ENLIL – CCMC Collaborations

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in collaboration with:
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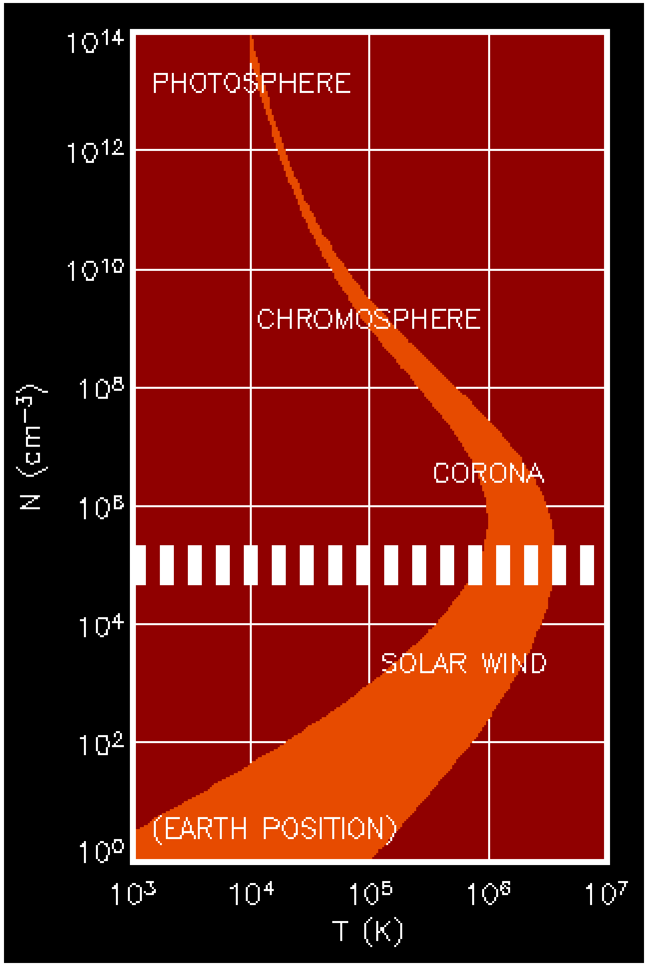
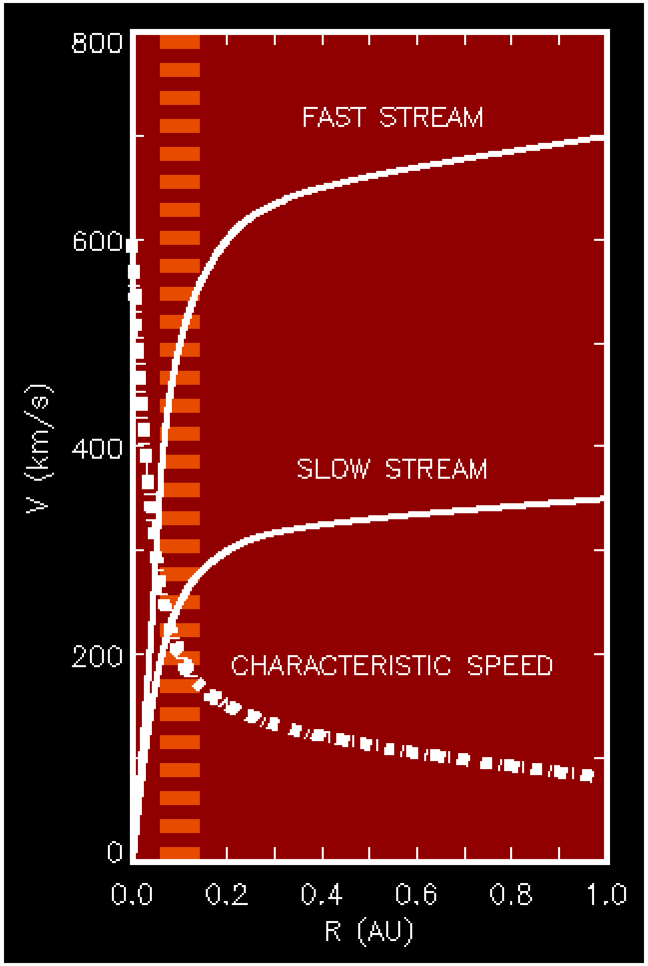
CCMC Workshop, Clearwater Beach, FL, October 11-14, 2005

Solar Wind Plasma Parameters

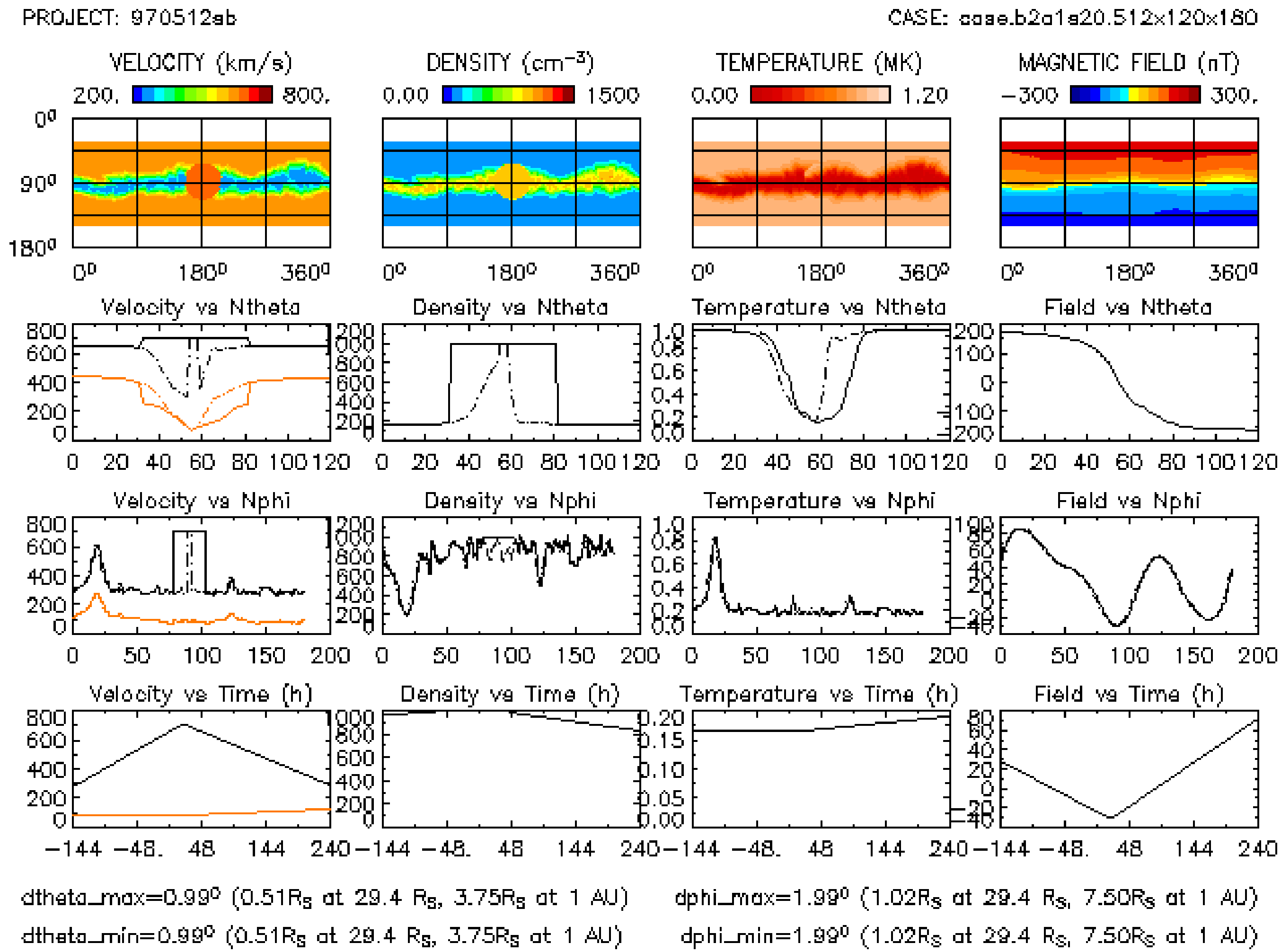


Large variations in plasma parameters between the Sun and Earth; different regions involve different processes and phenomena



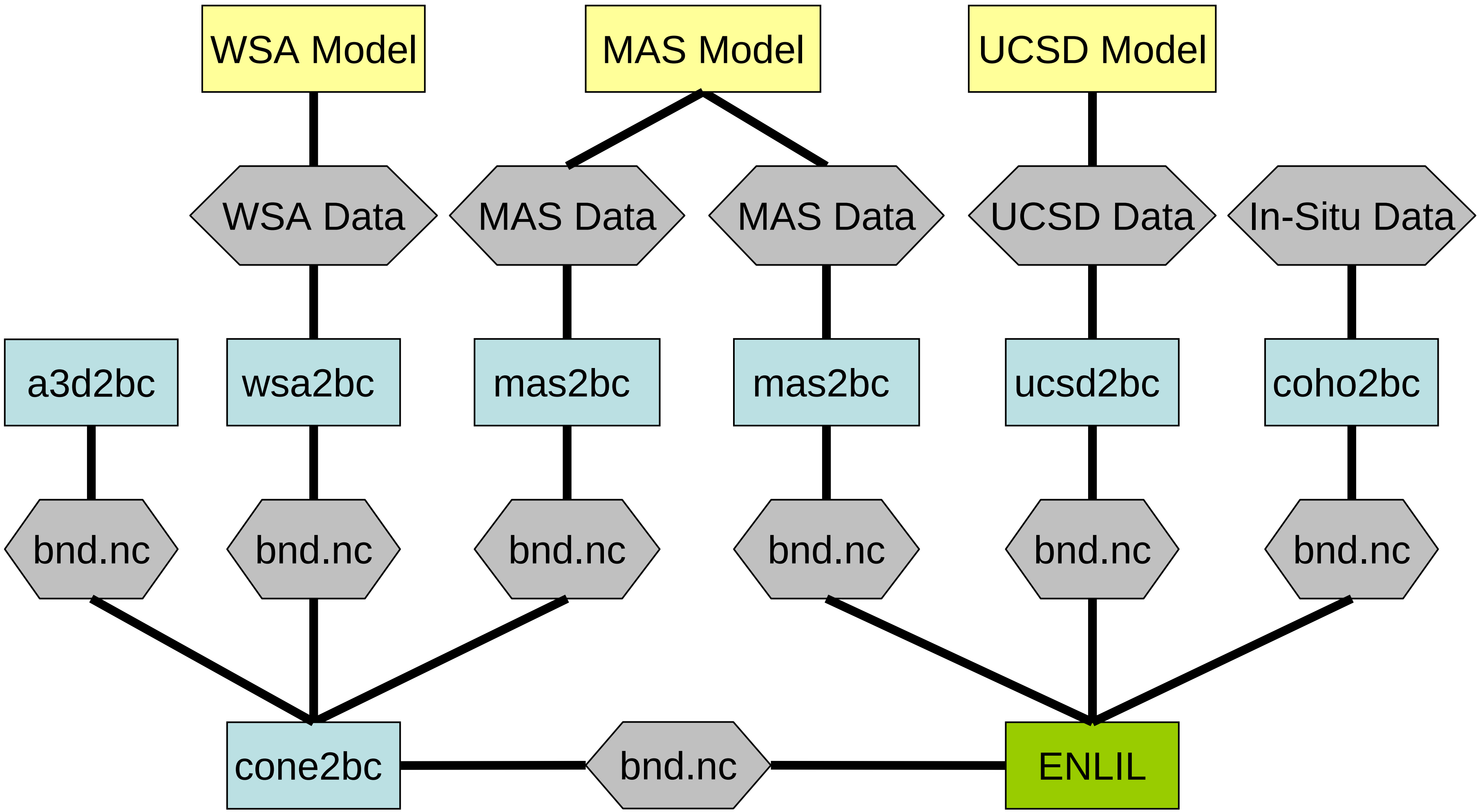
We distinguish between the coronal and heliospheric regions with an interface located in the super-critical flow region (usually 18-30 Rs)

Time-Dependent Boundary Conditions



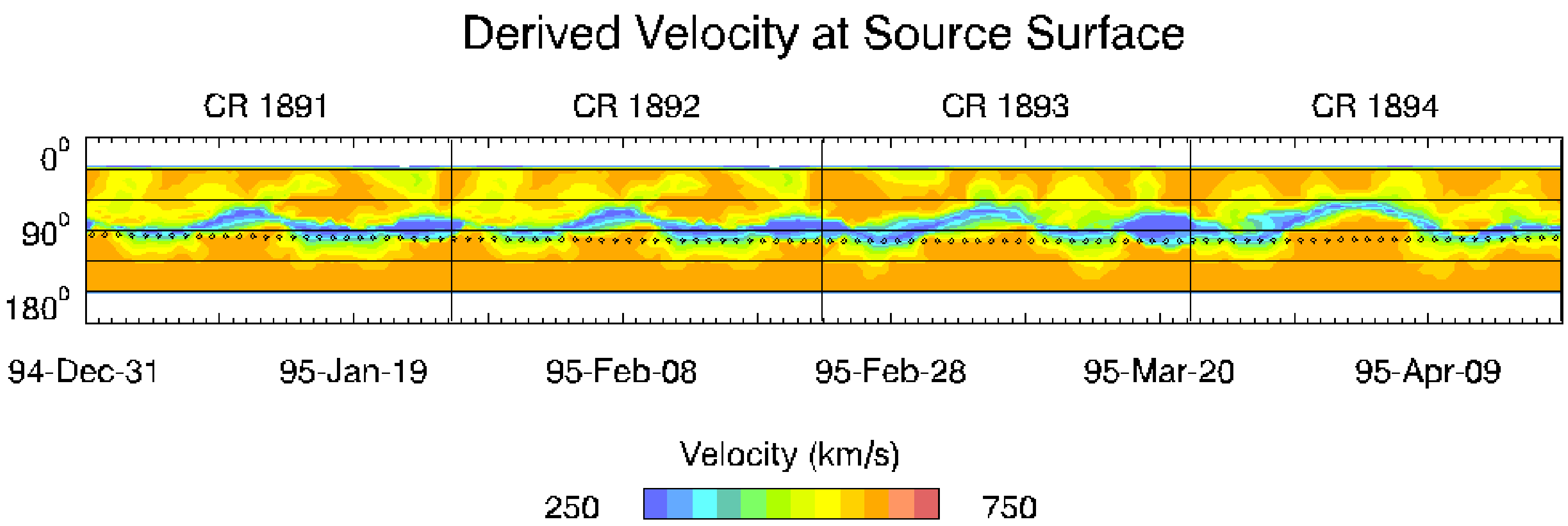
- Boundary conditions are necessary to drive the heliospheric computations
- Their generation is fully separated from the heliospheric model

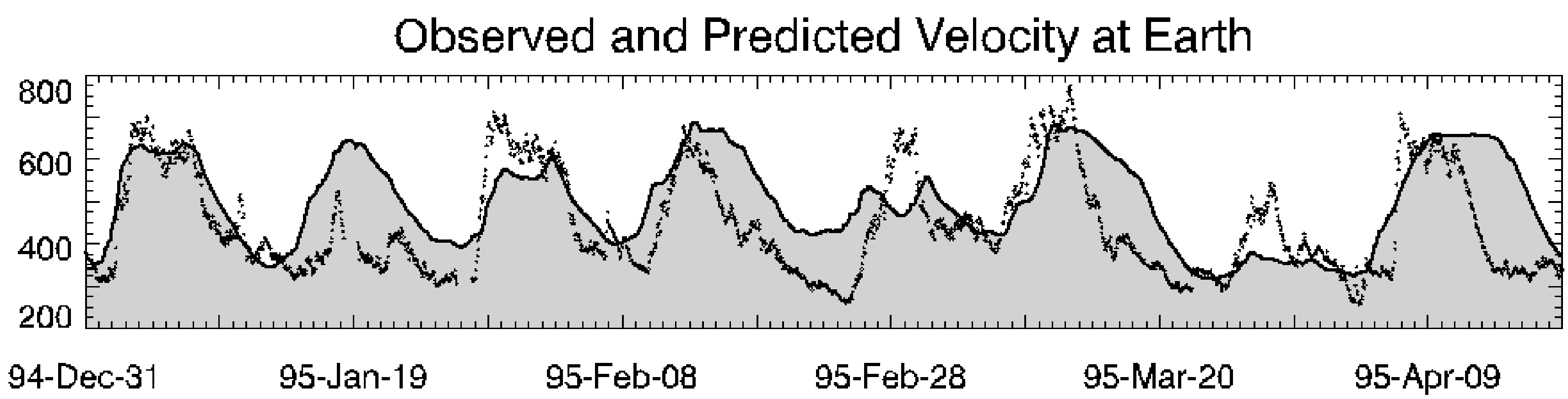
Driving Heliospheric Computations at CCMC



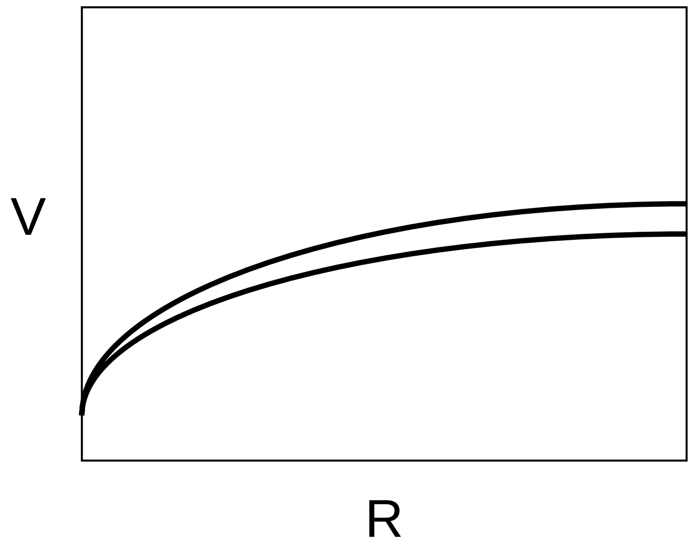
- Currently, there are three models (yellow) that can be used to drive ENLIL (green)
- Computational system shares data sets (grey) and uses couplers (blue)

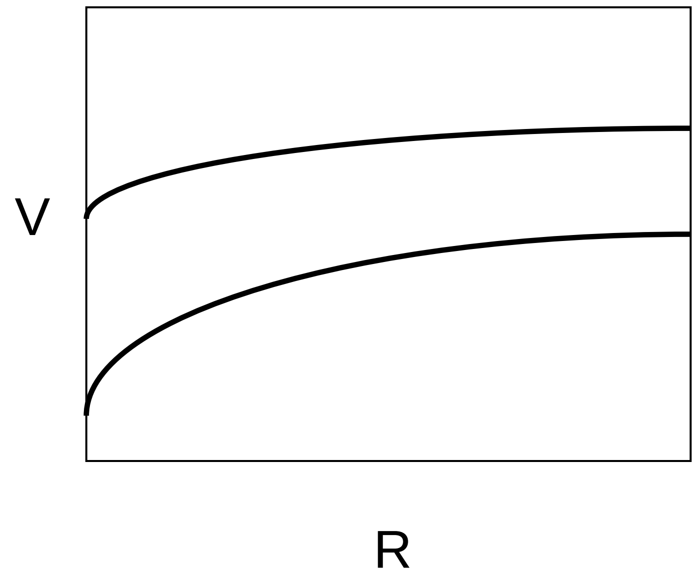
Prediction of Ambient Solar Wind





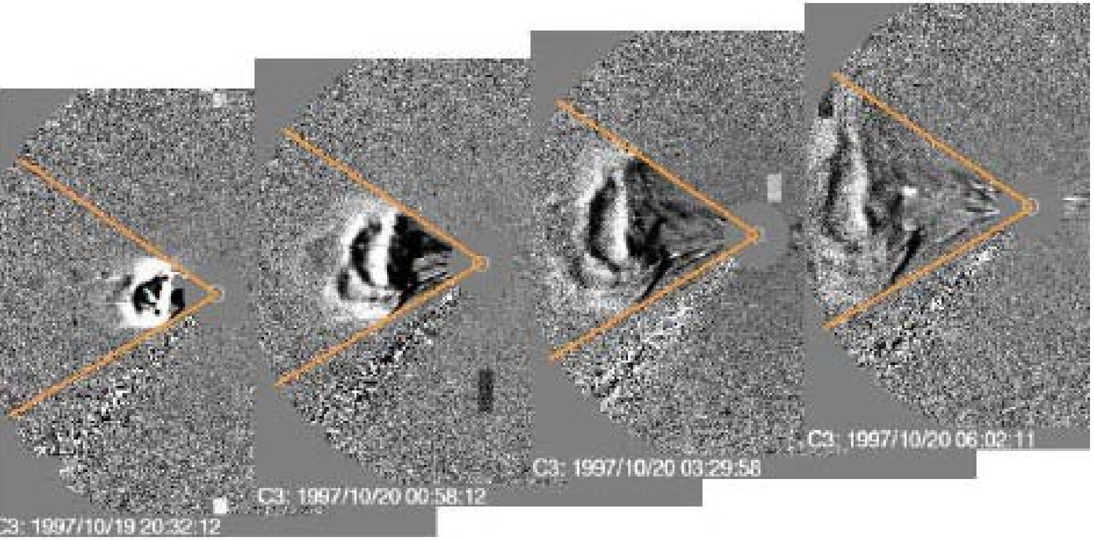
Calibration of WSA Input for ENLIL Needs

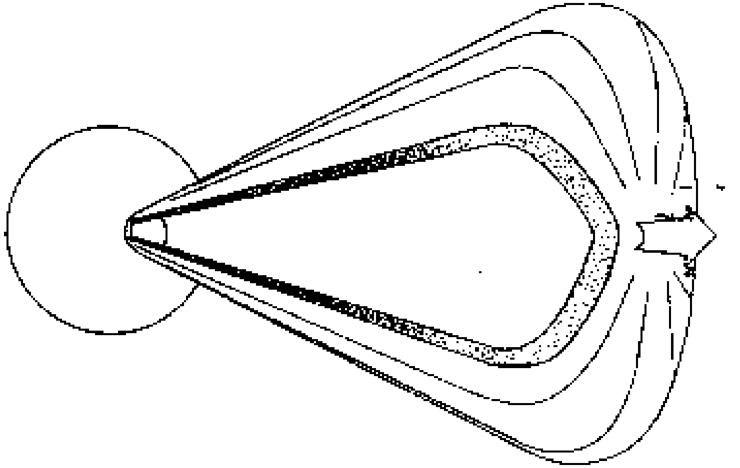




- WSA has been calibrated assuming constant solar wind flow speed.
- Solar wind expands: parameters at Earth depends on the coronal temperature, ratio of specific heats, and on initial speed.
- ENLIL needs to use re-calibrated WSA solar wind flow speeds at the inner boundary.

CME Cone Model





Observational evidence:
- CME expands self-similarly
- Angular extent is constant

Conceptual model:
- CME as a shell-like region of enhanced density

[*Howard et al,* 1982; *Fisher & Munro,* 1984]

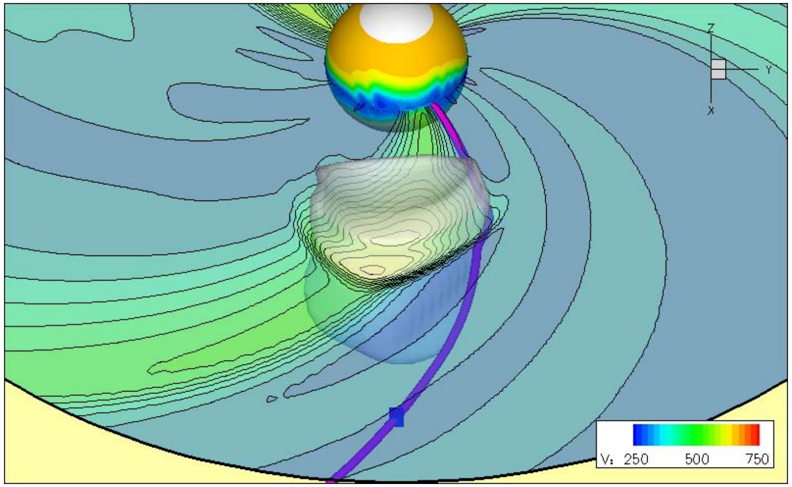
Cone Model Properties

	Property
Plus	▪ observationally based (main causal geo-effectivity link) ▪ simple specification (with direct control of consequences) ▪ numerically robust (beyond supercritical point) ▪ slightly more accurate than empirical formulae (realistic solar wind) ▪ global context (transient and background structures) ▪ interplanetary shocks and IMF line connectivity (shock-observer)
Minus	▪ absence of internal magnetic structure ▪ unphysical initial effect on surrounding solar wind ▪ origin of a reverse shock ▪ unspecified initial shock stand-off distance ▪ internal profile of parameters unspecified

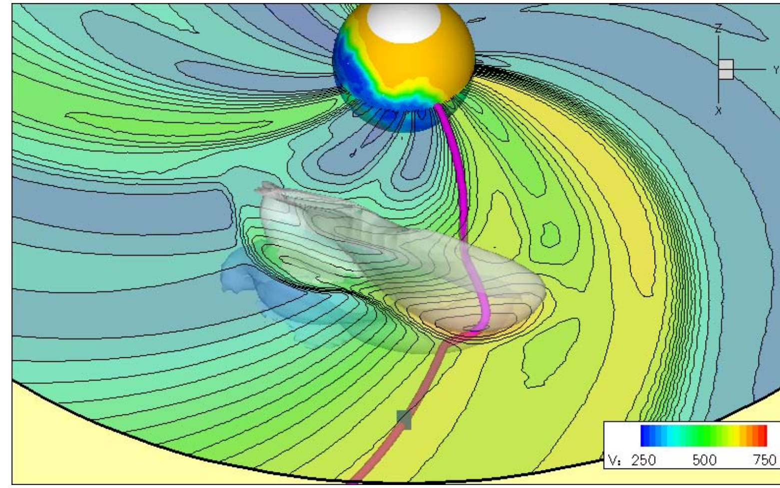
<u>Cone models</u> – Intermediate approach until more realistic coronal models can support routine application

Application of the CME Cone Model

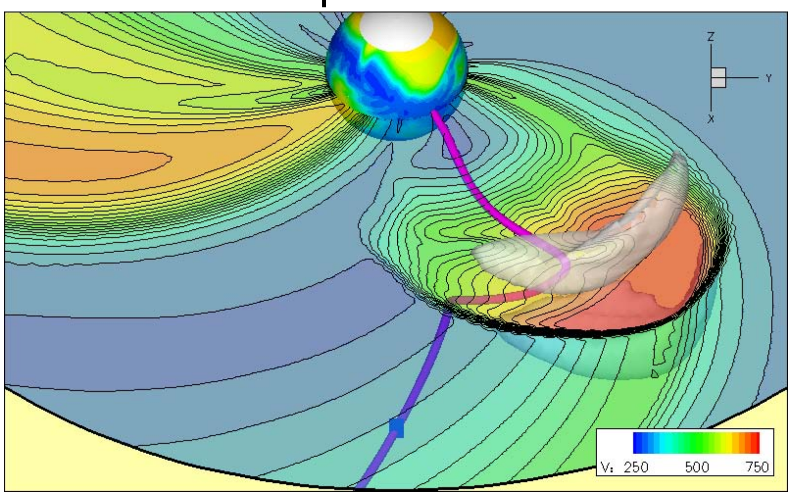
12 May 1997



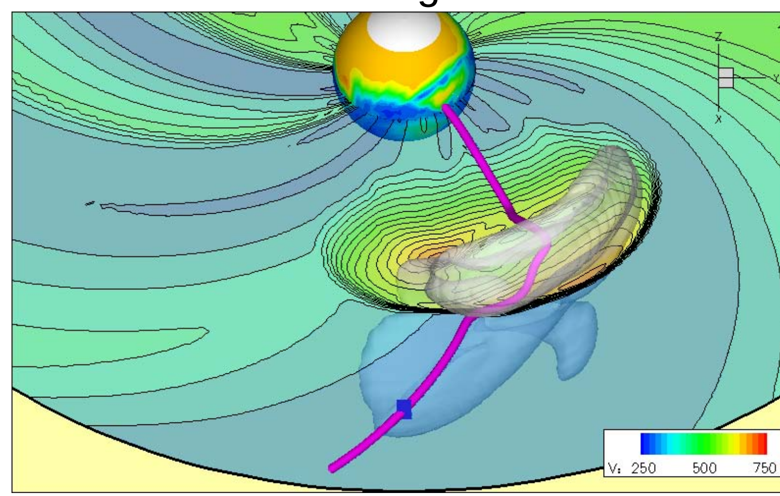
1 May 1998



21 April 2002

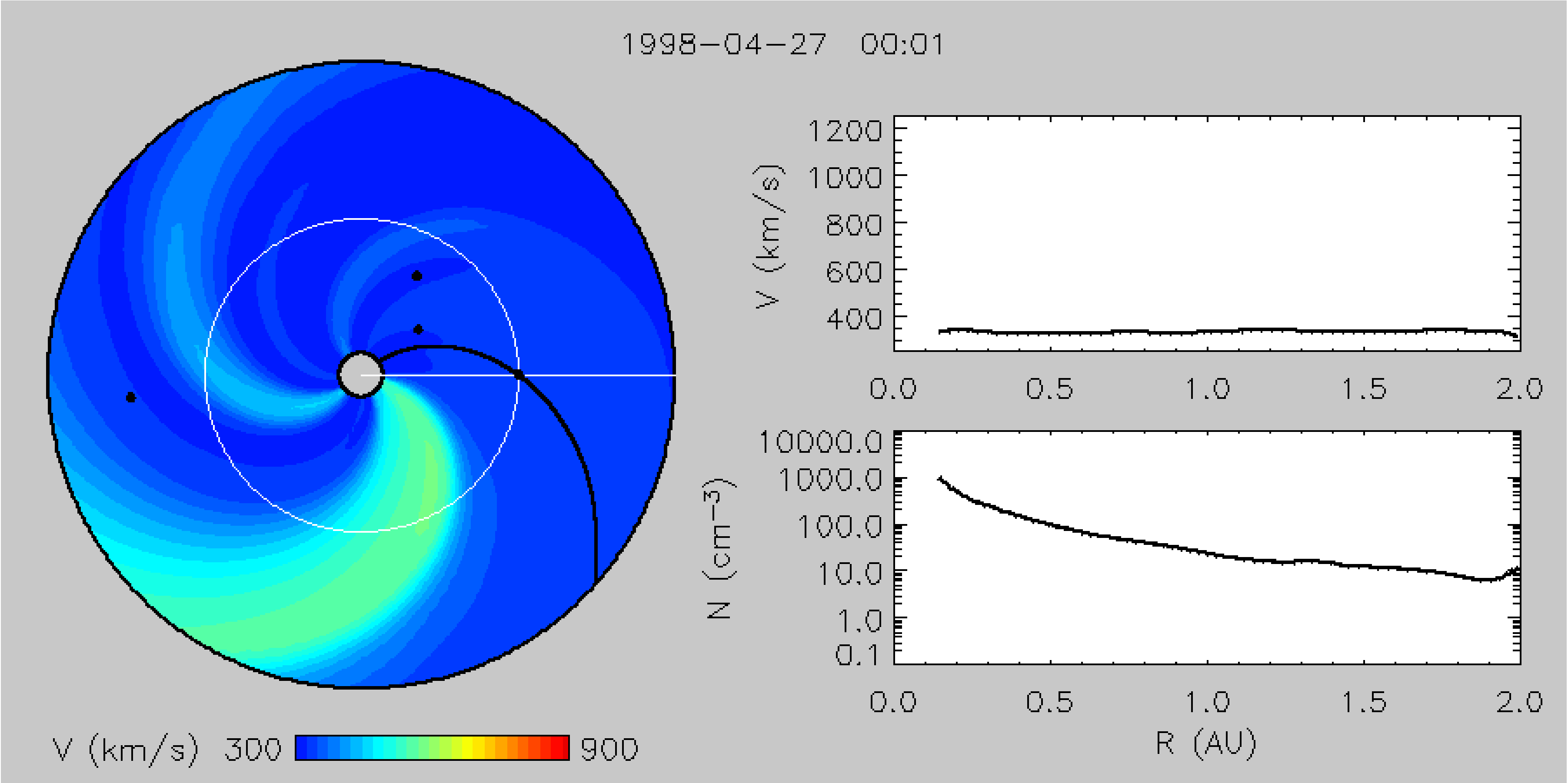


24 August 2002



The heliospheric simulations may provide a global context of transient disturbances within a co-rotating, structured solar wind and they can serve as an intermediate solution until more sophisticated CME models become available.

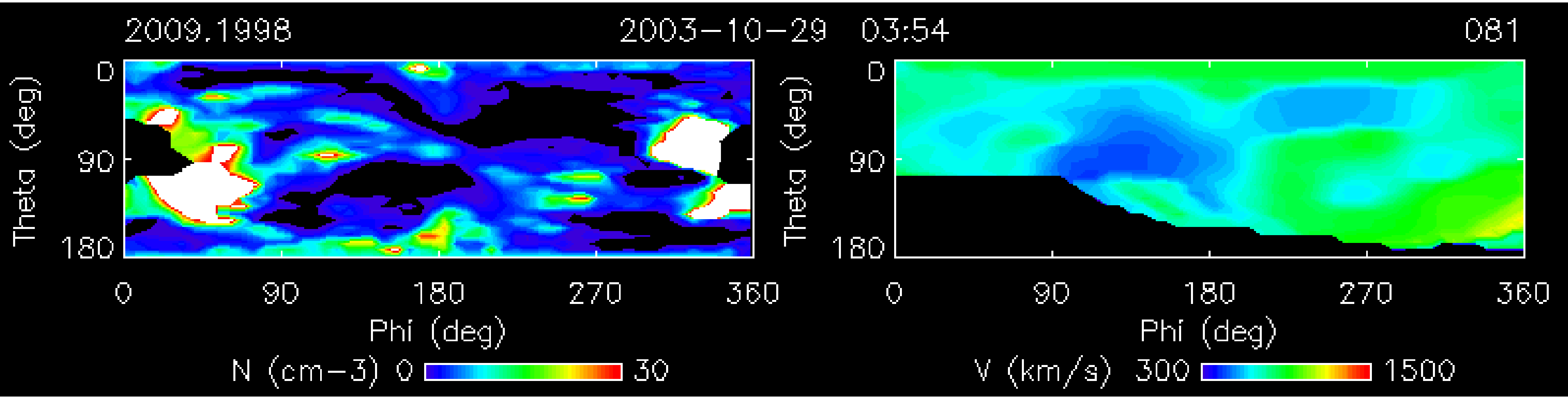
Multiple Interplanetary Disturbances



- CMEs launched into solar wind generate shock and trailing rarefaction-wave region
- Transient disturbances propagate into solar wind disturbed by preceding CME
- Accurate prediction of the CME properties at Earth requires simulation of other of CMEs launched up to 2 days earlier

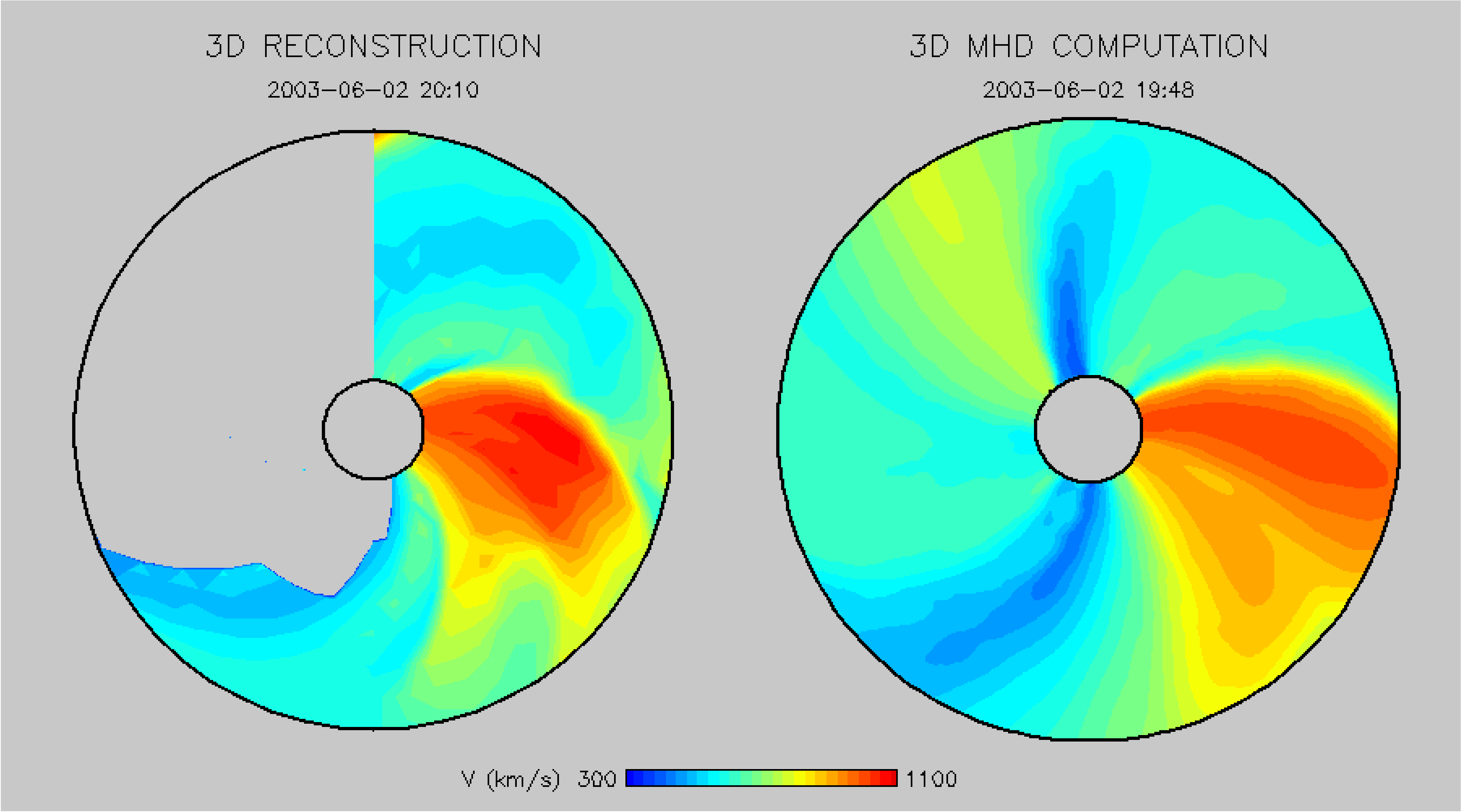
Utilization of IPS and SMEI Observations

Numerical 3-D MHD model requires reconstruction of the density and velocity across the whole inner boundary and specification of the temperature and magnetic field

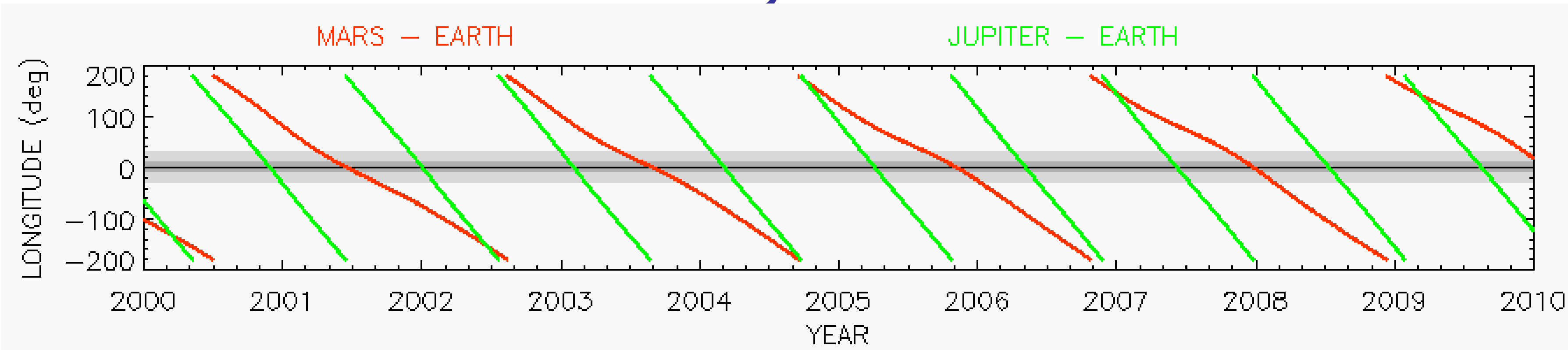


• Distribution of solar wind density (left) and velocity (right) at 35 Rs as extracted from the heliospheric tomography model.
• Black areas show missing values and white areas show values out of range

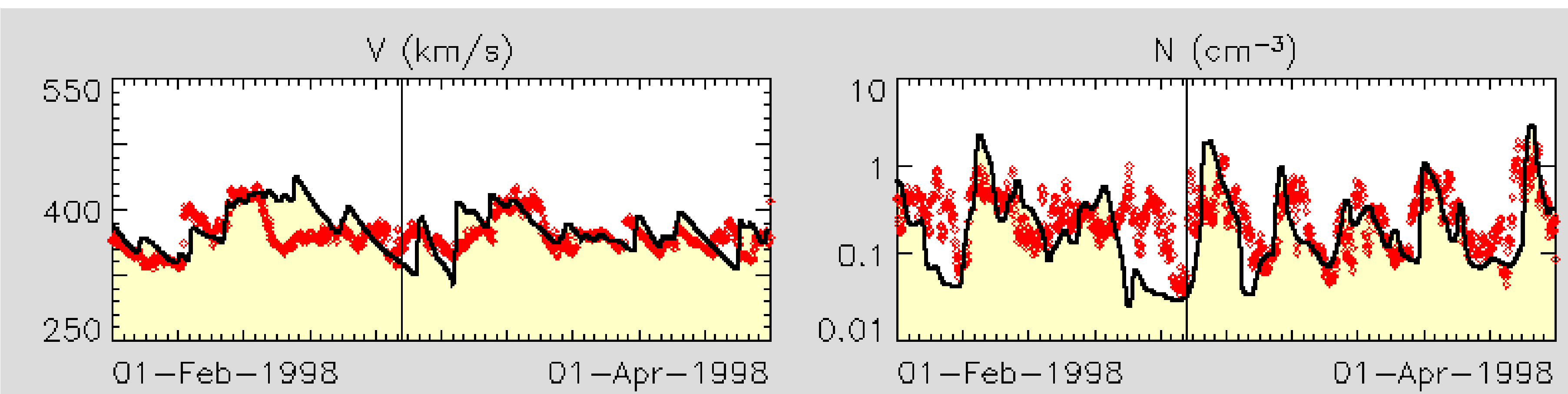
Driving Computations by UCSD/IPS+SMEI



Predictions Driven by In-Situ Observations

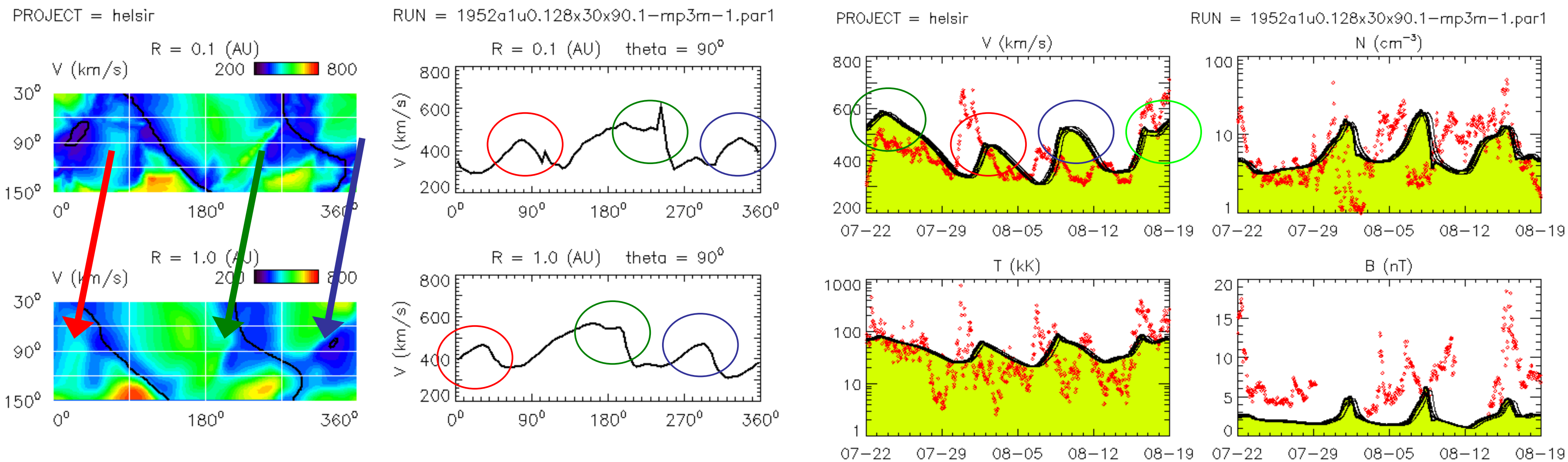


- Heliospheric computations can be driven by accurate in-situ observations of solar wind parameters
- This approach can be strictly applied only during times of radial alignment, and potentially important 3-D interactions are not accounted for



Prediction of the solar wind flow velocity (left) and proton number density (right) at Ulysses. Red dots show observations by Ulysses and a solid line shows results from 1-D MHD simulations driven by values observed at Earth.

Interpreting Computational Graphics



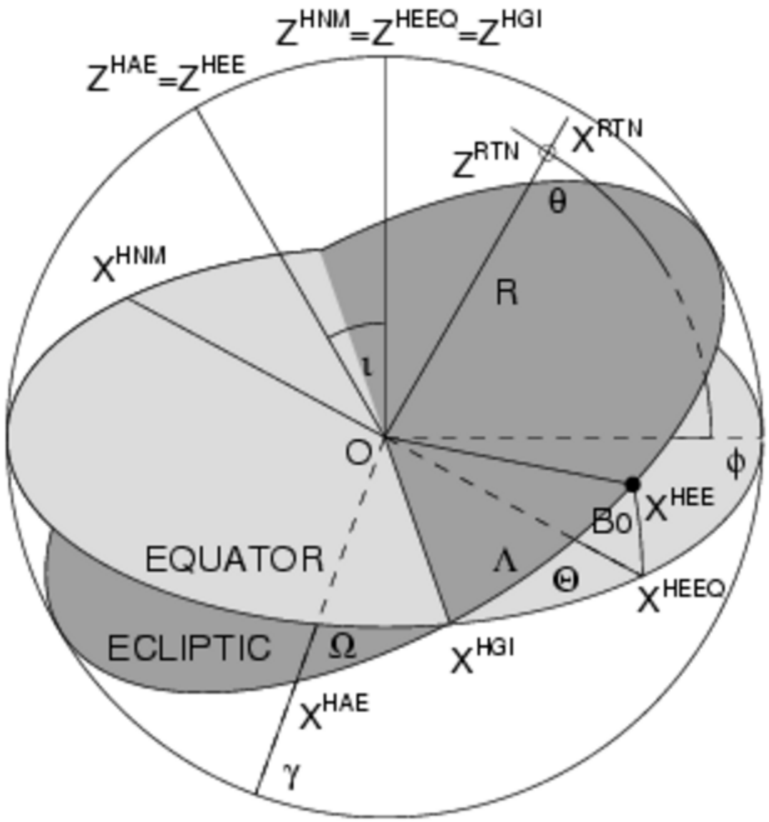
TIME ←

TIME →

- Time is reversed in plots using helio longitude as ordinate (on left)
- Time is shifted by half a solar rotation on left
- Longitudinal shifts in stream-structure profiles corresponds to propagation between 0.1 and 1.0 AU (depends on actual speeds)
- Profiles in helio longitude plots are for the equatorial plane while plots on the right are at Earth location

Heliospheric Coordinate Transformations

Heliospheric computations are realized most naturally in HNM system



Geospace computations can utilize data transformed into GSE system

HNM – Heliospheric Numerical Model

Rotate in equatorial plane by 180^0

HEEQ – Heliospheric Earth Equatorial

Rotate in equatorial plane by Θ

HGI – Heliographic Inertial

Incline by ι (7.25^0)

Rotate in ecliptic plane by Λ

HEE – Heliocentric Earth Ecliptic

Reverse system origin

GSE – Geocentric Solar Ecliptic

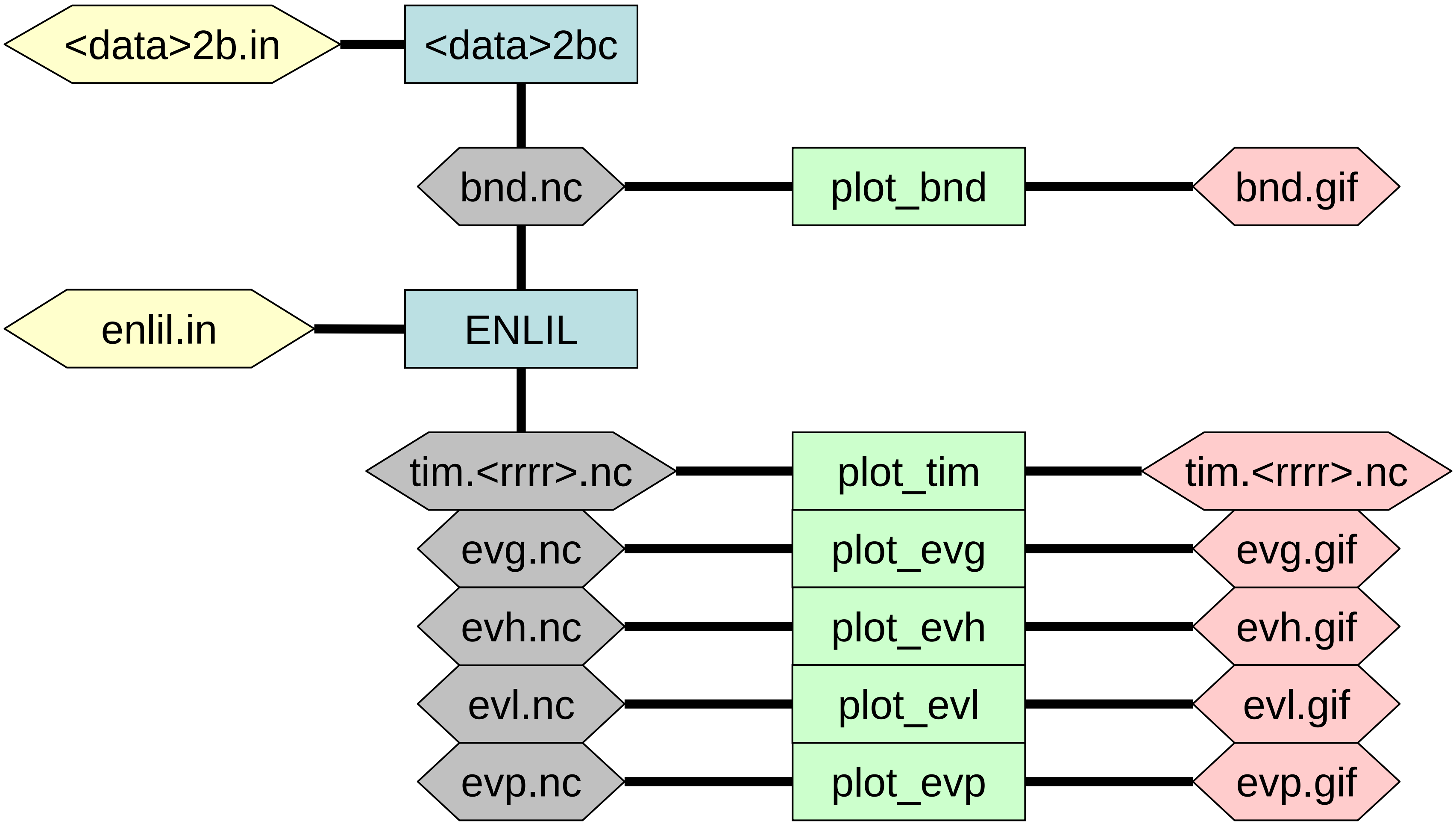
Providing Standard Visualization

Currently:
- GUI enables plotting results and downloading data
- Very flexible, features various options

Suggested addition:
- IDL procedures will automatically produce standard graphics just after end of computations; web link will be provided

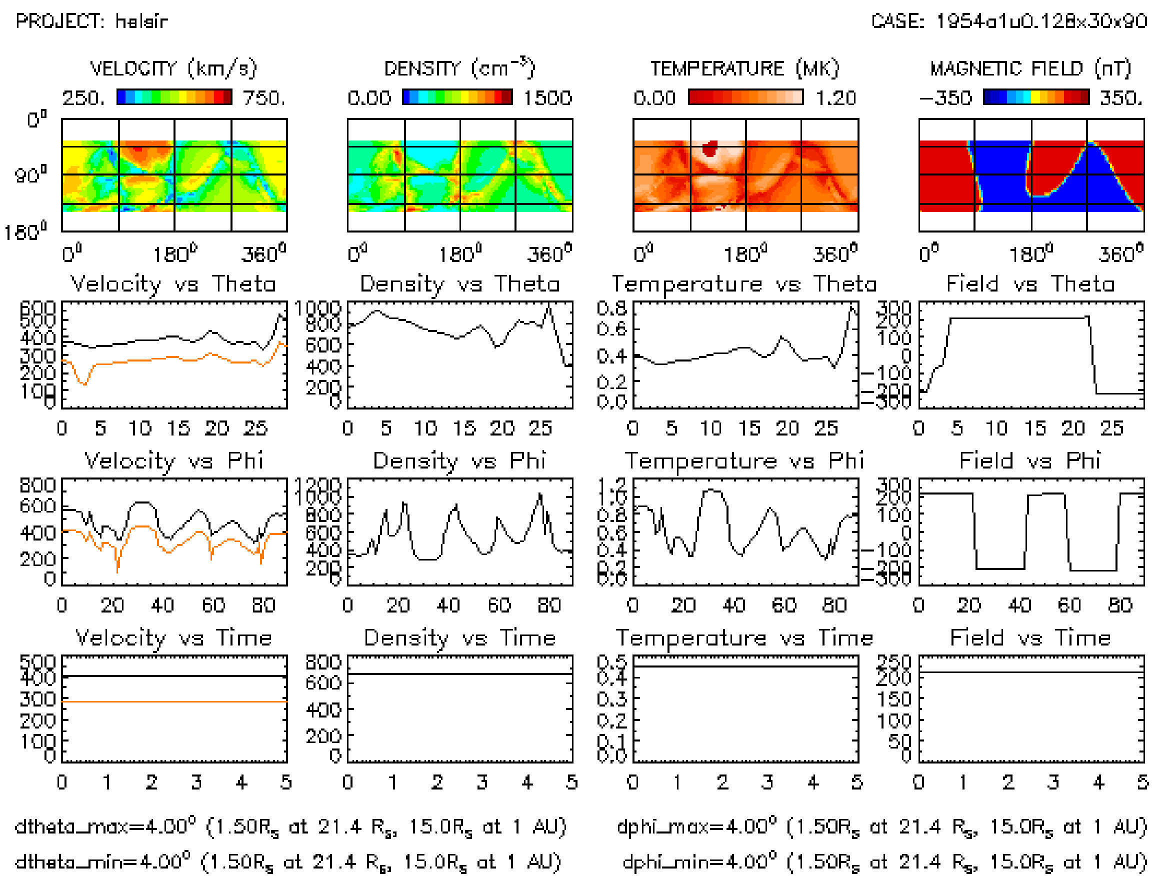
Benefits:
- Easy to see whether input boundary data are as intended
- Easy to see whether heliospheric computations finished correctly
- Facilitates overview of parametric studies
- Would satisfy many user needs:
    - e.g., to see whether Mars was in high-speed stream on given date
    - e.g., to identify unsatisfactory results (re-run with different parameters)
- Will enable some users to locate region of interest, range of variables, position of planets, etc. for more detailed analysis using GUI or using users tools on the downloaded data sets
- Will facilitate involvement of model developer in making corrections or improvements to code

Providing Standard Visualization



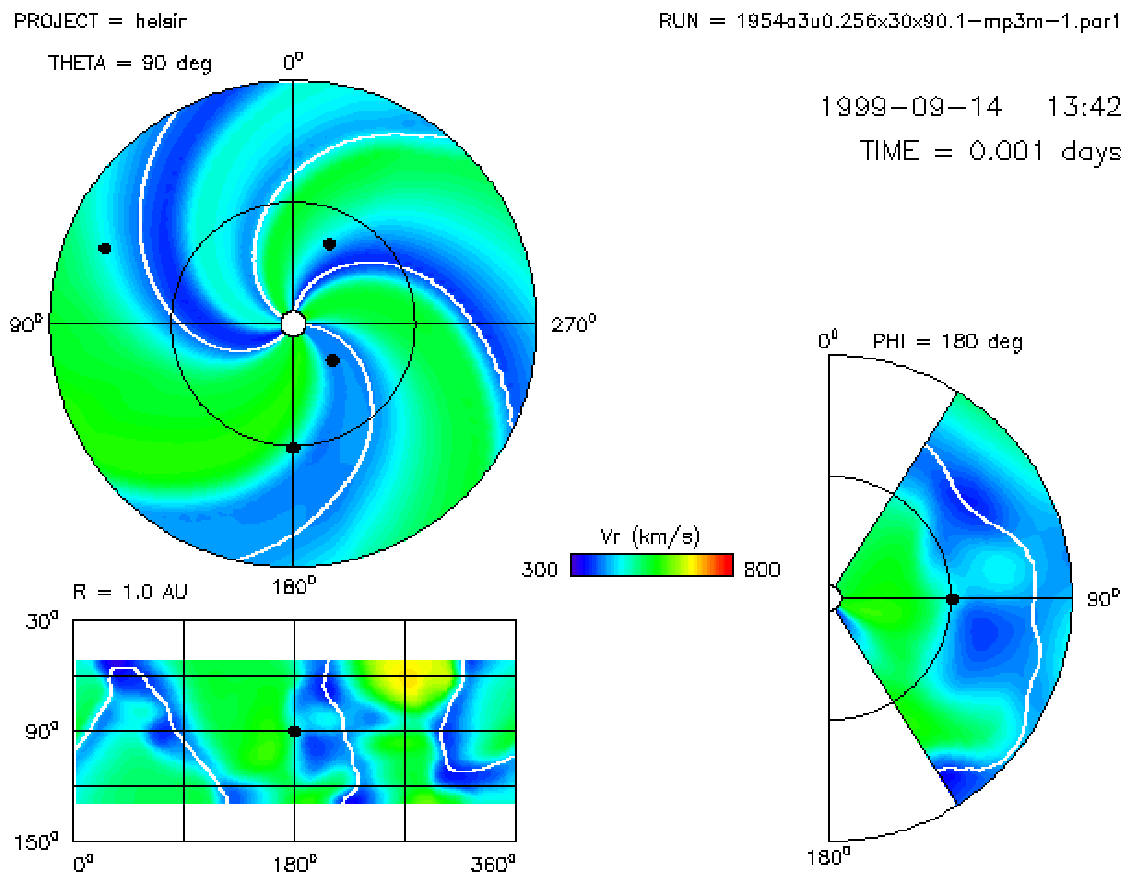
- Each file used or produced by ENLIL has associated standard visualization
- This visualization is automatically produced when executing the system

Boundary Conditions – bnd.nc



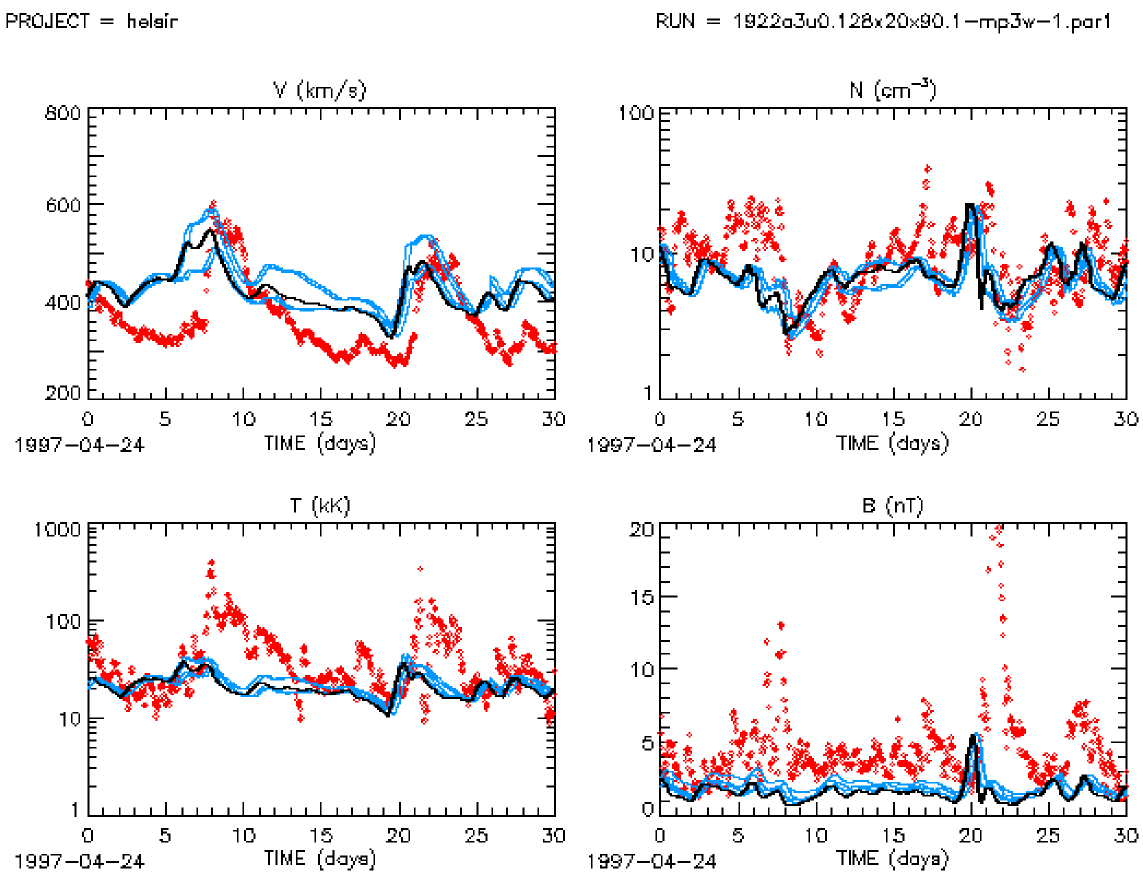
- Primary variables are shown at the inner boundary, latitudinal and longitudinal cuts intersecting the central meridian, and temporal evolution.
- Characteristic speed (red line) must be lower than the outflow speed.
- Grid spacing info is included at bottom.

3-D Values at Time Level – tim.****.nc



- Values are shown on various slices passing through Earth.
- Current sheet is shown by white line.
- Planet positions are shown by black spheres.
- Calendar data and physical time correspond to file record number (****).

Evolution at Geospace Positions – evg.nc



• Values are stored at Earth position (thick black line) and nearby grid points (light blue lines).
• Observations from NASA-OMNIweb are shown by red dots.
• Viewing evolution at nearby points can reveal effect of numerical resolution and can provide inclination of structures for geospace models