Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting

(Helio-Weather — Next Generation WSA-ENLIL-Cone)

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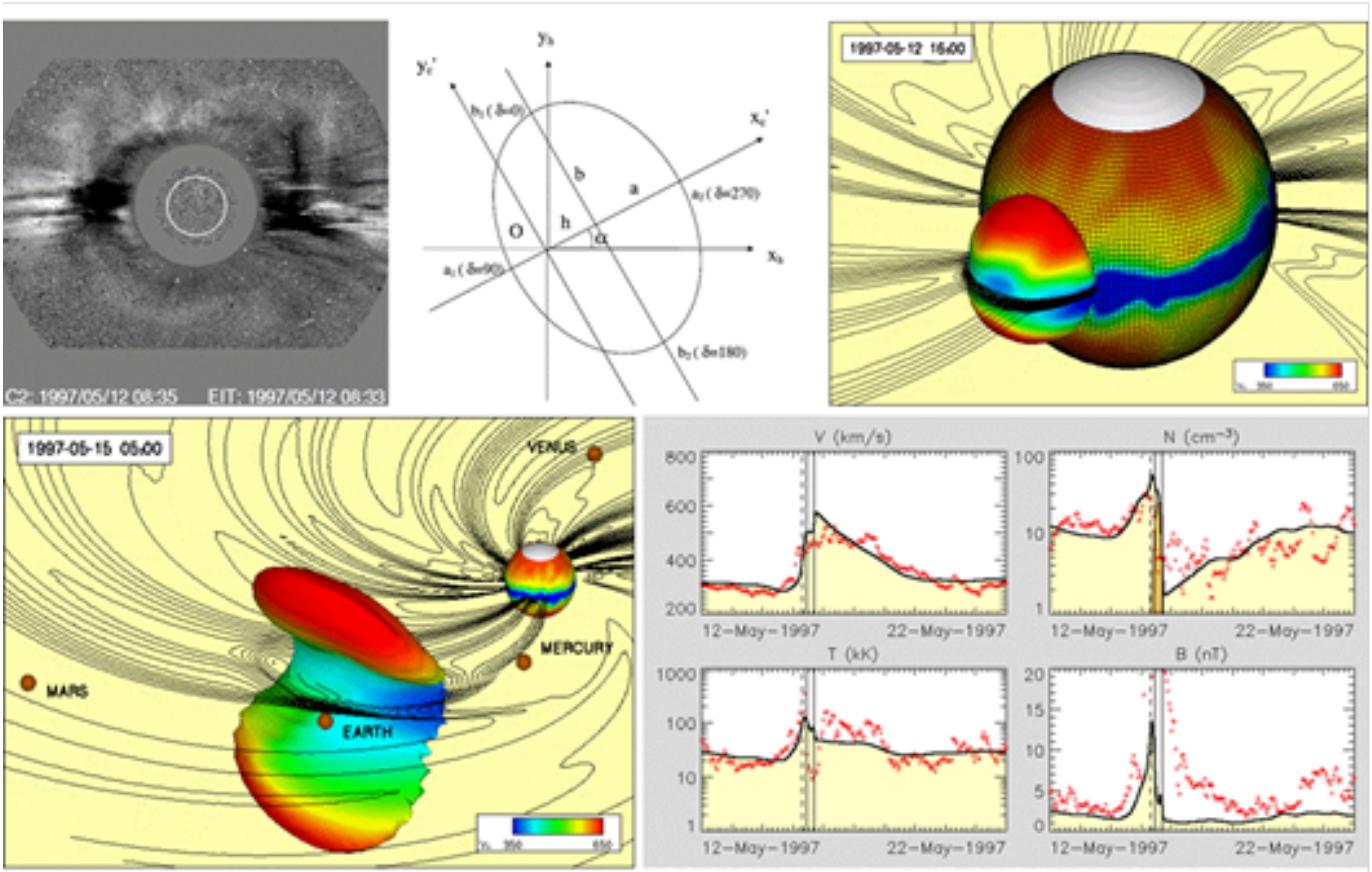
Background — WSA-ENLIL-Cone Model

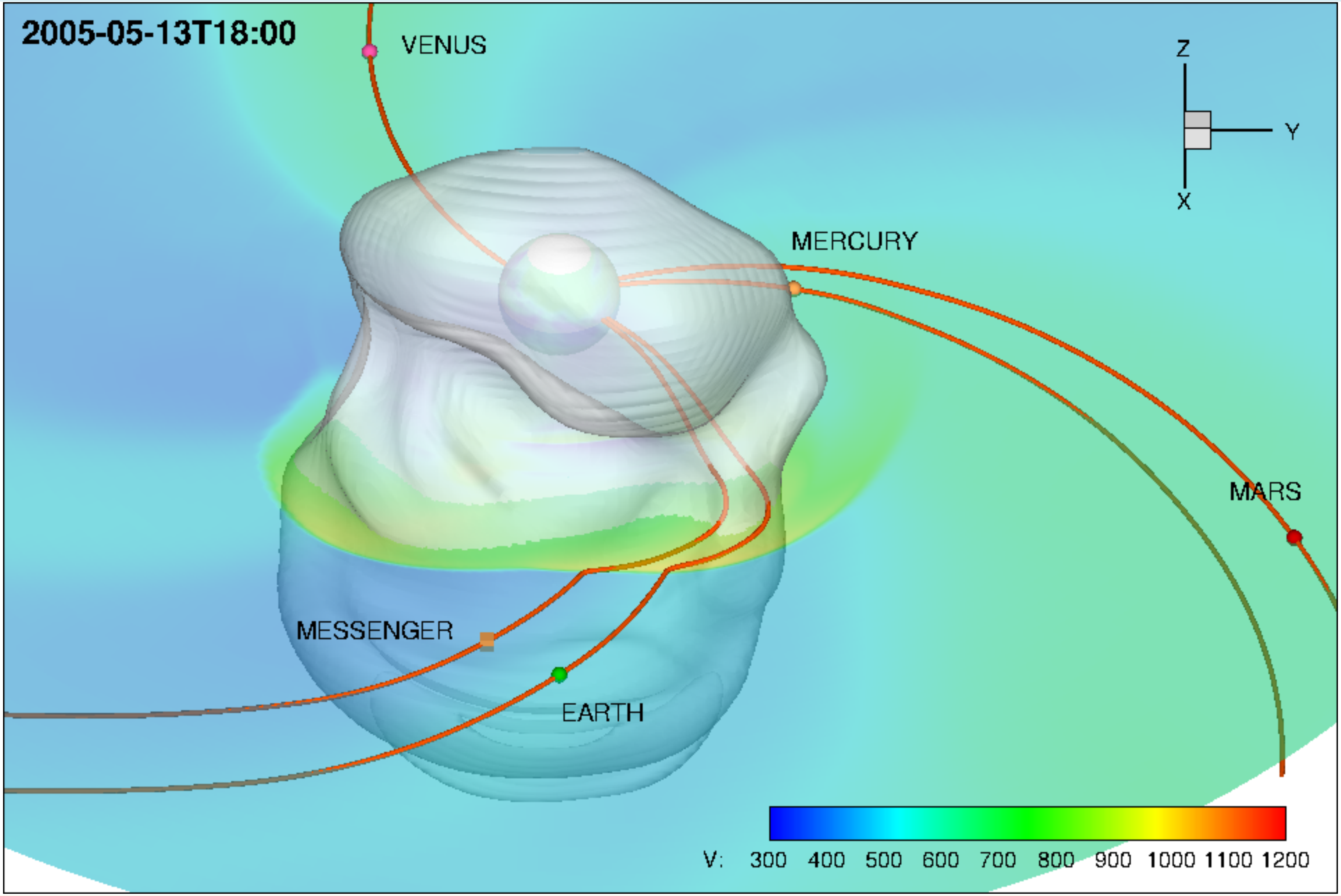
- Prediction of the heliospheric space weather — corotating & transient disturbances
- Implemented at: NASA/CCMC, NOAA/SWPC, UK/MetOffice, KSWC

Solar Wind in Mid-Heliosphere — Driven by Single Map



- Observationally driven, near-real time, “hybrid” modeling system
- Routine simulation of co-rotating streams & CMEs, event-by-event, much faster than real-time
- Used at NASA/CCMC & NOAA/SWPC; further development supported mainly by NASA & AFOSR

2005-05-13 CME — "Cone" Model Simulation

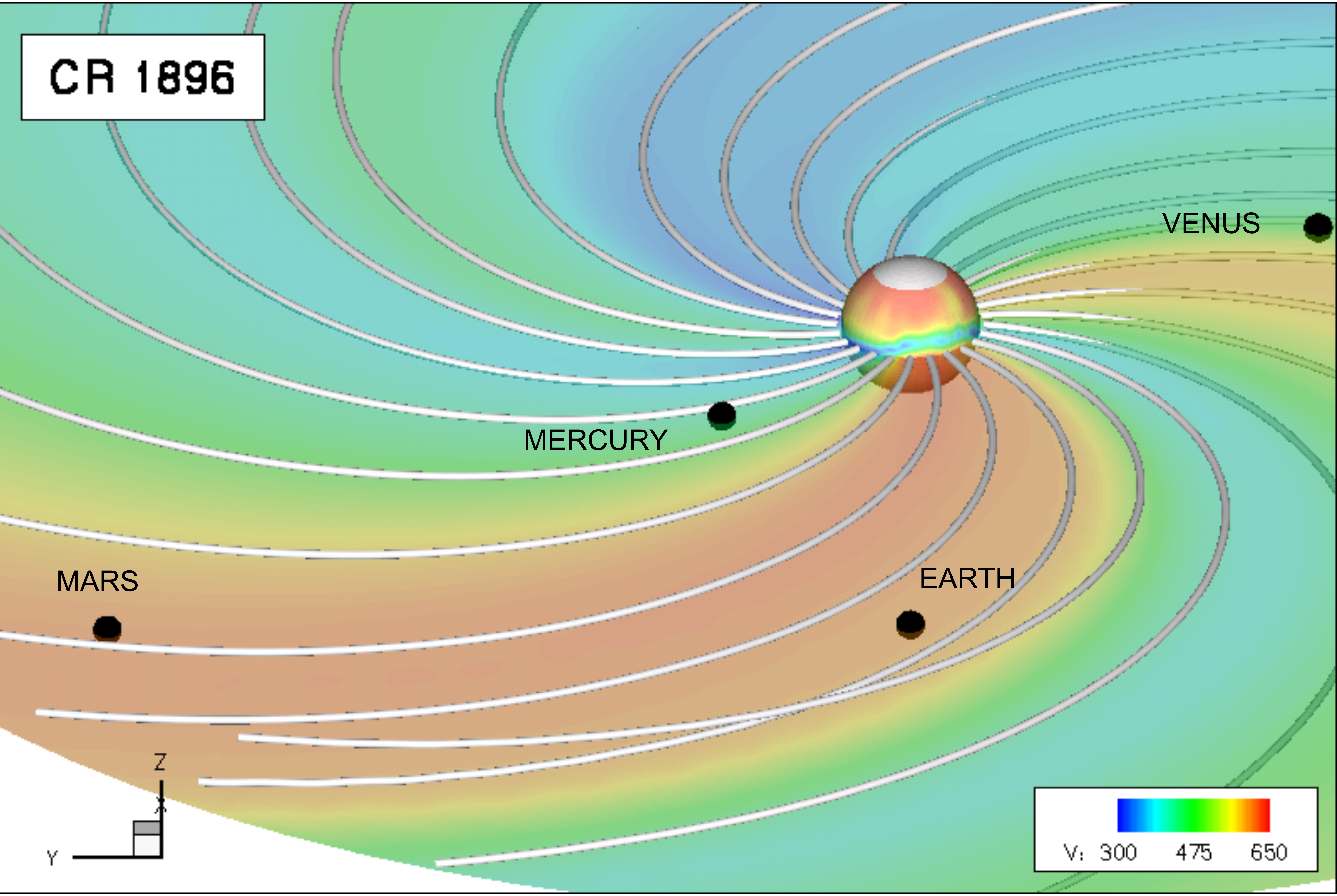


- CME axis close to the Sun-Earth direction — no Bz by shock compression and/or IMF draping
- Model can predict arrival of shock and/or ejecta, and IMF topology
- Simulation is very fast — operational predictions, parametric studies, ensemble modeling

Solar Wind — Calibration & Validation

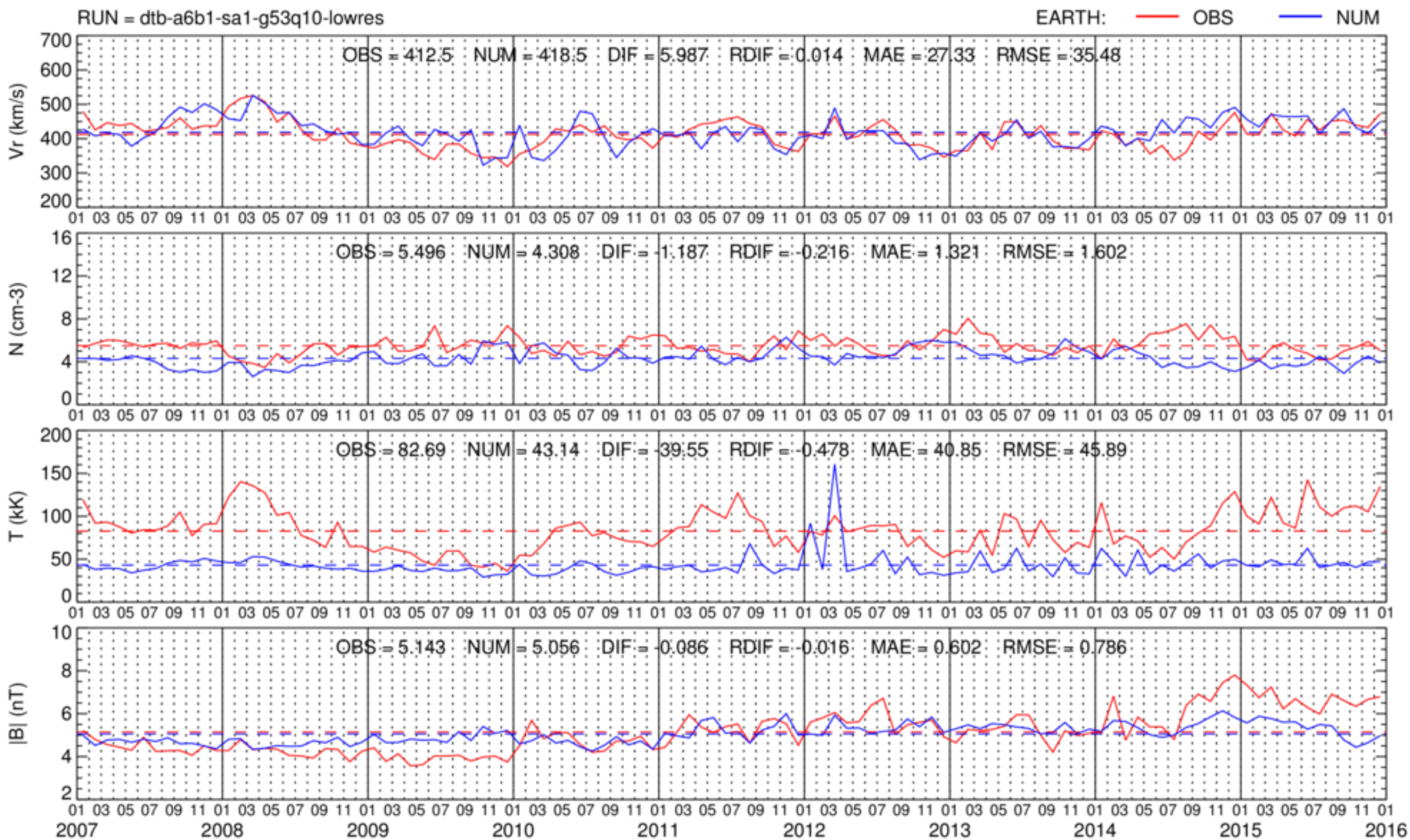
- ENLIL is driven by outputs from coronal models: WSA+Cone
- Incomplete input is supplemented by empirical formula for density & temperature
- Model-free parameters need to be calibrate to provide as best background as possible

Near Solar Minimum



E2.8 — wsadt — corobs=gongb — amb=a6b1 — runpar=g53q5

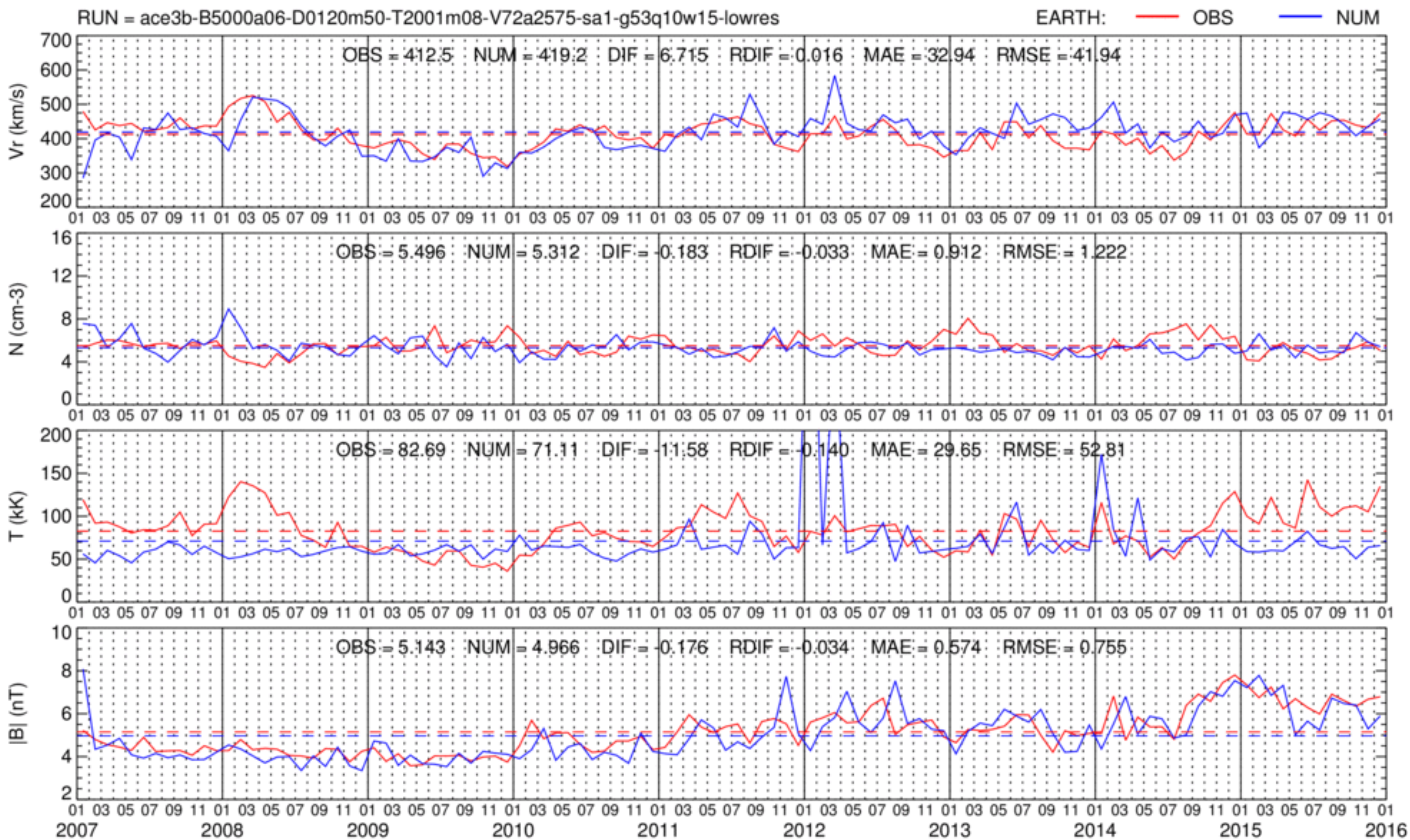
B=Bwsa*4 (0/350), V=Vwsa (200-75/700-25), Dfast=125 cm-3, Tfast=1.5 MK



- Parameters found to match average global solar wind measured at L1 — THIS IS USED AT CCMC & SWPC
- Fixed model parameters do not reflect variations over the solar cycle

E2.9 — wsadt — corobs=gongb — amb=ace3a — runpar=g53q10w15

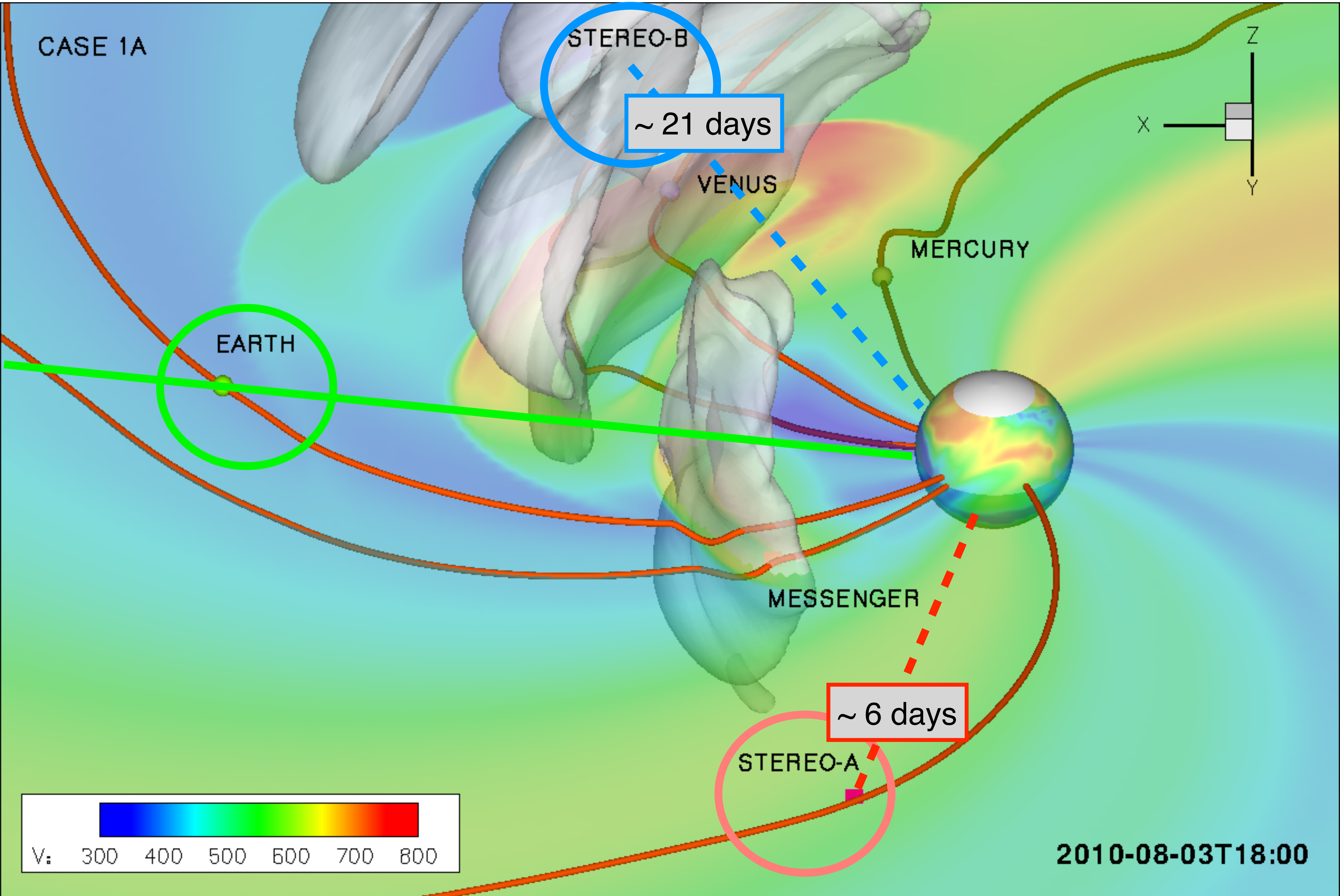
B=Bwsa*Bace*0.6 (0/500), V=Vwsa*Vace (200-75/700-25), Dmean=500 cm-3, Tmean=0.8 MK



- ACE beacon data are used to set parameters for each month — predictions reflects solar-cycle variations
- Solving both thermal and total energy ensures more accurate shocks and smooth rarefactions

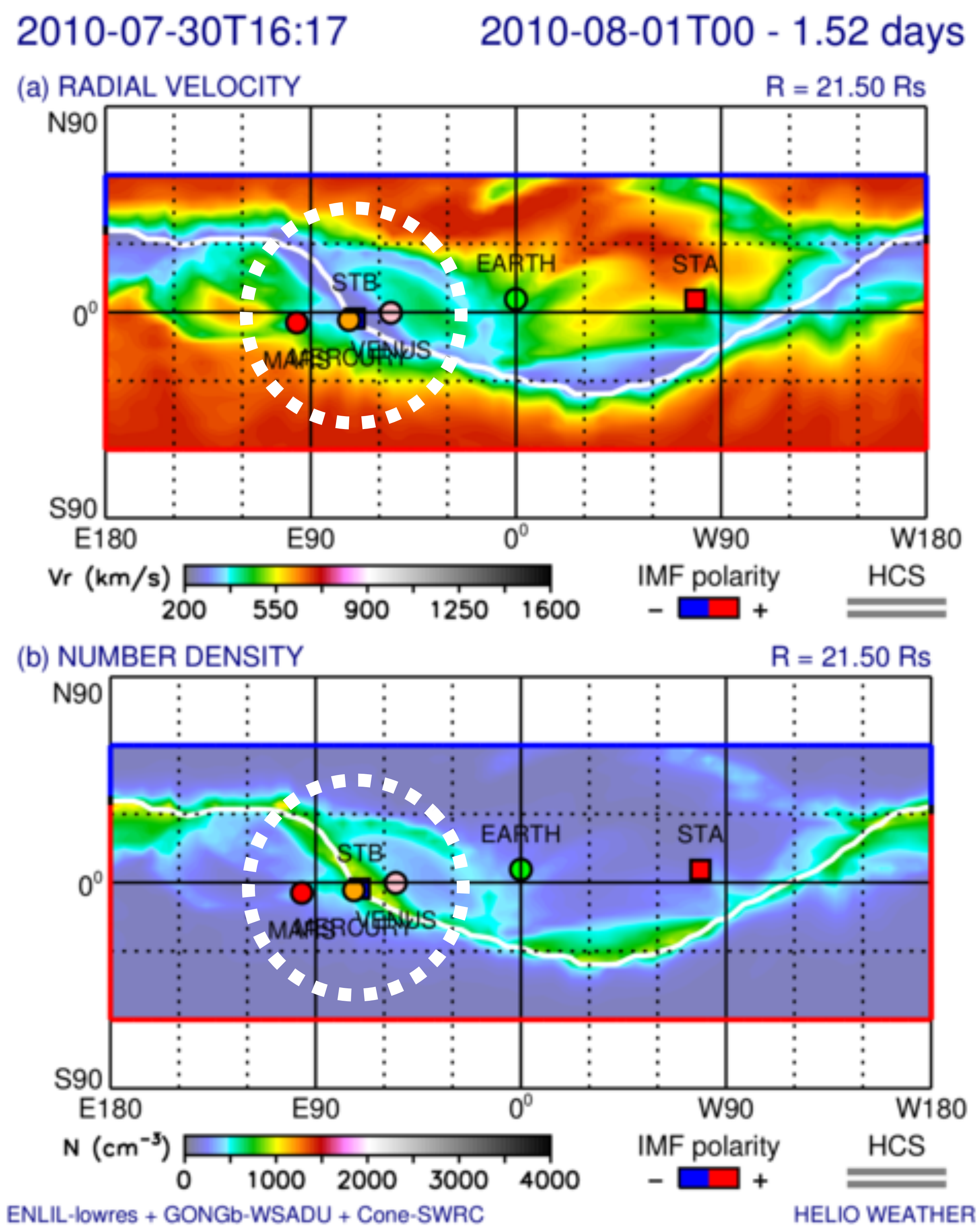
Background Solar Wind — Need for L4/L5 Observations

Simulation of Multi-CME Events

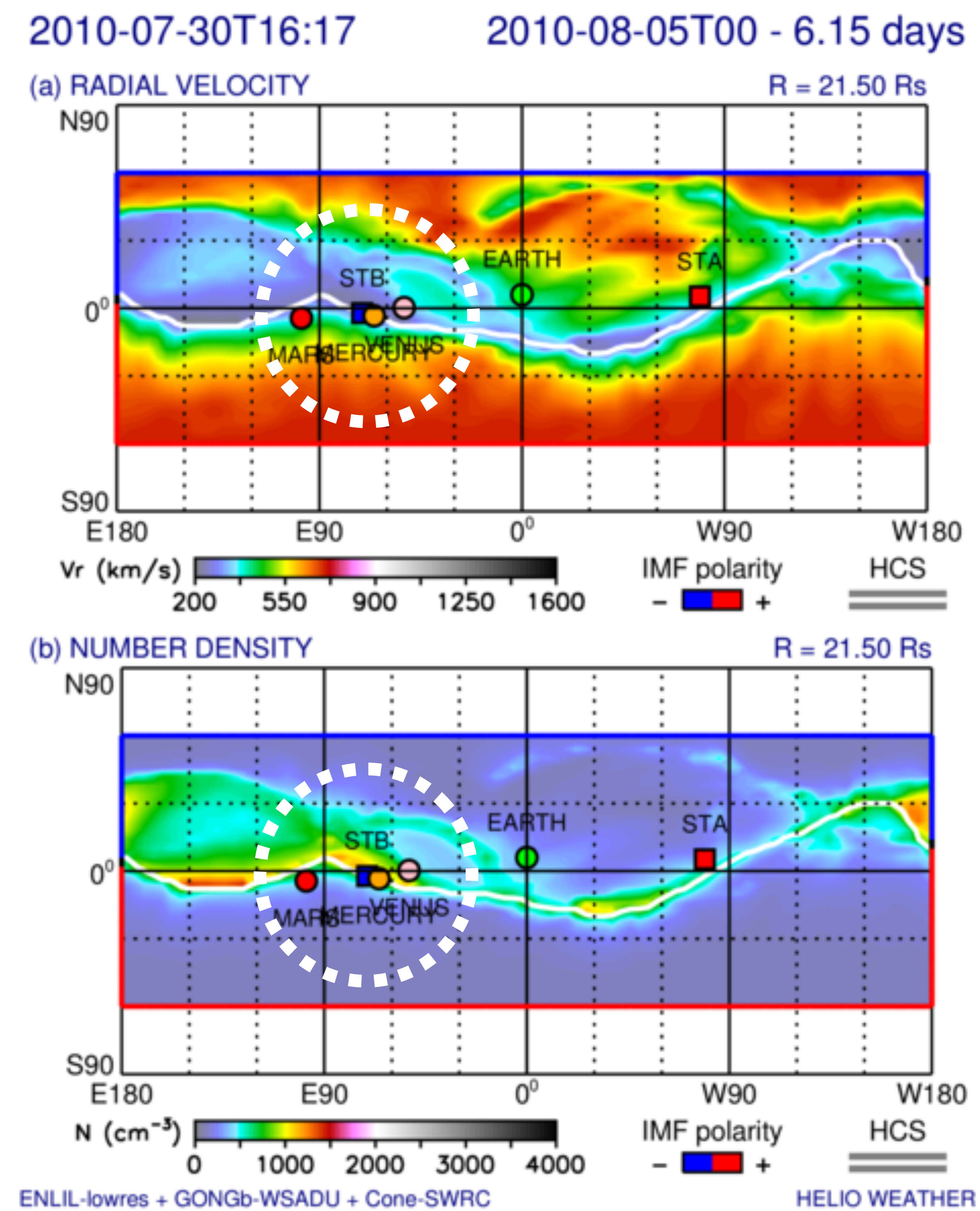


Boundary Conditions – Single WSA Map

Using WSA Map of Aug 1

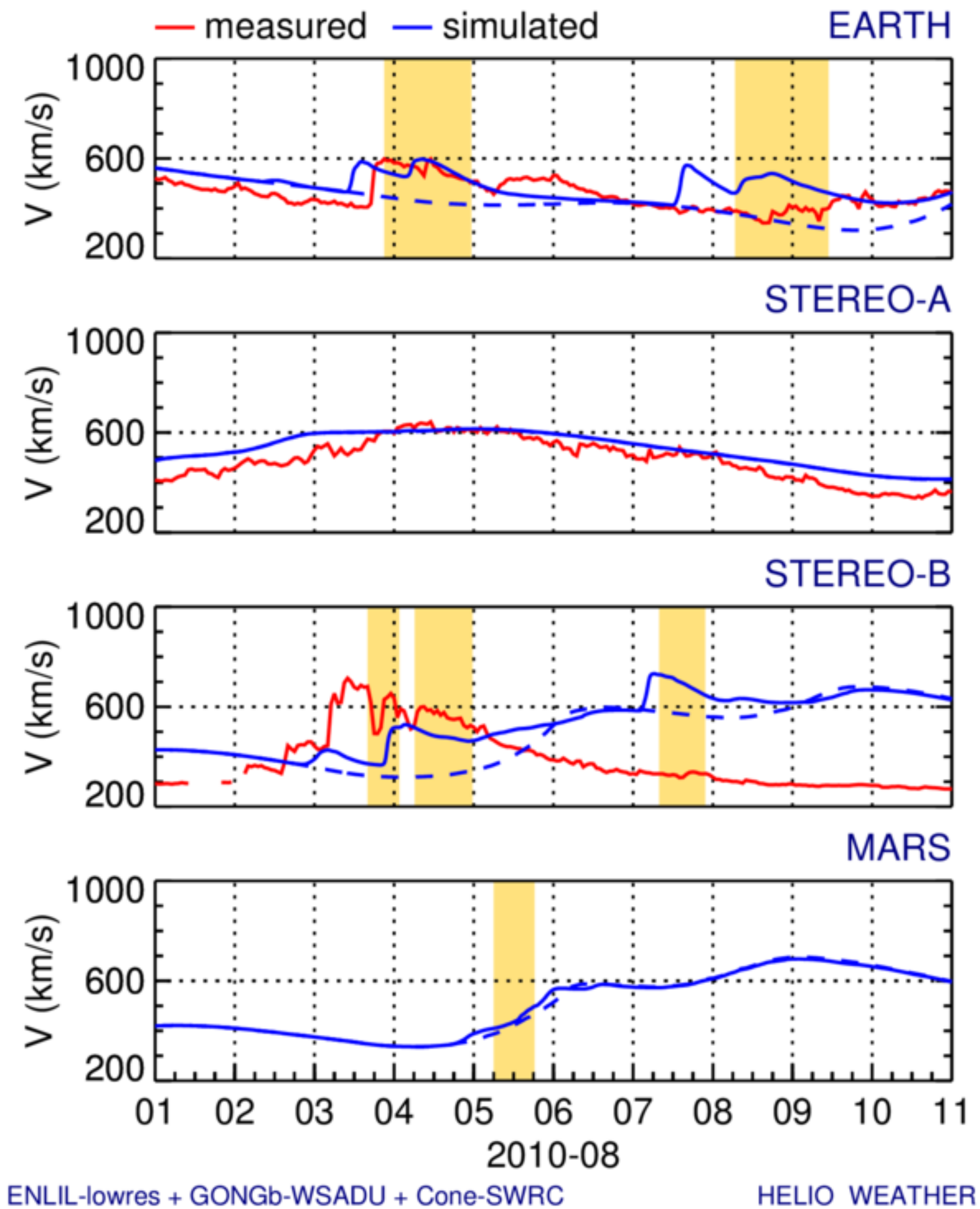


Using WSA Map of Aug 5

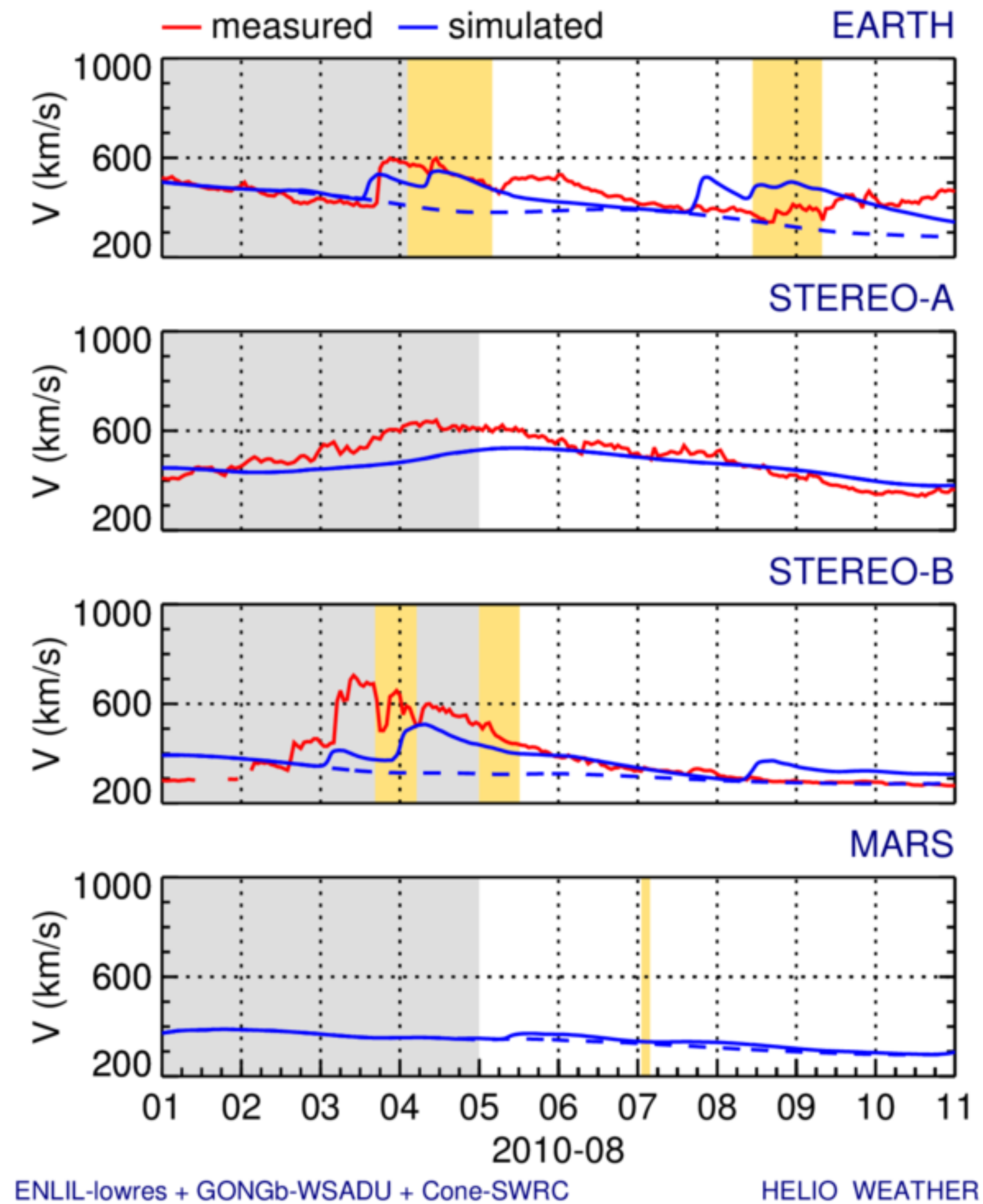


Solar Wind Velocity at Various Locations

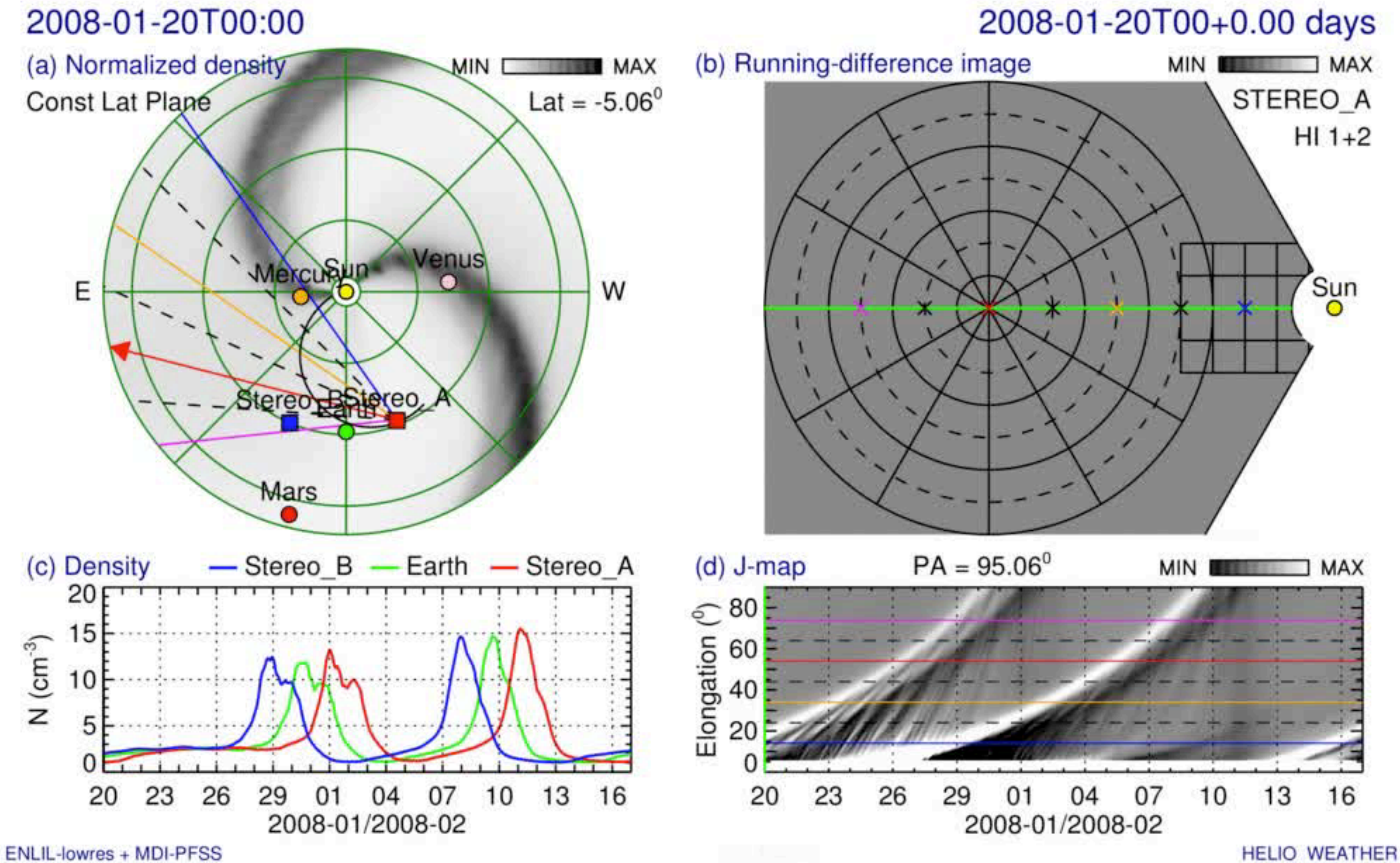
Using WSA Map of Aug 1



Using WSA Map of Aug 5

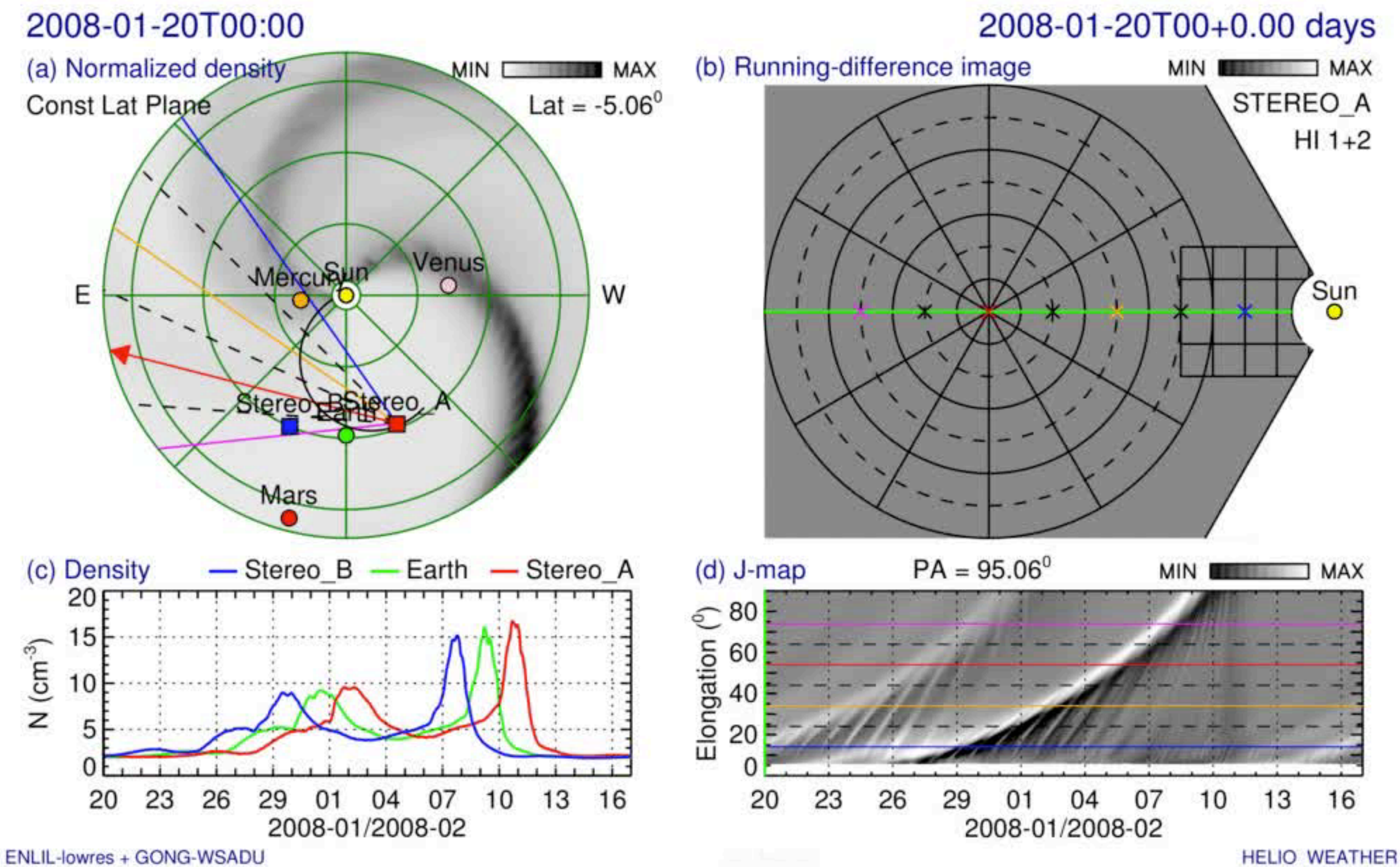


Prediction of High-Speed Streams — PFSS/MDI



- Remote observations by heliospheric imagers (STA & L4) can provide evaluation of various numerical predictions well before corotating and/or transient disturbances arrive at Earth
- Numerical results are presented with streams visibility enhanced by small-scale “blobs”

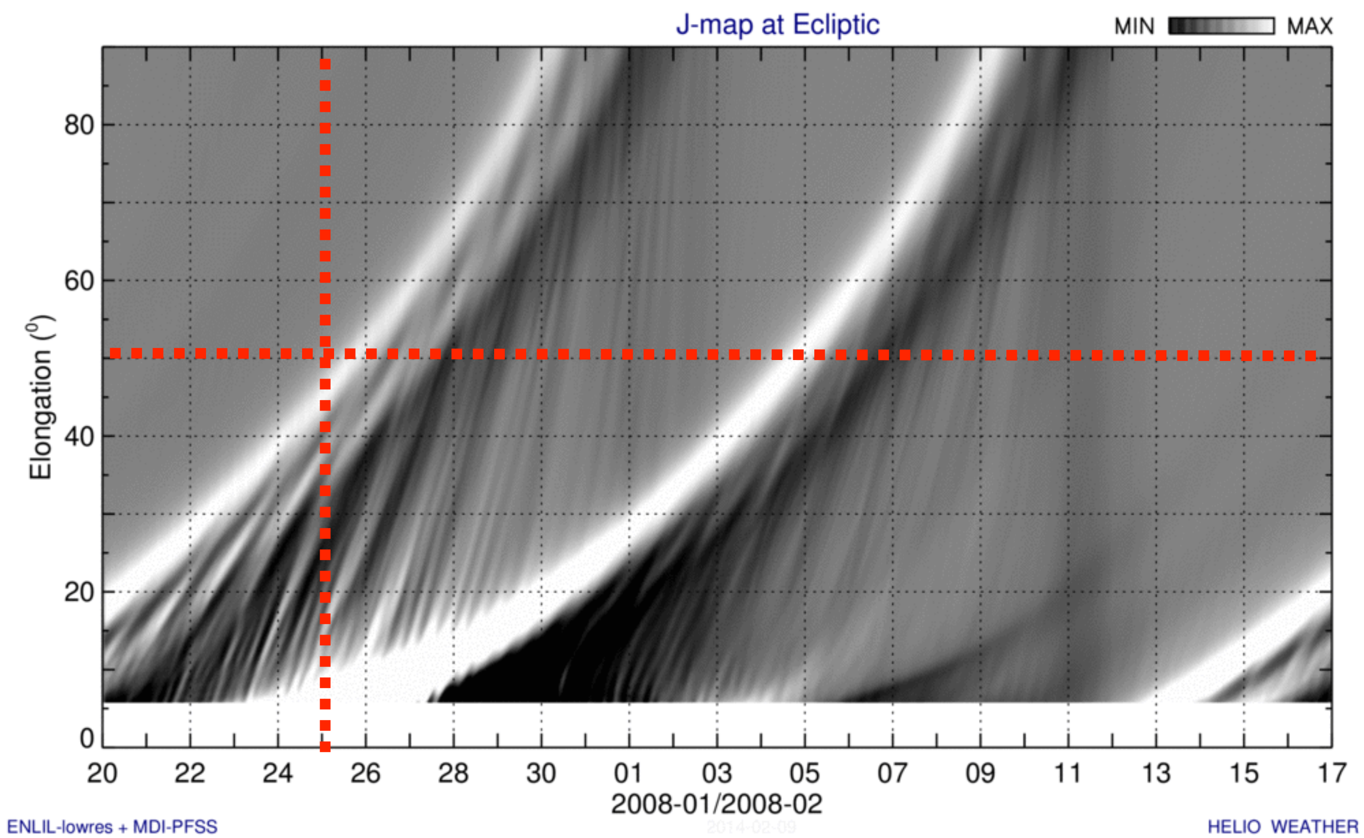
Prediction of High-Speed Streams — WSA/GONG



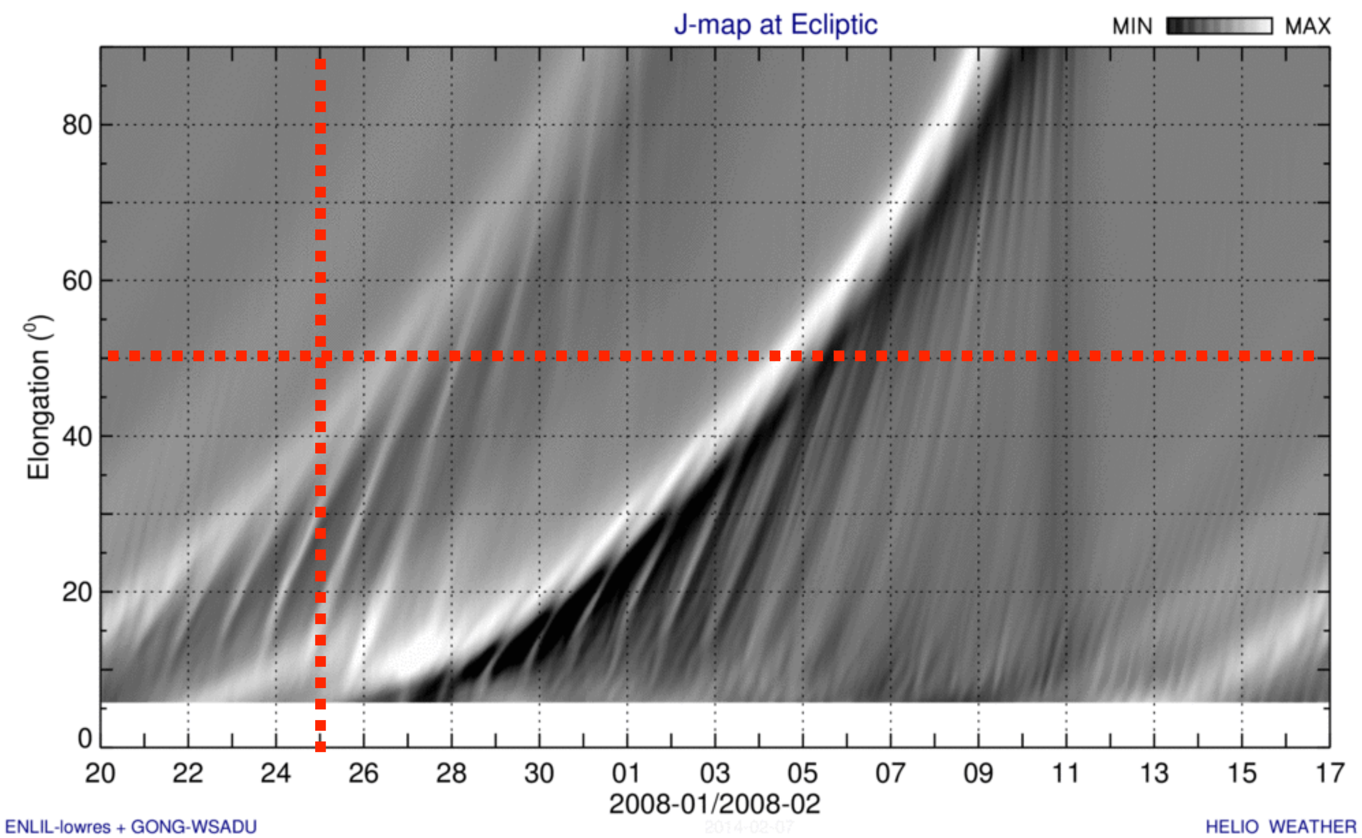
- Remote observations by heliospheric imagers (STA & L4) can provide evaluation of various numerical predictions well before corotating and/or transient disturbances arrive at Earth
- This output is routinely available at CCMC now

Comparison of Two Predictions — J-Maps

Run with MDI-PFSS



Run with GONG-WSADU



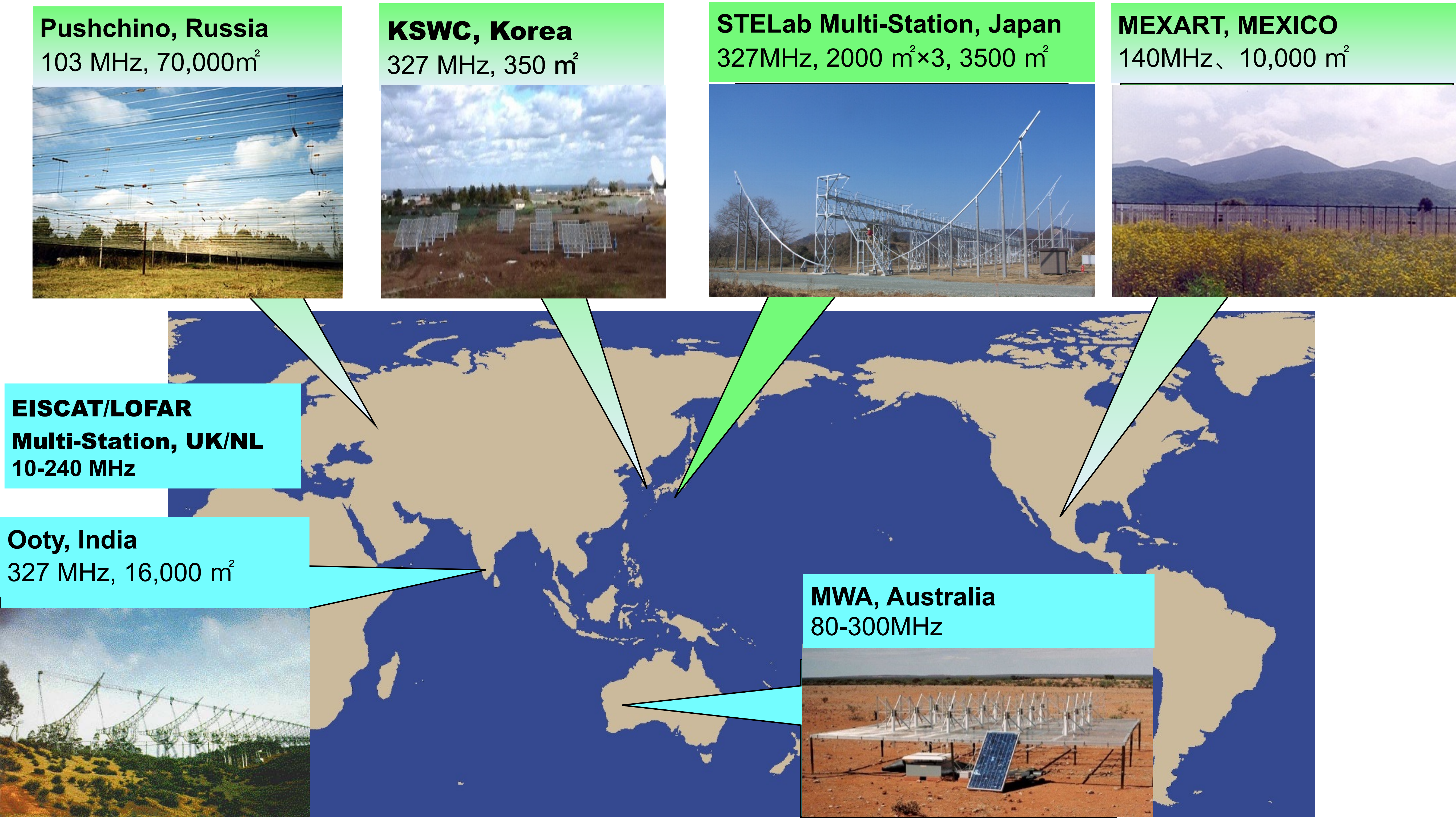
- Both runs show two bright structures – compressed density by solar wind stream interaction
- Converging patterns of small-scale structures correspond to blobs that are overtaken by fast streams (this helps to differentiate between CMEs and streams)
- Difference in the brightness and slope can be clearly seen for the first streamer track while the second stream is about the same
- This suggests that the MDI-PFSS run will cause stronger streamer with earlier arrival to Earth
- Since the stream interaction regions can be seen well before their arrival to Earth, scientific (i.e., no need for beacon) data can be also used to suggest which prediction is more accurate
- There are very few clear "textbook" examples for possible "mid-course" correction use

Incorporation of IPS Observations

- Fully automatized alternative to inputs from coronagraphs
- Modeling support to world-wide observation network
- Collaboration with KSWC & UCSD

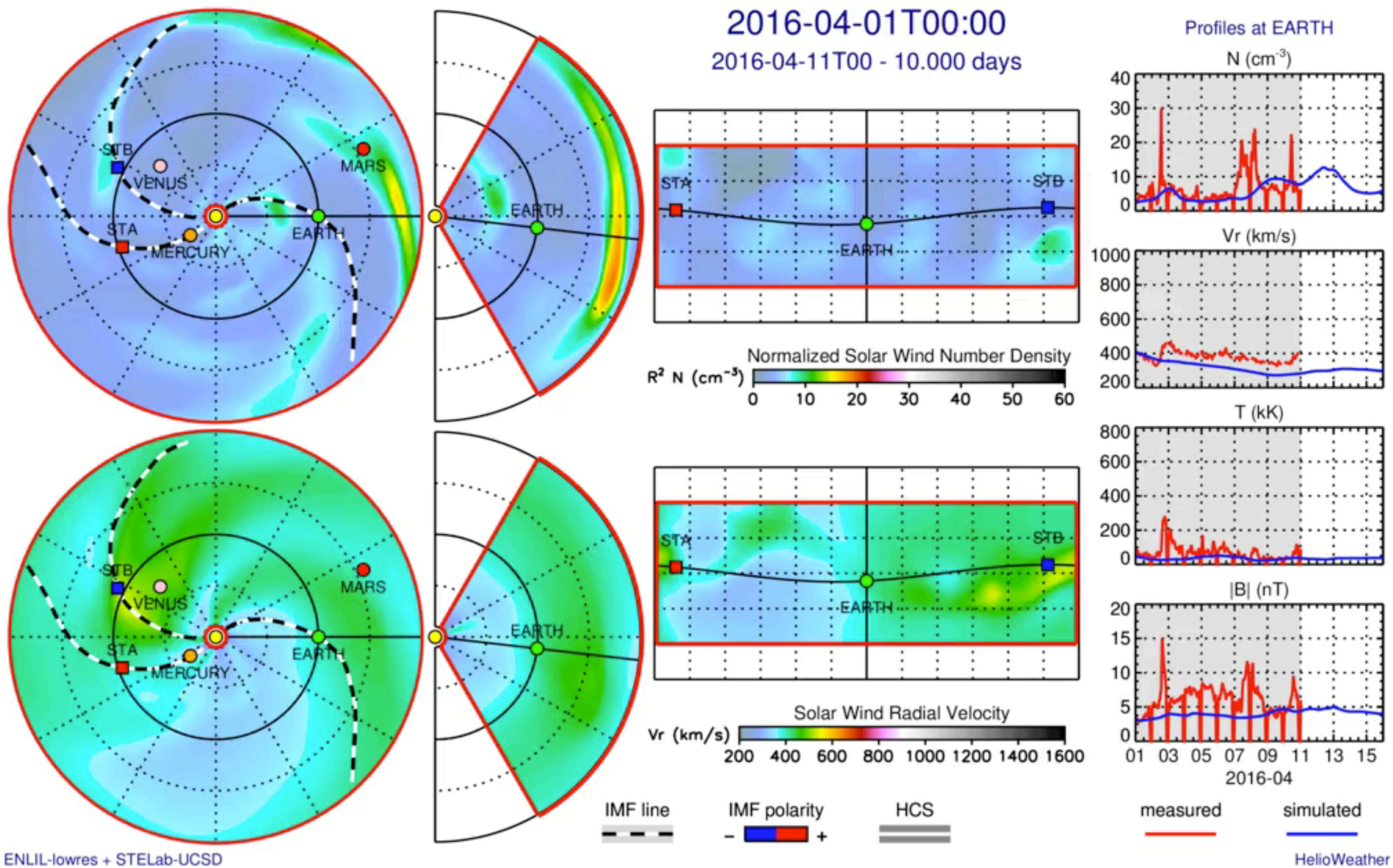
World-Wide IPS Observation Network

(Adapted from B. V. Jackson)



- Currently — only one operational IPS radio array system — STELab (Japan)
- Near future — MEXART (Mexico), {Pushchino (Russia) — later: KSWC (Jeju, Korea)
- Existing/constructed arrays for research — Ooty (India), EISCAT/LOFAR (UK/NL), MWA (Australia)

Using IPS Data to Drive Heliospheric Predictions

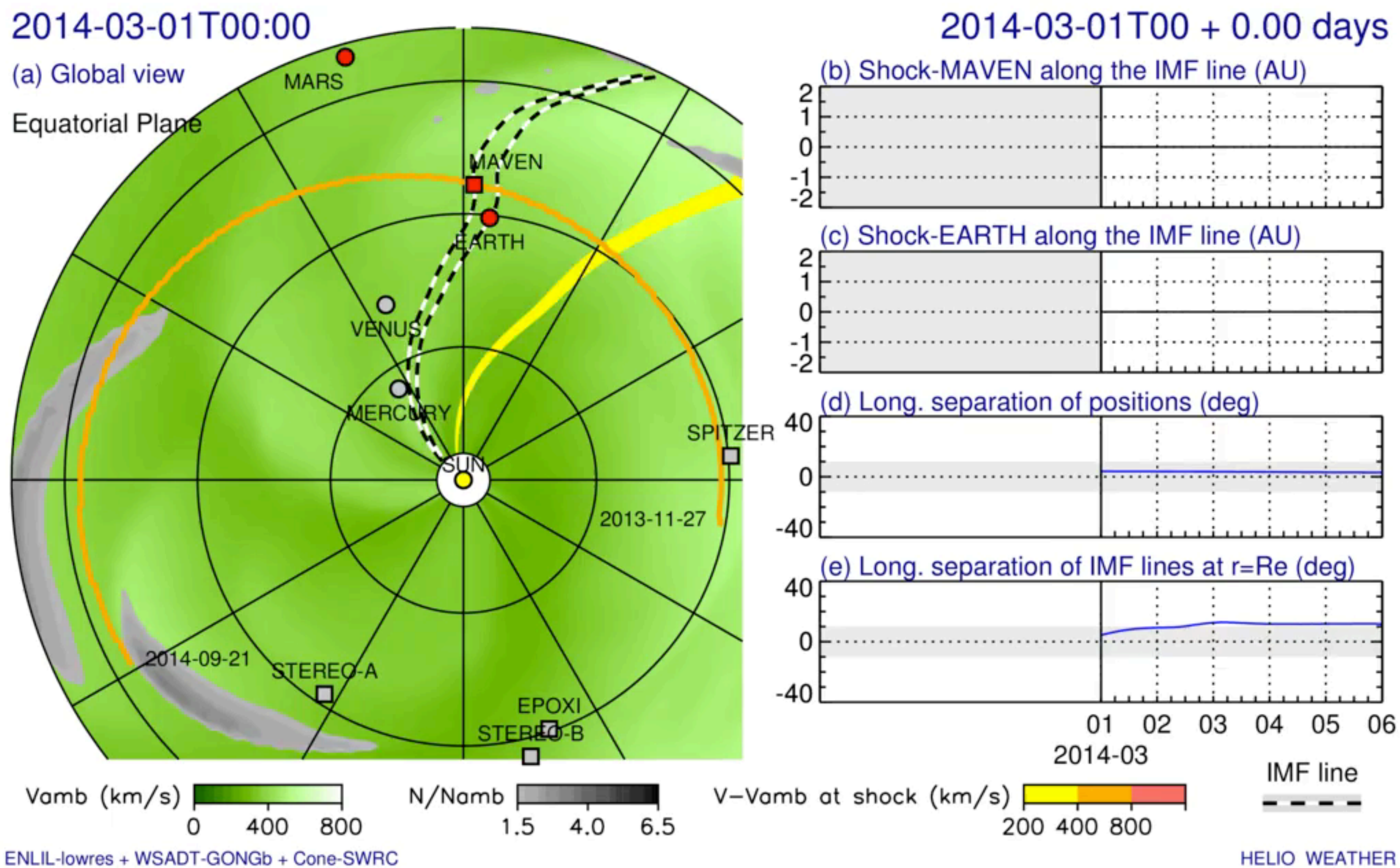


- IPS observations from STELab + UCSD tomographic reconstruction — values at 0.1 AU
- Time-dependent boundary values drive ENLIL heliospheric computations
- Fully automatized alternative (backup) to coronagraph fitting — will improve with more radio arrays

NASA Mission Support

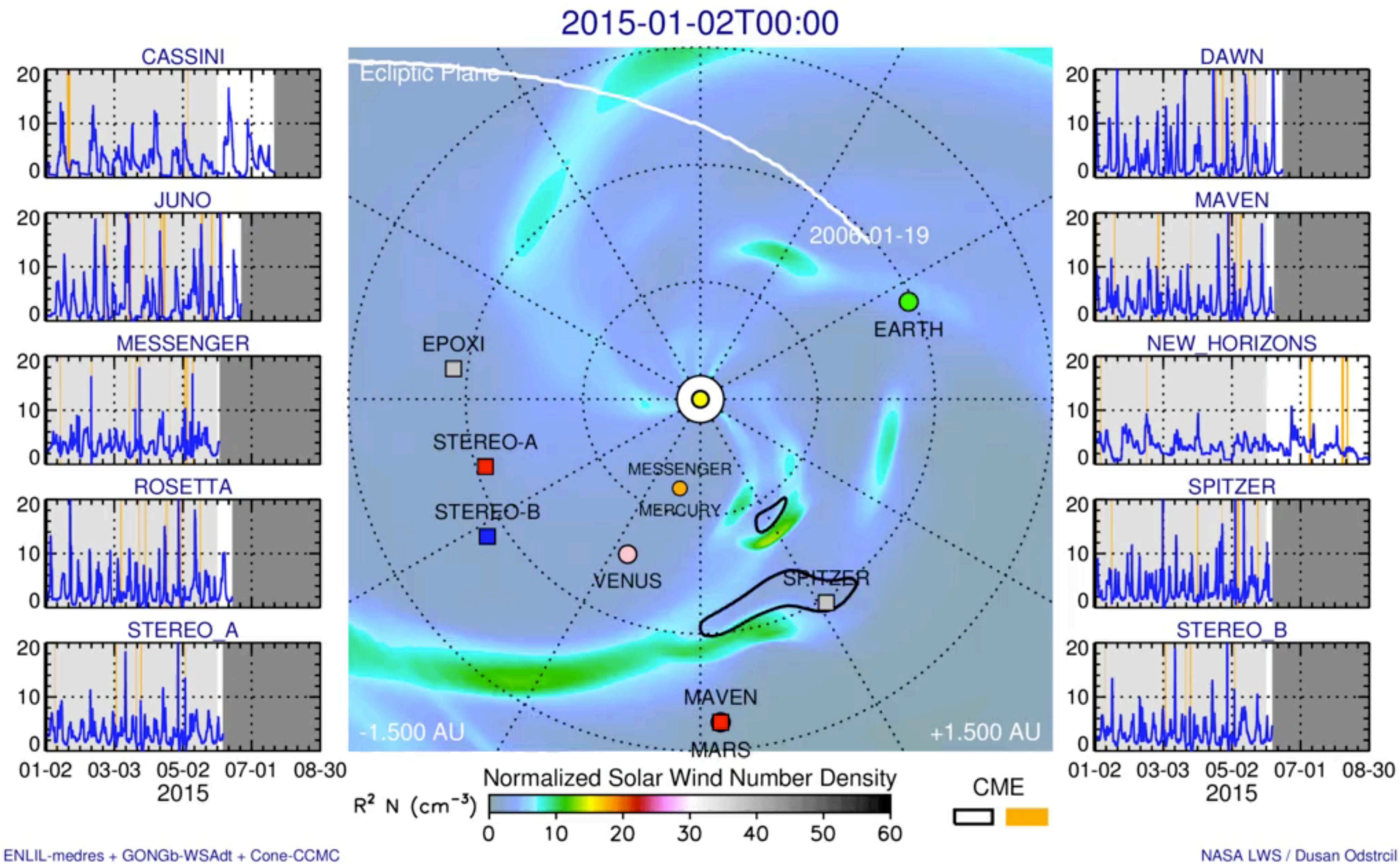
- Heliospheric space weather prediction — CCMC/SWRC forecasts
- Mission planning — special-request runs
- Community science & education support — CCMC run-on-request

MAVEN Cruise to Mars — Predicted SEPs 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

WSA-ENLIL-Cone — Operational Heliospheric Predictions



- 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

Conclusions

- WSA-ENLIL-Cone can 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)

- Versions delivered to CCMC: v2.7 (2014), v2.8 (2014/2015,) v2.9 (in progress)

- The Helio-Weather Project is very grateful to CCMC, collaboration with its staff helped to compensate the budget reduction, provided modeling support and feedback, and enhanced research and prediction applications