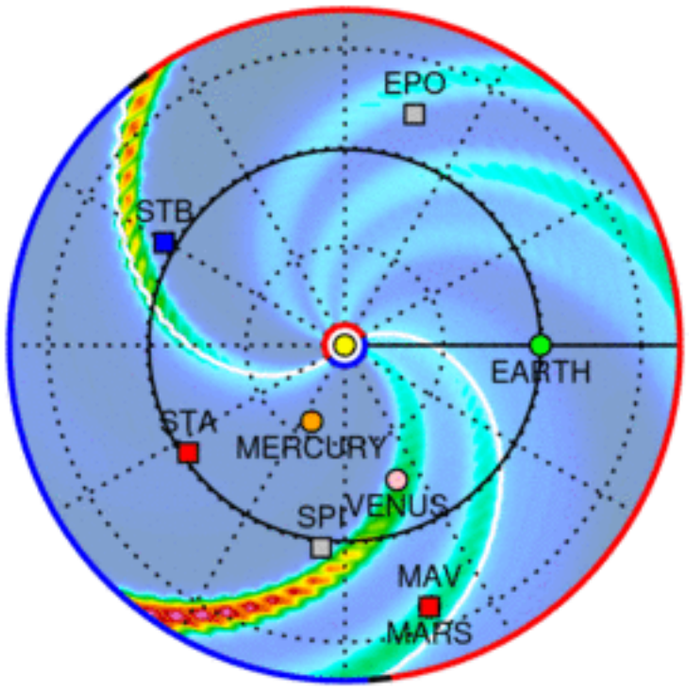


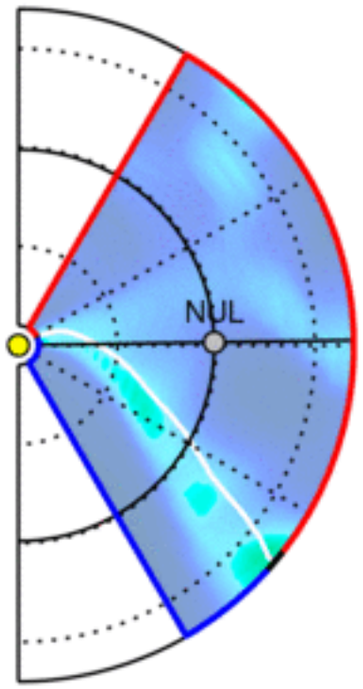
ENLIL-lowres + GONGb-WSAtu + Cone-CCMC / a6b1-d4t1x1 / g53h10 HelioWeather

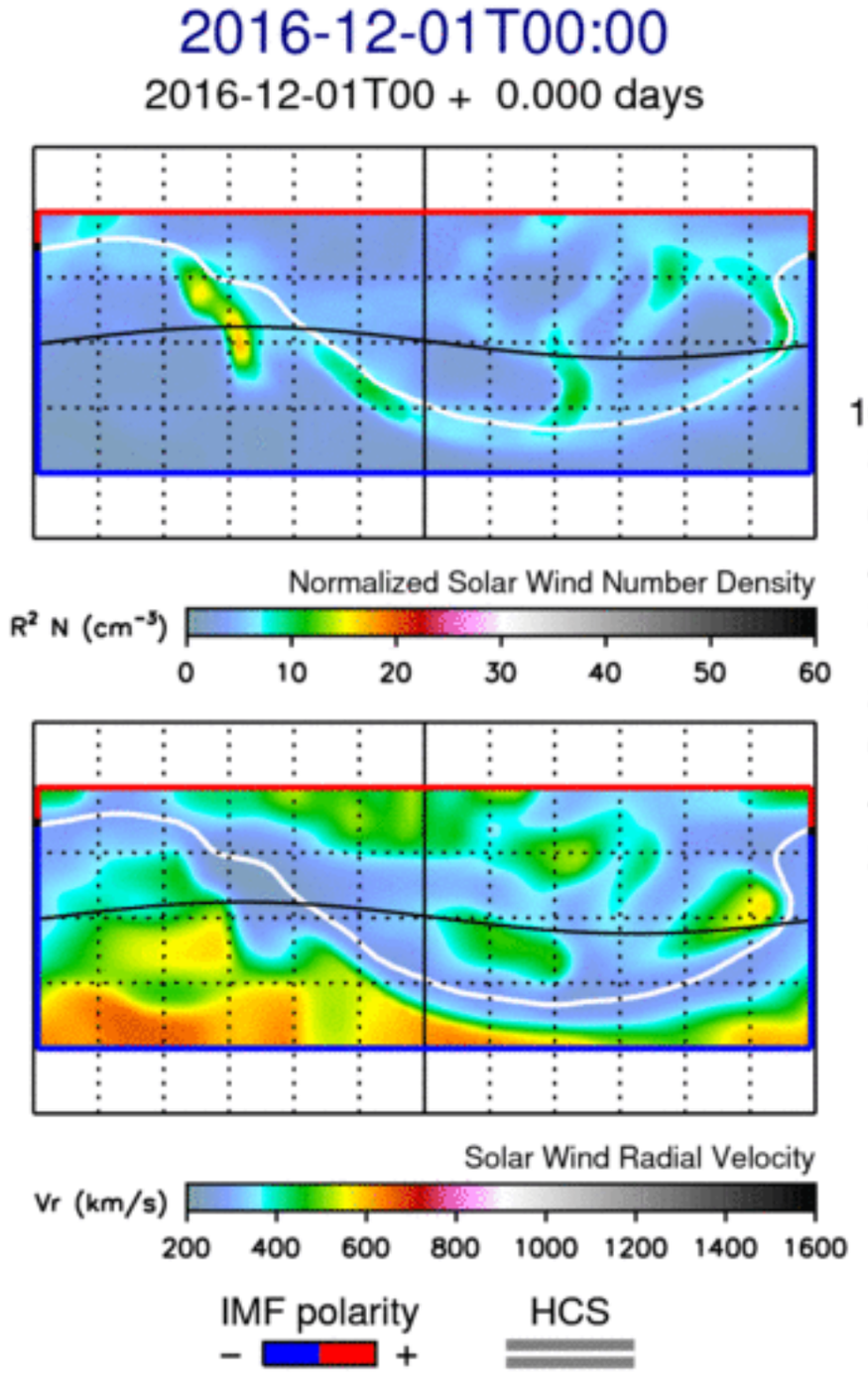


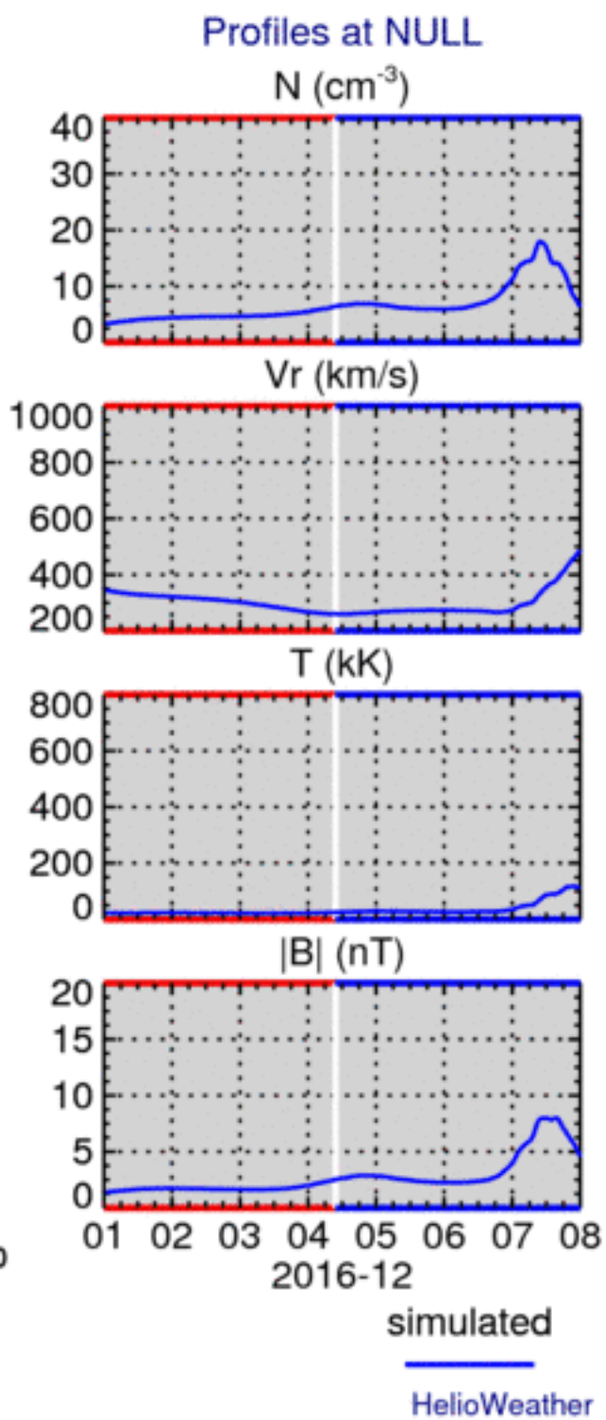
ENLIL-lowres + GONGb-WSAtu + Cone-CCMC / a8b1-d4t1x1 / g53h10 HelioWeather

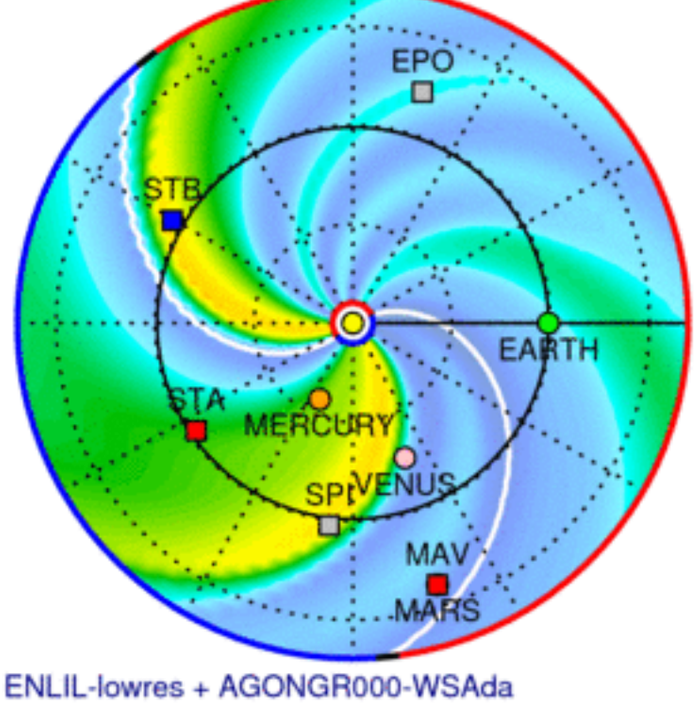
12 WSADA Maps — Solar Wind Speed on 2016-12-01

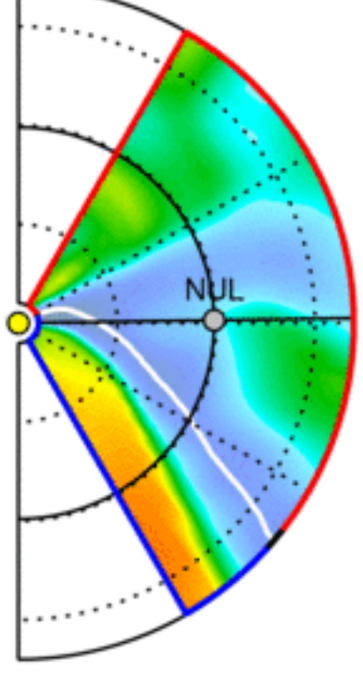








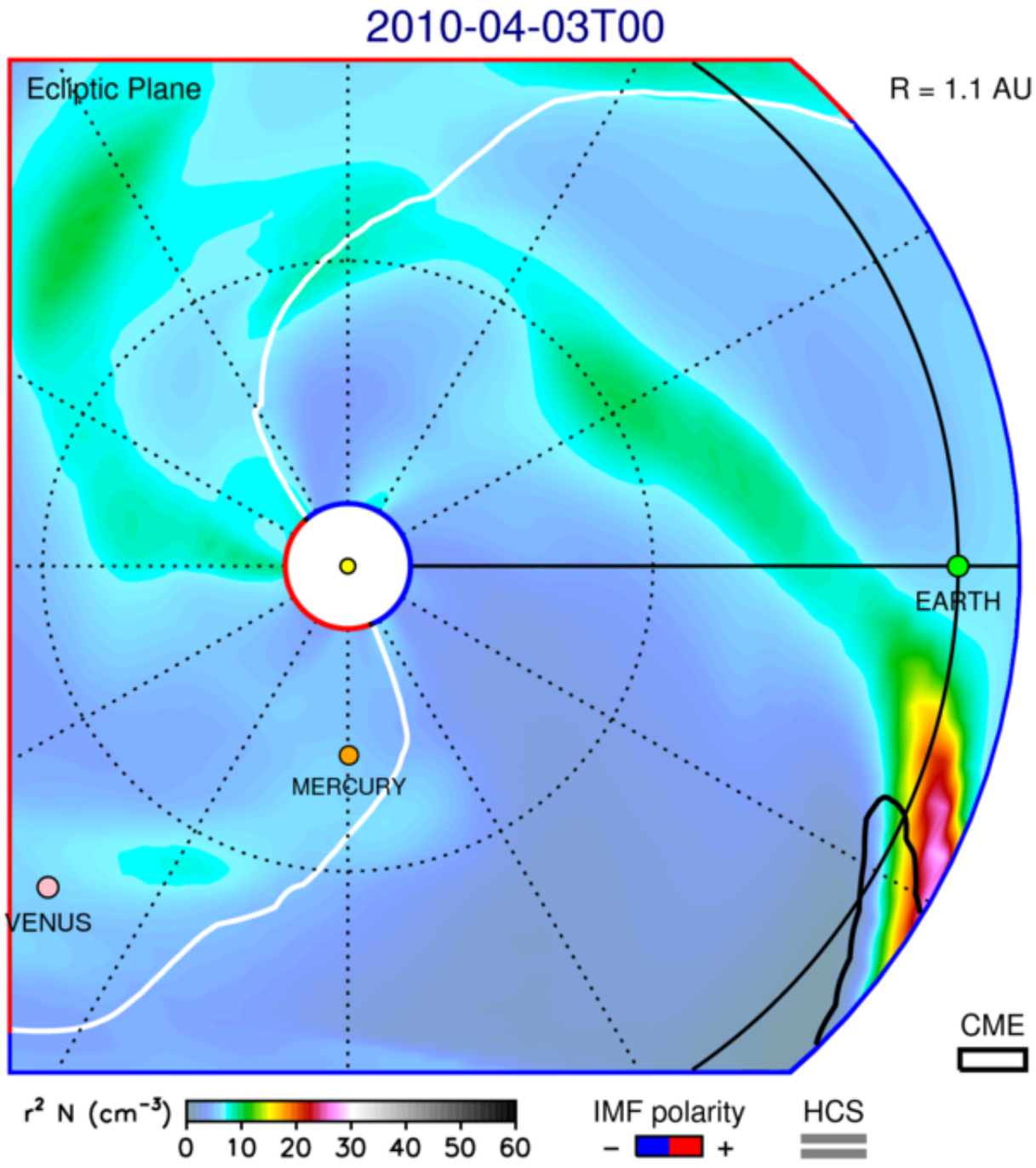


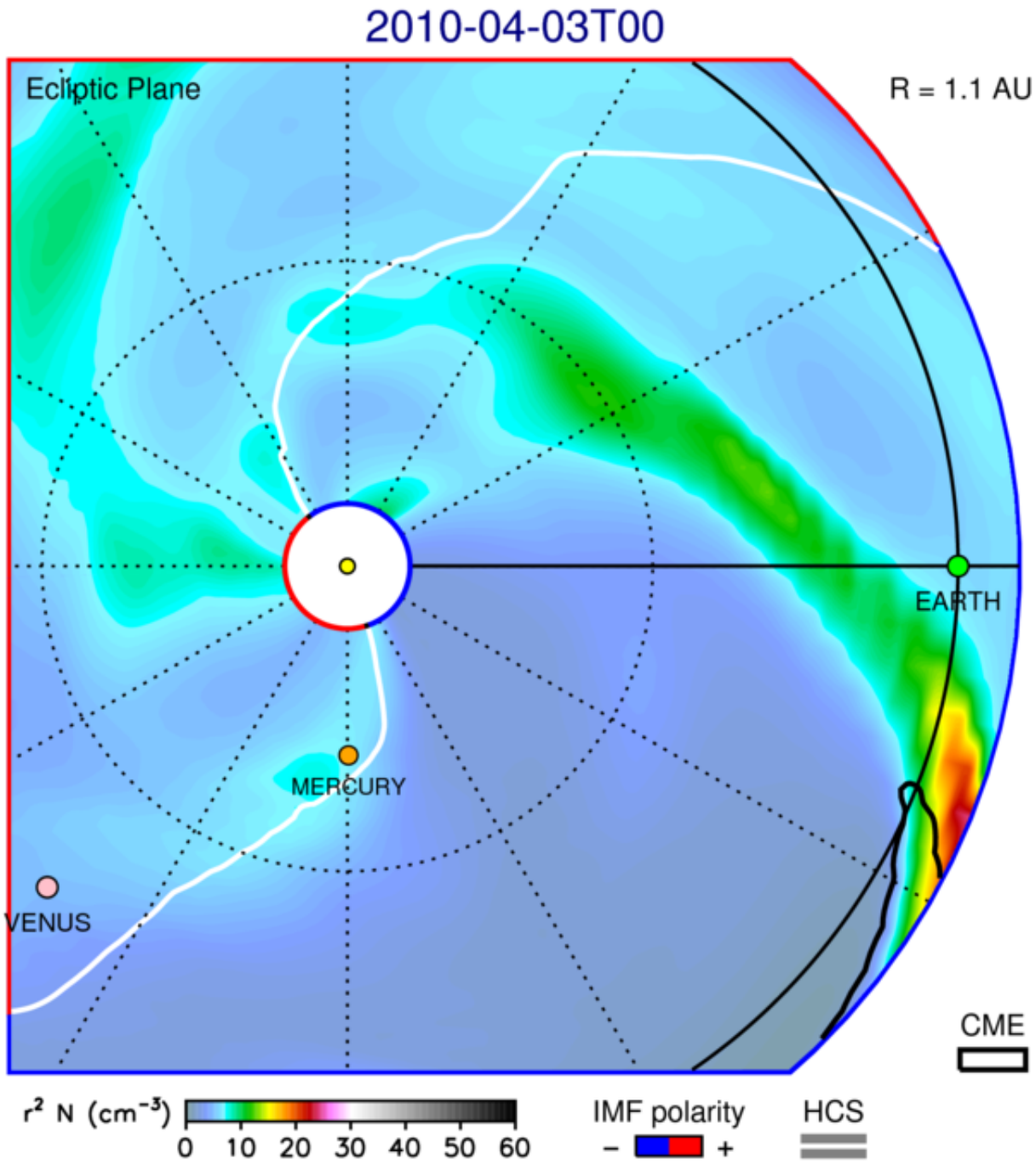


ENLIL-lowres + AGONGR000-WSAda

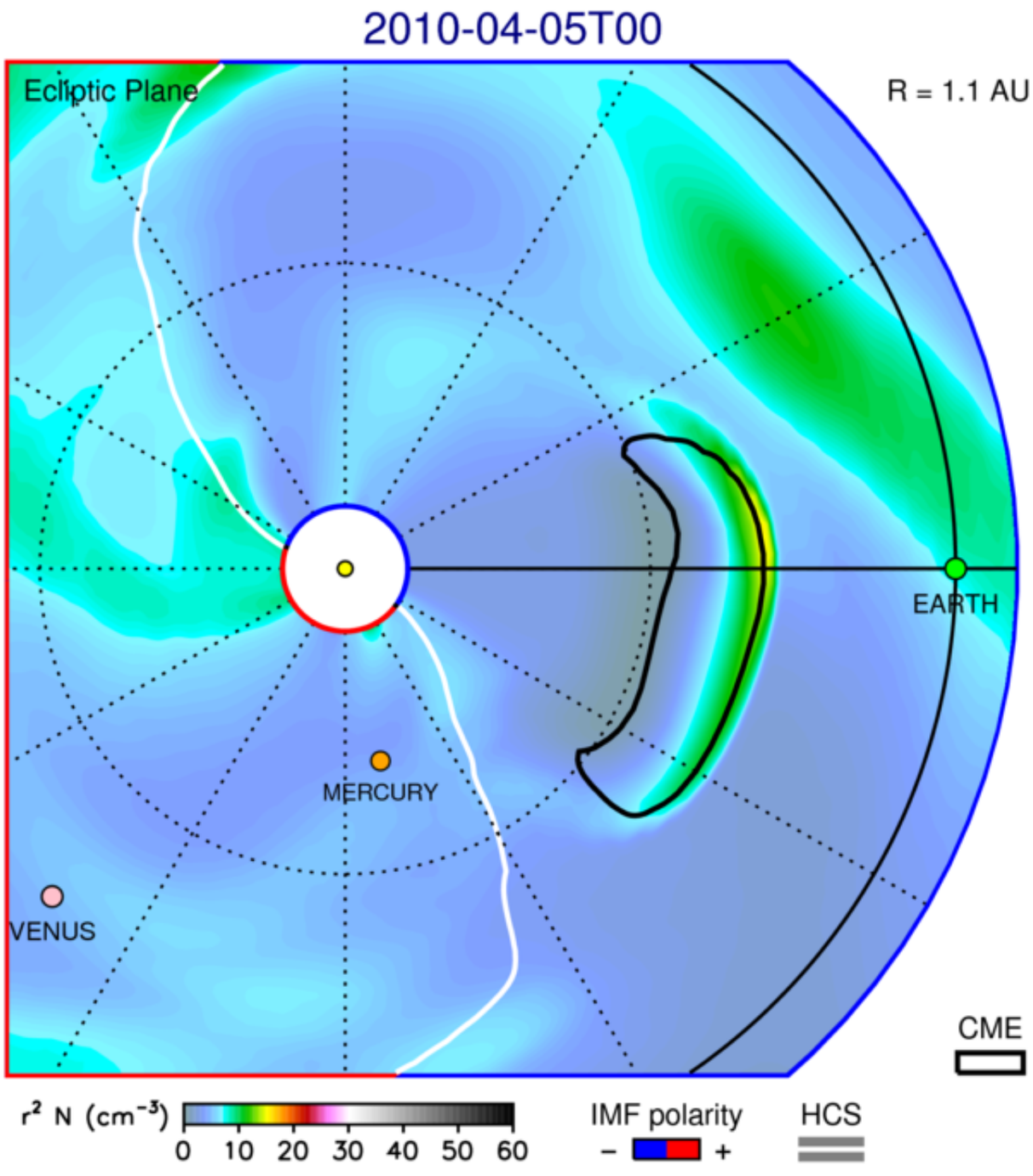
HelioWeather

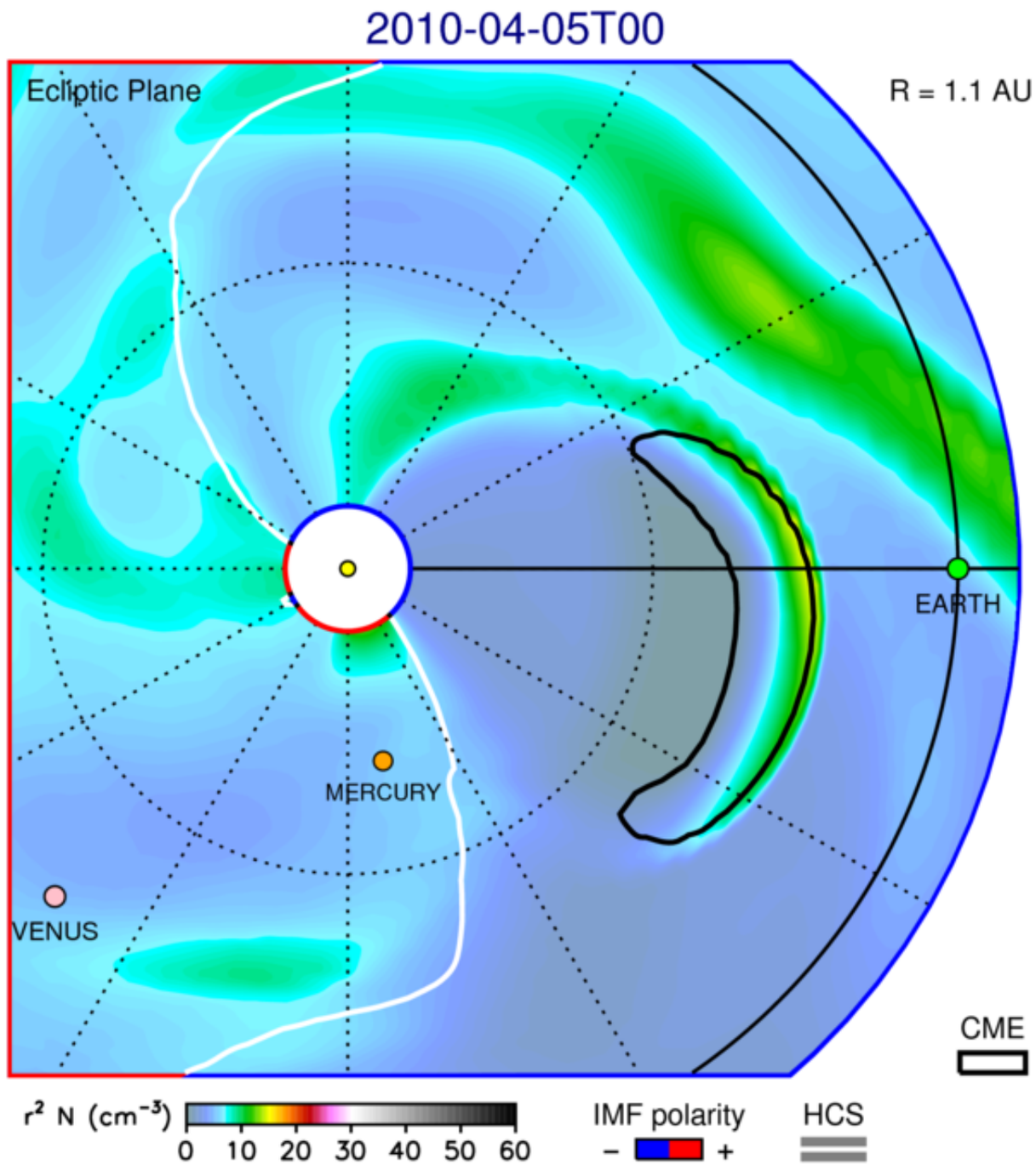
WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03





WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03





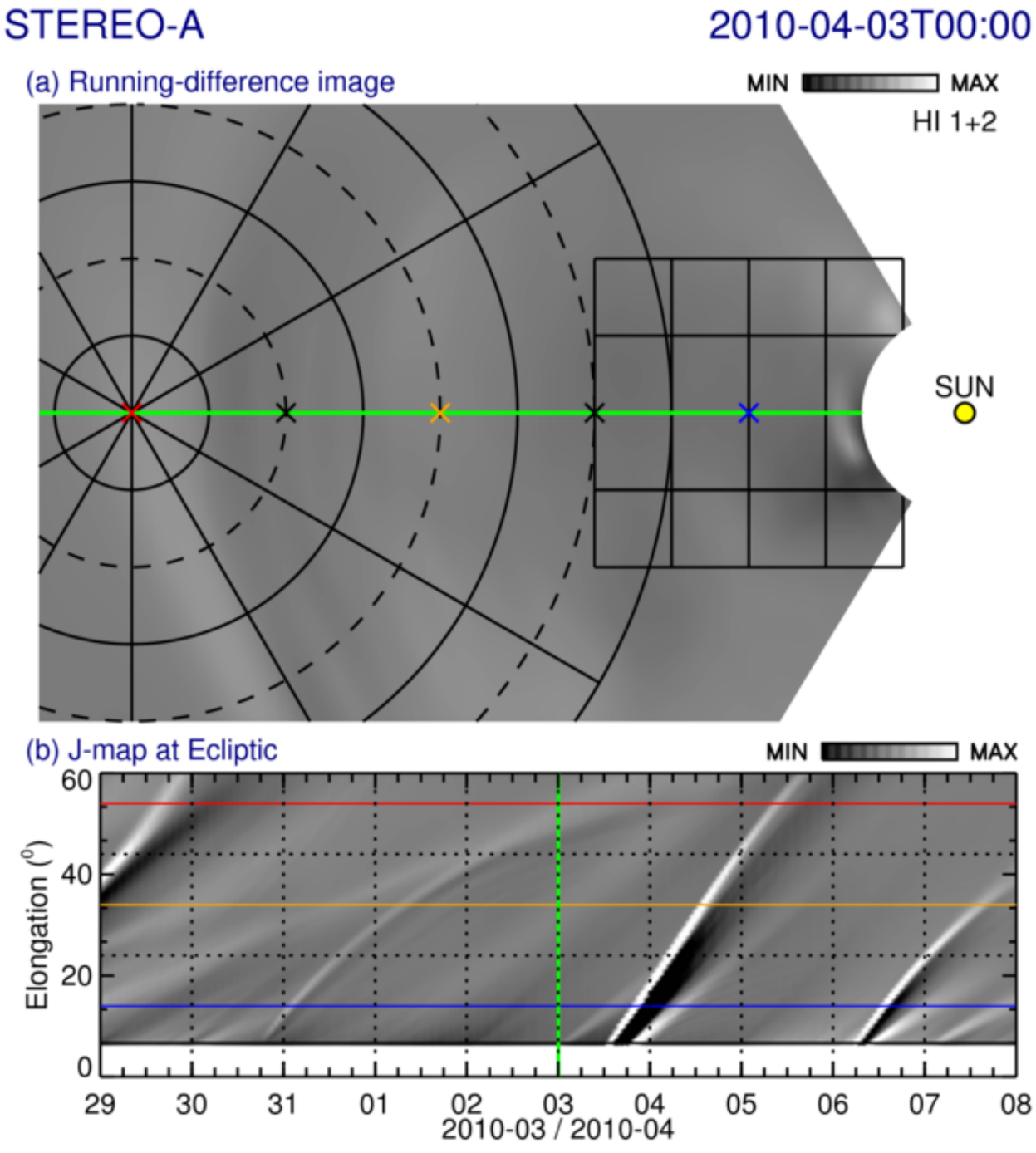
ENLIL-lowres + GONGb-WSAtu-Cone / a6b1-d4t1x1

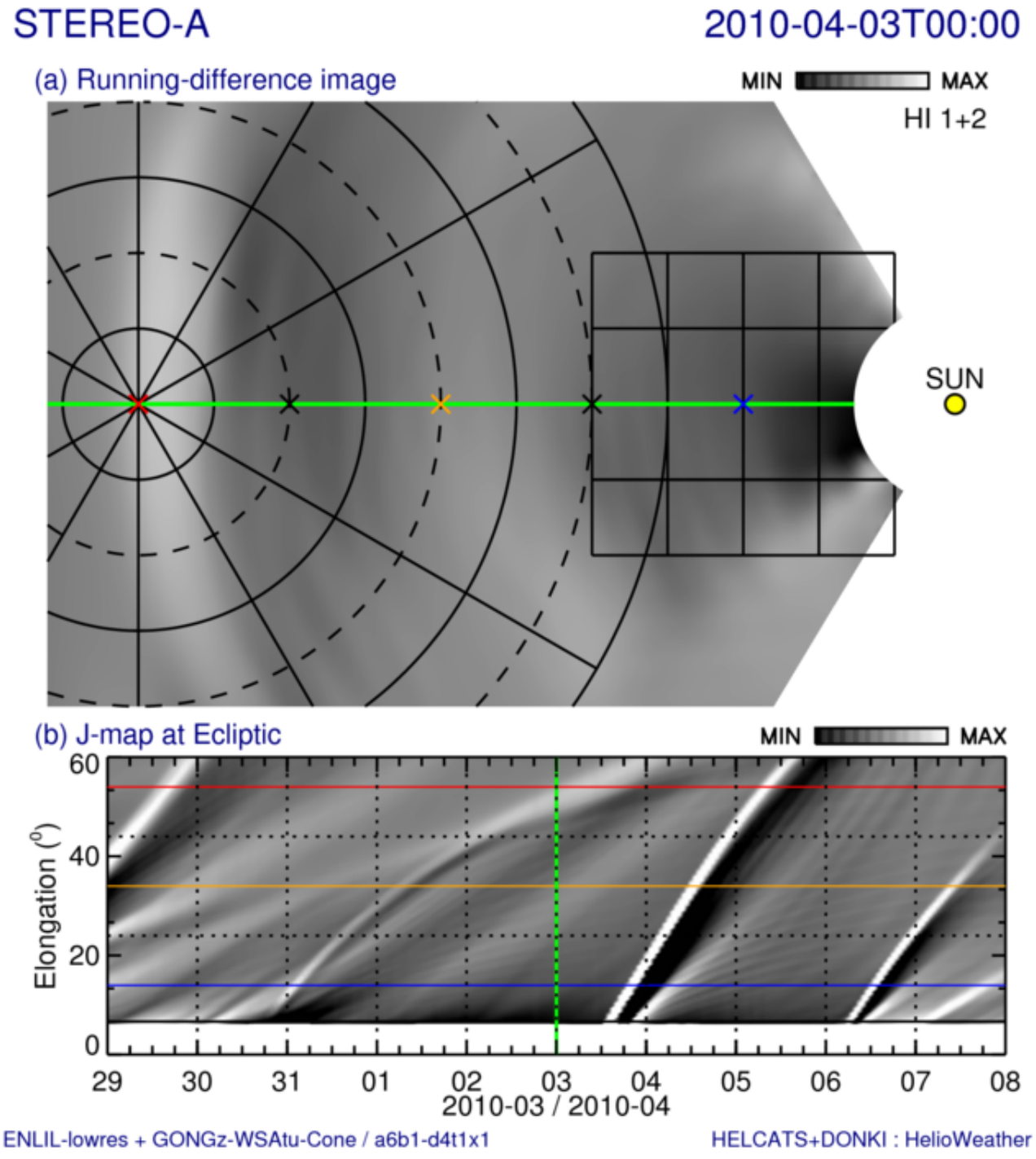
HELCATS+DONKI : HelioWeathe

ENLIL-lowres + GONGz-WSAtu-Cone / a6b1-d4t1x1

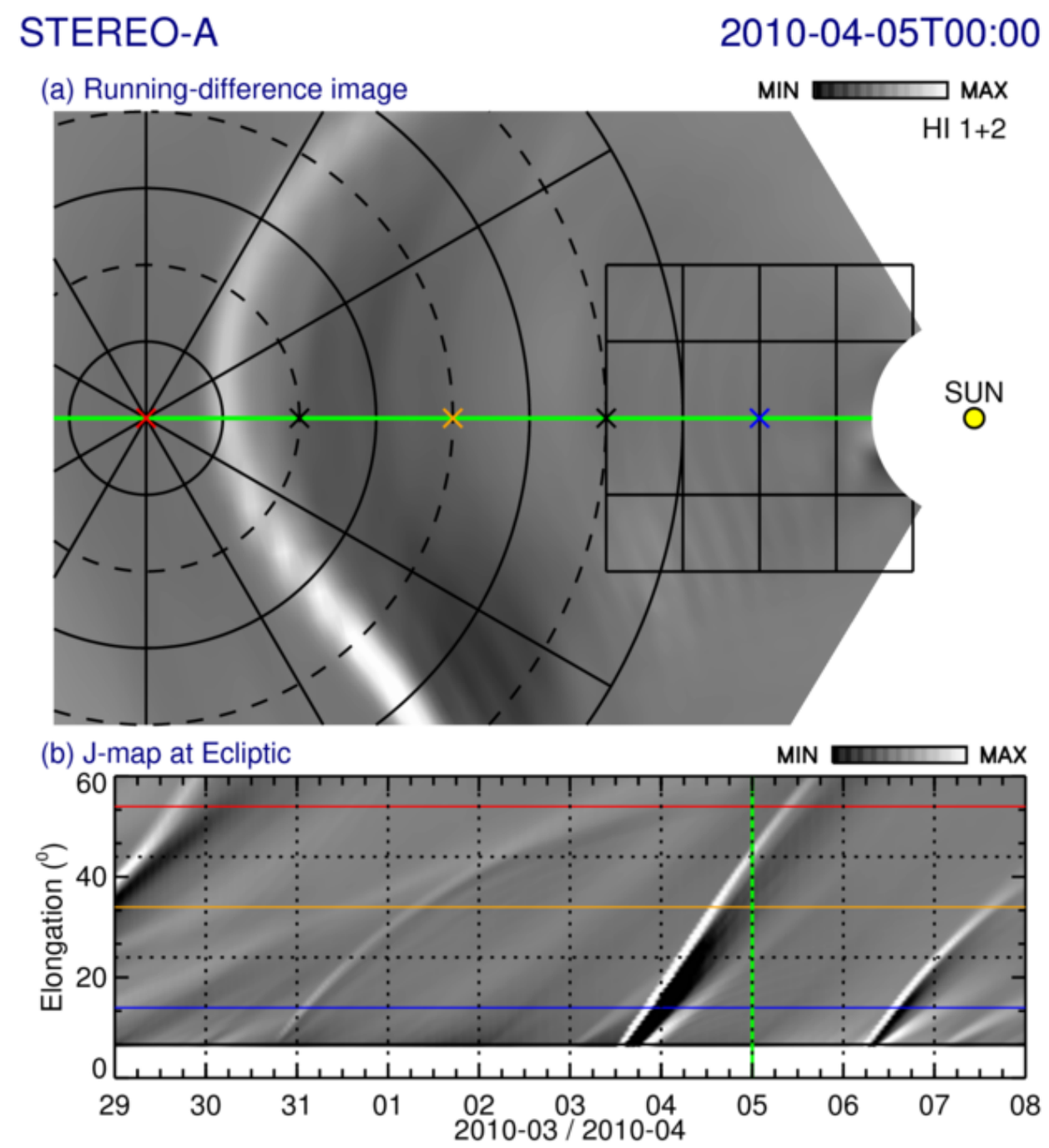
HELCATS+DONKI : HelioWeather

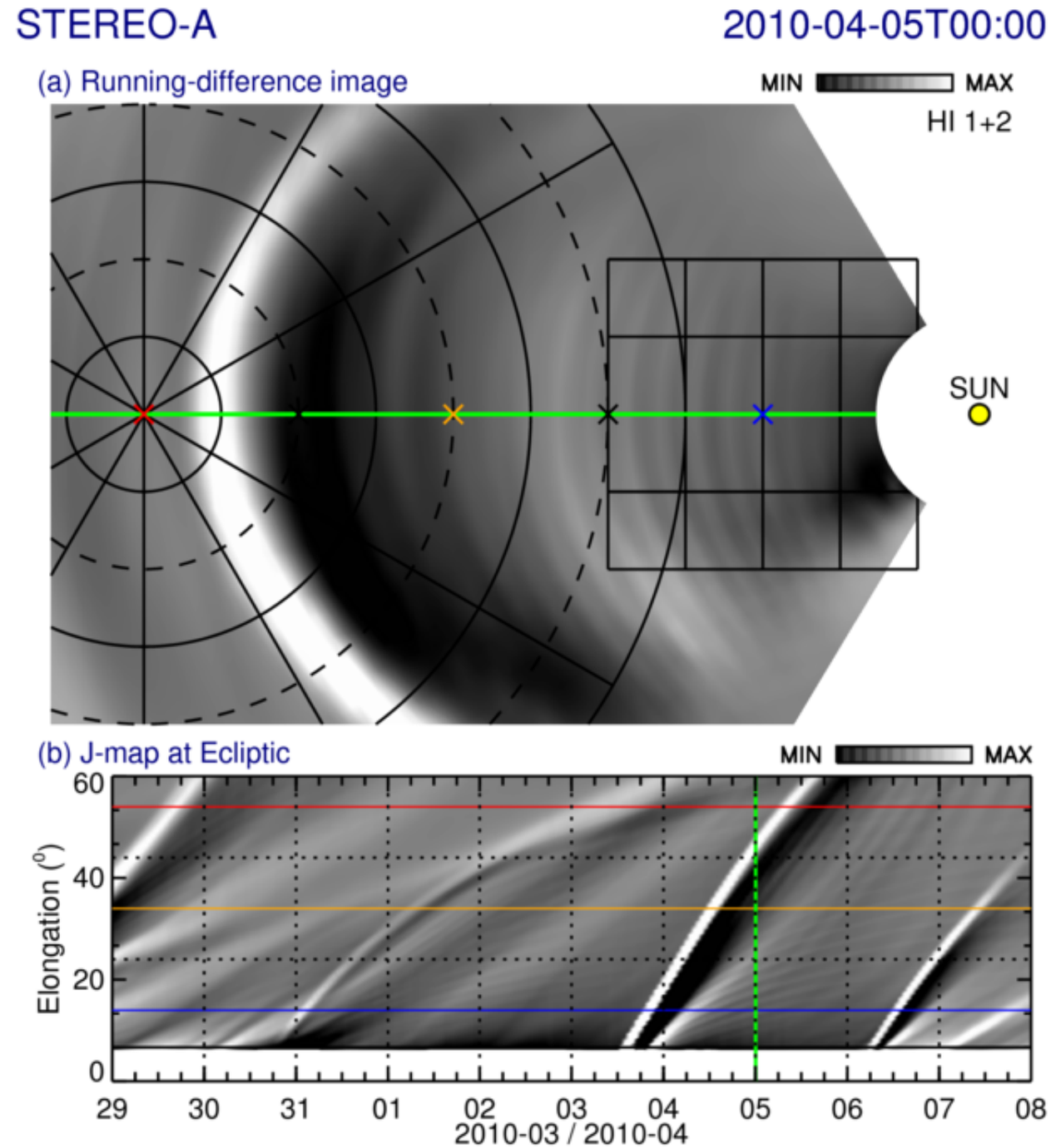
WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03



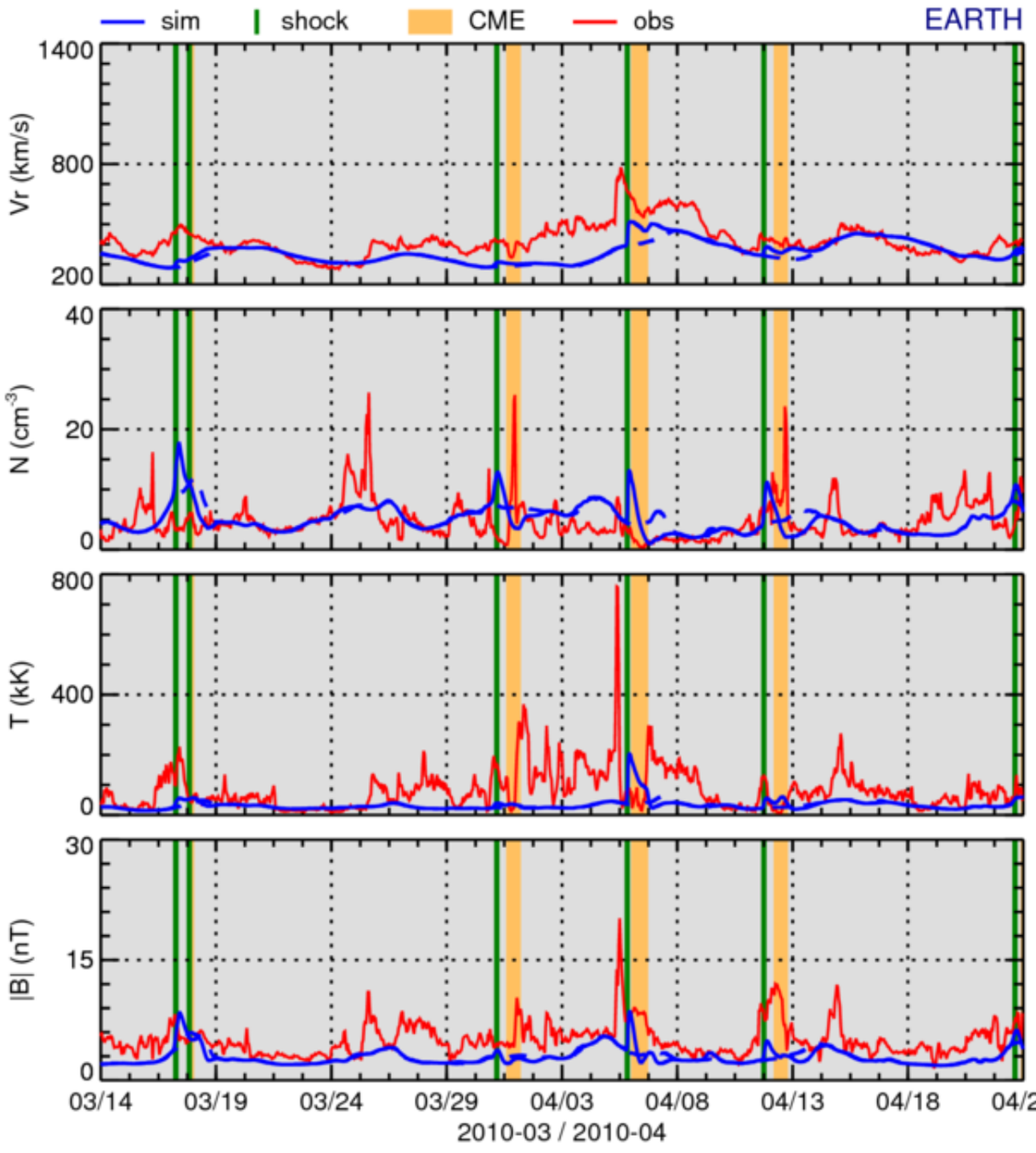


WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03



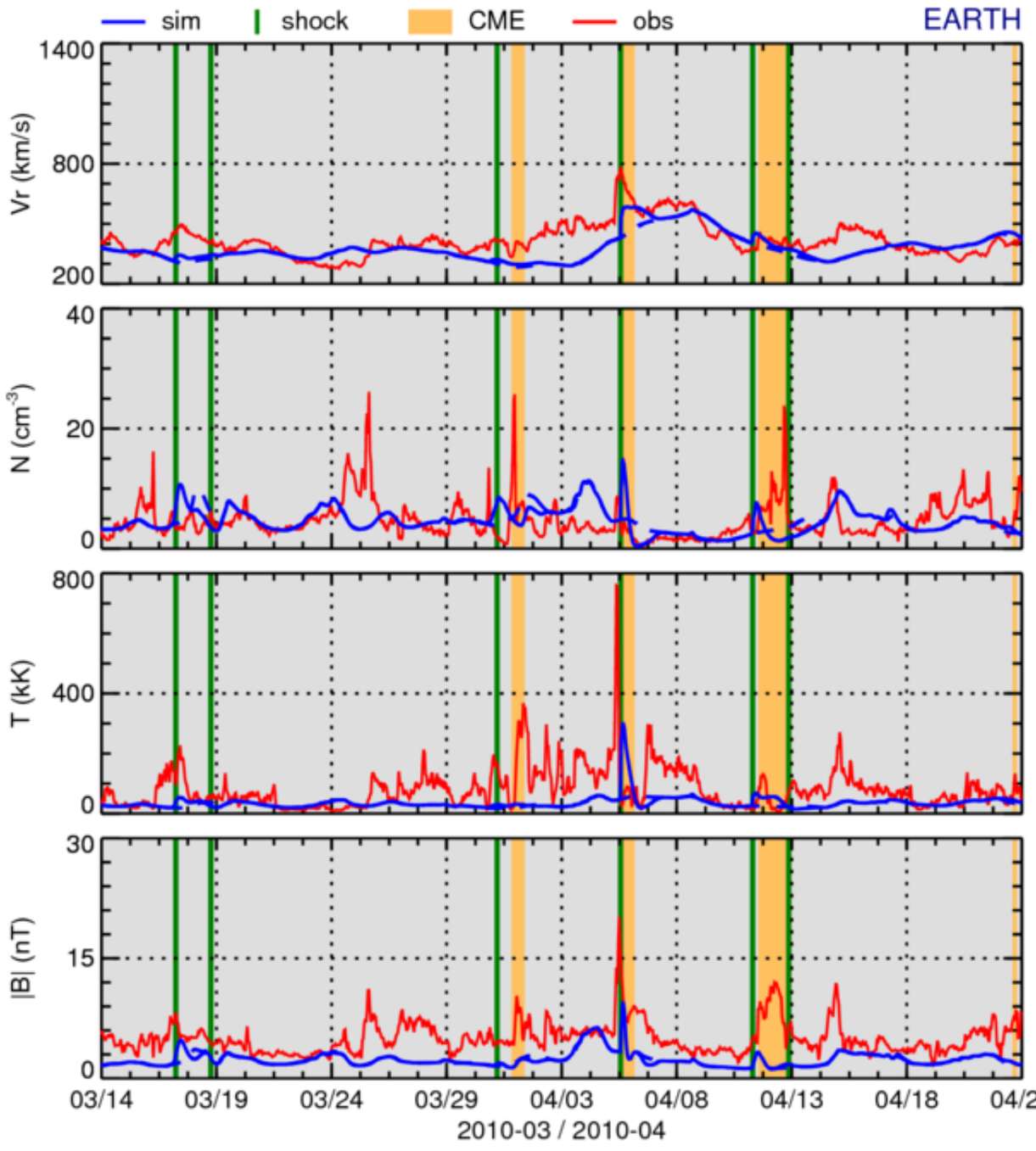


WSA-ENLIL-DONKI-HELCATS — Solar Wind Speed in 2012-03



ENLIL-lowres + GONGb-WSAtu-Cone / a6b1-d4t1x1

HELCATS+DONKI @ HelioWeather



ENLIL-lowres + GONGz-WSAtu-Cone / a6b1-d4t1x1

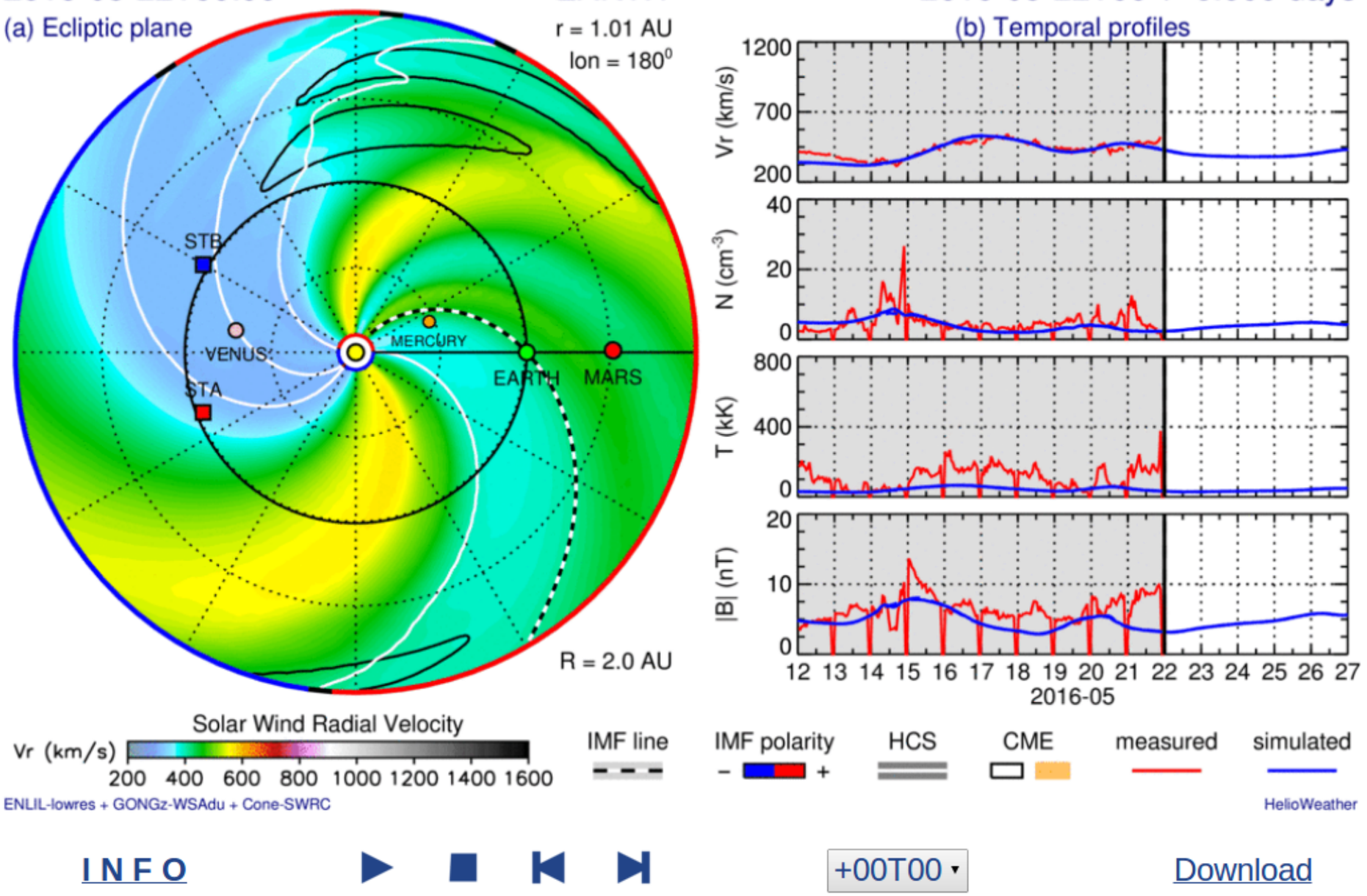
HELCATS+DONKI @ HelioWeather

Project Experimental Testbed — http://helioweather.net

WSAduz-SWRC – ENLIL Solar Wind Prediction – Velocity-2

Model Input:

- IPSbd
- WSAdub-SWRC
- WSAduz-SWRC
- WSAdtb-SWRC
- WSAdwb-SWRC



Model Output:

- Velocity-1
- Velocity-2
- Density-1
- Density-2
- STEREO-A
- STEREO-B
- Shock-SEP
- Evolution
- J-Maps

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- Various models & various outputs — continuous near-real time verification
- Fixed model parameters do not reflect variations over the solar cycle

International Use of ENLIL for Operational Space Services
(input T. Onsager, NOAA/SWPC)

- Enlil is utilized internationally for operational prediction of the background solar wind and CME propagation and is an essential forecasting tool

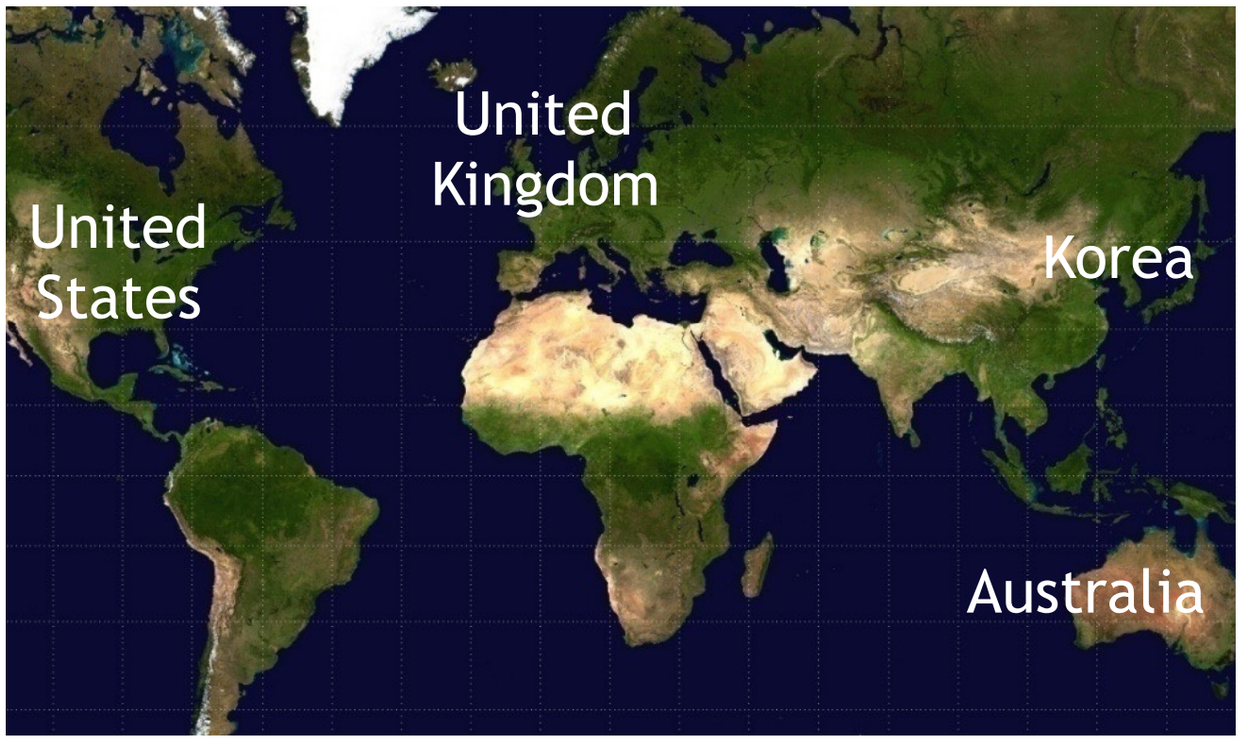
- Memorandums of Understanding and non-disclosure agreements with operational partners have been signed with Enlil as an element of cooperation

- Software versioning is maintained to ensure consistent product

- In operations, multiple runs may be evaluated for official forecasts

- Current partners include:
  - United Kingdom (Met Office)
  - Korea (RRA/KSWC)
  - Australia (BoM/SWS)

- Additional international partners have expressed interest



ENLIL at NASA/CCMC

(input from Anna Chulaki and L. M. Mays, NASA/CCMC)

- Community Coordinated Modeling Center (CCMC) is a multi-agency facility operated at NASA/GSFC

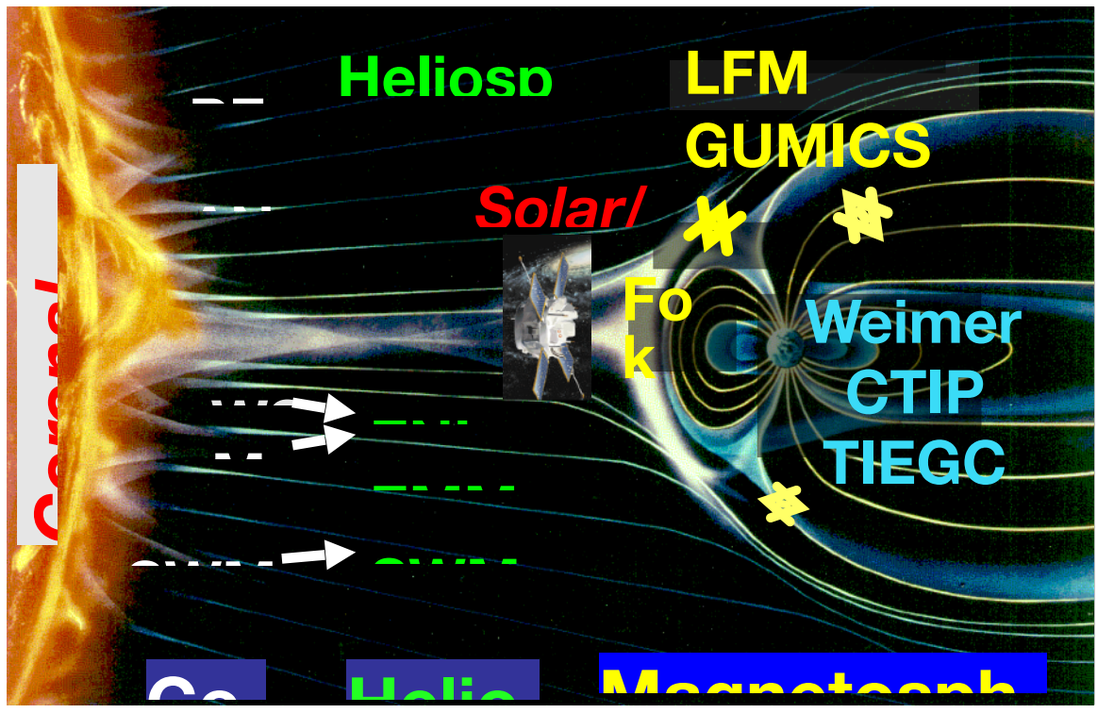
- ENLIL was implemented at CCMC in 2005 (legacy of NSF/CISM project) and it is used continuously since then for run-on-request & mission support services

- Total number of ENLIL requests is 5703 (as of May 17, 2016)

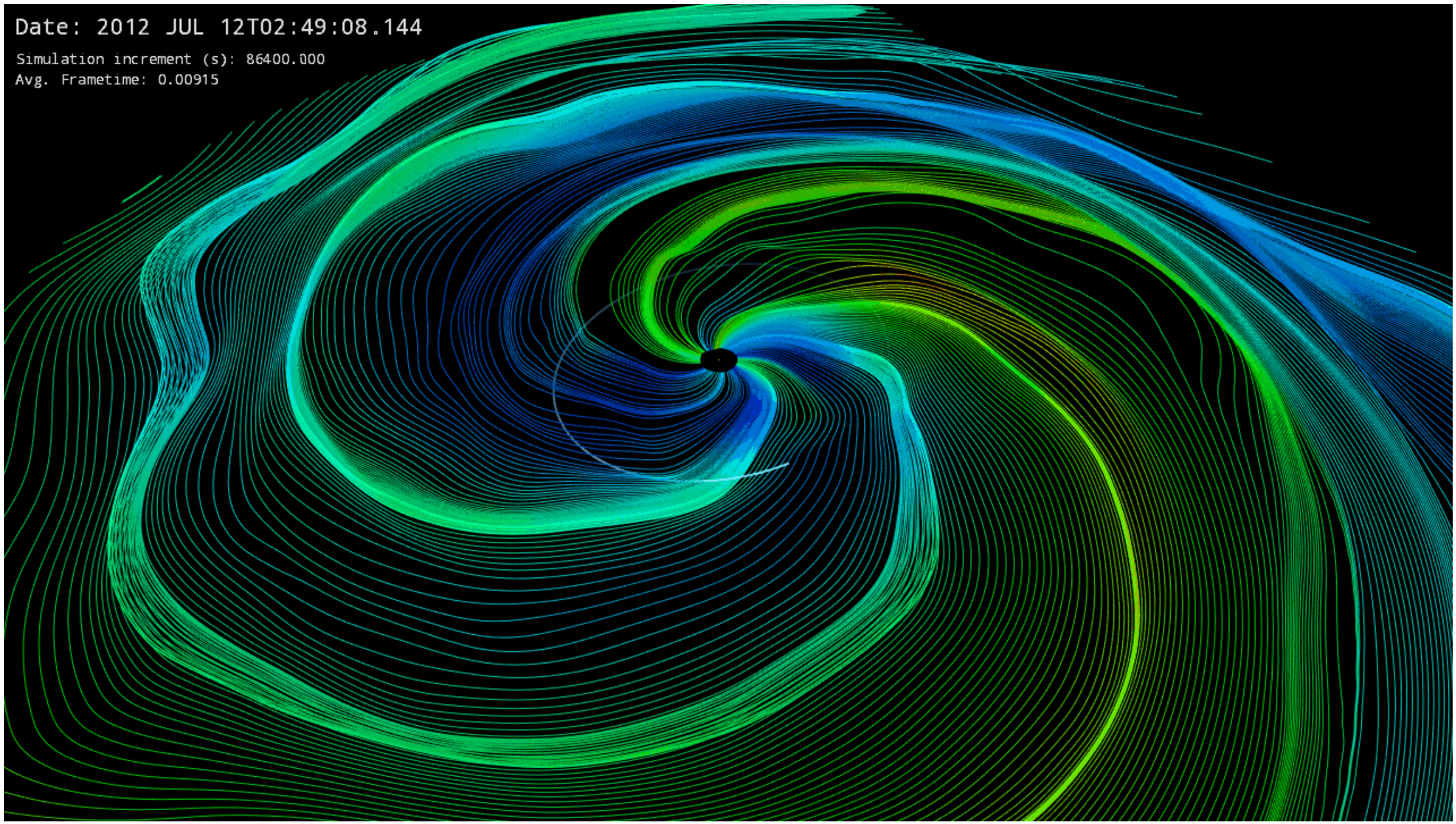
- There are only 9 papers & 22 presentations in CCMC database that explicitly mention ENLIL by name in their title. This is probably a very small subset of papers/publications that utilized ENLIL

- CCMC staff also independently evaluates and validates the modeling system and uses it for space weather predictions to support NASA robotic missions

- It is also used for education and public outreach



Visualization of Heliospheric Simulations at Planetariums



- OpenSpace is a multi-scale rendering software platform
- OpenSpace is open source software available for MacOD, PC, Linux on laptops, desktops, classrooms, planetariums, virtual reality
- OpenSpace enables interactive 3D visualization of space weather models at the NASA/CCMC
- ENLIL will be featured in the Sun-Earth day planetarium at AMNH (New York) on July 27, 2017

Visualization of Heliospheric Simulations at Planetariums

Morrison Planetarium (San Francisco, CA)

Hayden Planetarium (New York, NY)

- Collaborative project between NASA/CCMC, Linkoping Univ (Sweden), and American Museum of Natural History (New York, NY)
- OpenSpace tool — interactive, multi-scale, multi-display environments to explore out current understanding of Universe
- Ultimate goal — a general open-source visualization software enabling synchronized presentations in planetariums across the globe

Summary

- We developed new versions of the WSA-ENLIL-Cone modeling system capable to handle new inputs & produce new outputs
- We set up the project testbed system for “on-fly” verifications of various new versions under near-real-time conditions
- Updated WSA-ENLIL-Cone modeling system can now routinely predict:
  - ICME arrival times (ejecta and/or shock) in mid-heliosphere
  - ensemble modeling
  - evolving background solar wind
  - IMF topology and shock parameters for SEP models & alert plots
  - synthetic white-light images (for “mid-course” correction)
- We realized large-scale calibration & validation studies to evaluate new features, compare with previous versions, and with other models implemented at CCMC
- We continued in development of the SEP model and applied it to selected multi-CME event scenarios observed during maximum of solar activity
- We authored or co-authored 18 papers and made numerous presentations at domestic and international conferences. Impact of our work has been enhanced by CCMC users.
- Updated WSA-ENLILCone modeling system facilitates:
  - direct comparison with remote and in-situ observations at planets and spacecraft
  - high-quality images and animations red for presentations/publications
  - scripting system to support research and prediction activities
  - supports heliospheric predictions & mission planning relevant to NASA missions