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The WSA Model at the CCMC

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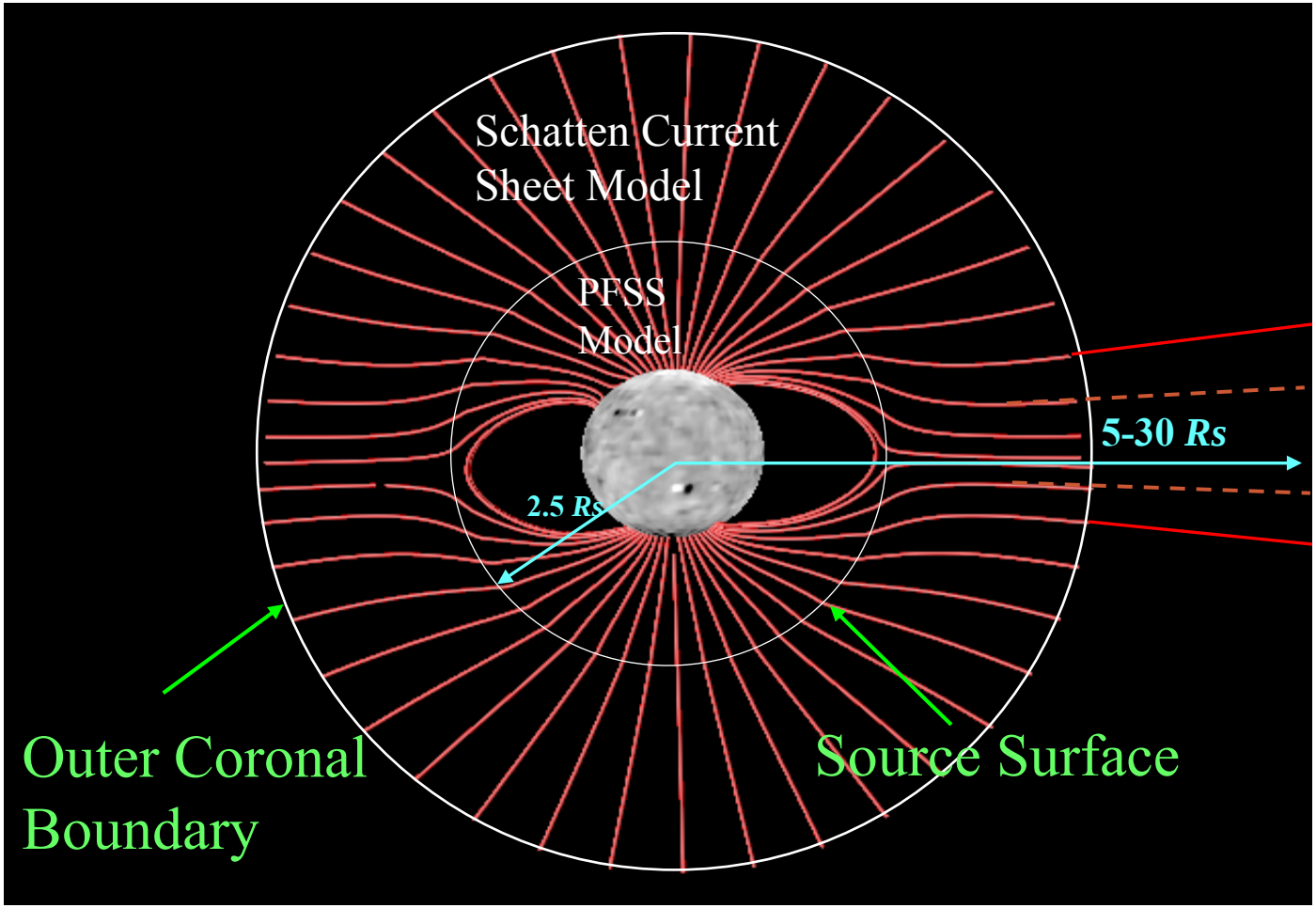
Space Vehicles Directorate/Air Force Research Laboratory

The 5th CCMC Community Workshop

Overview

- Overview of the structure and function of the WSA Model (Version 2.1)
- Present status of WSA
- Planned upgrades to WSA
- Other items being developed of potential interest to the CCMC and community
- Summary

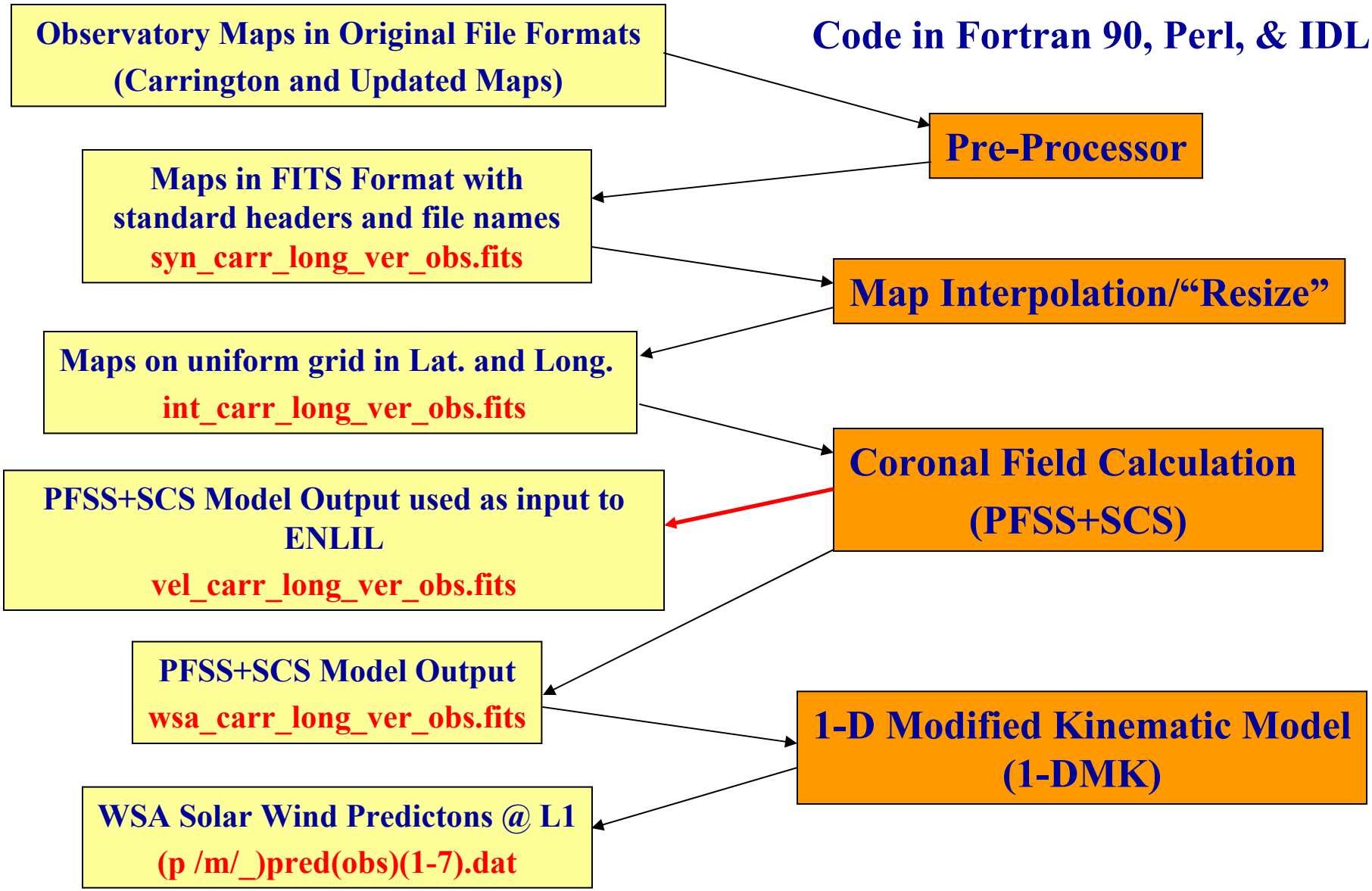
WSA Coronal & Solar Wind Model



Solar Wind Model (e.g., WSA 1D Kinematic model, ENLIL, HAF, LFM-Helio) (5-30*Rs* to 1AU)

CISM
Center for Integrated Space Weather Modeling

WSA Data Flow Diagram



WSA Pre-Processor

- Routines that converts imported synoptic maps (updated, Carrington, etc.) to “standardized” WSA files in FITS format

- Header information recast and key words added where/when needed

- Corrections made if applicable/necessary
  - Saturation Effects
  - B angle
  - Radial field approximation applied

- All files passing through the Pre-Processor are renamed using a standard file format

WSA Map Interpolation/"Resize" Step

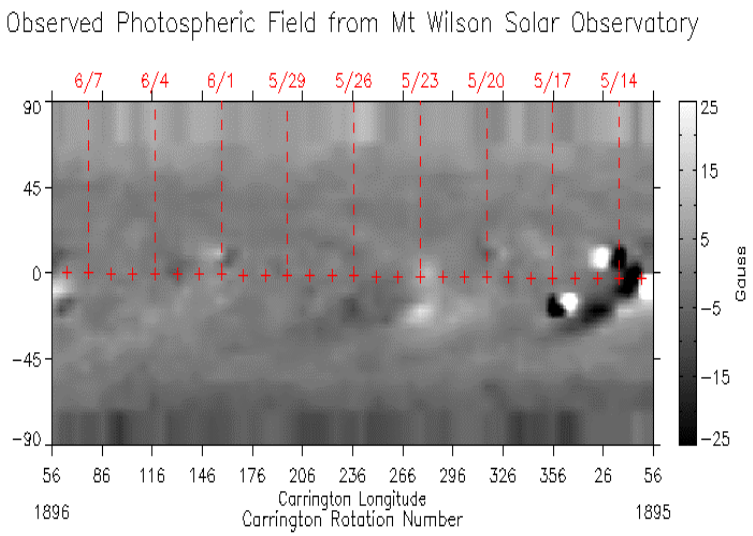
- **Maps interpolated to a uniform grid in degrees Longitude and Latitude with cell resolution specified by user**
  - **Done so that flux is conserved**
  - **Monopole removed**
- **All files passing through the Resize step are renamed using a standard file format**

Coronal Field Calculation

- Parameters for coronal calculation that may be set by user
  - Source Surface radius
  - Outer Coronal Boundary
  - Grid resolution
  - Number of Spherical Harmonics
- Potential Field Source Surface (PFSS) solution calculated
- Schatten Current Sheet (SCS) solution calculated
- Tracing field lines
  - Down from the outer coronal boundary starting at
    - Cell centers
    - Sub-Earth points
  - Up from the photosphere starting at cell centers
    - Handles those grid cells with open field lines occasionally missed by downward tracing

WSA Model Coronal Input/Output

Model Input



Time

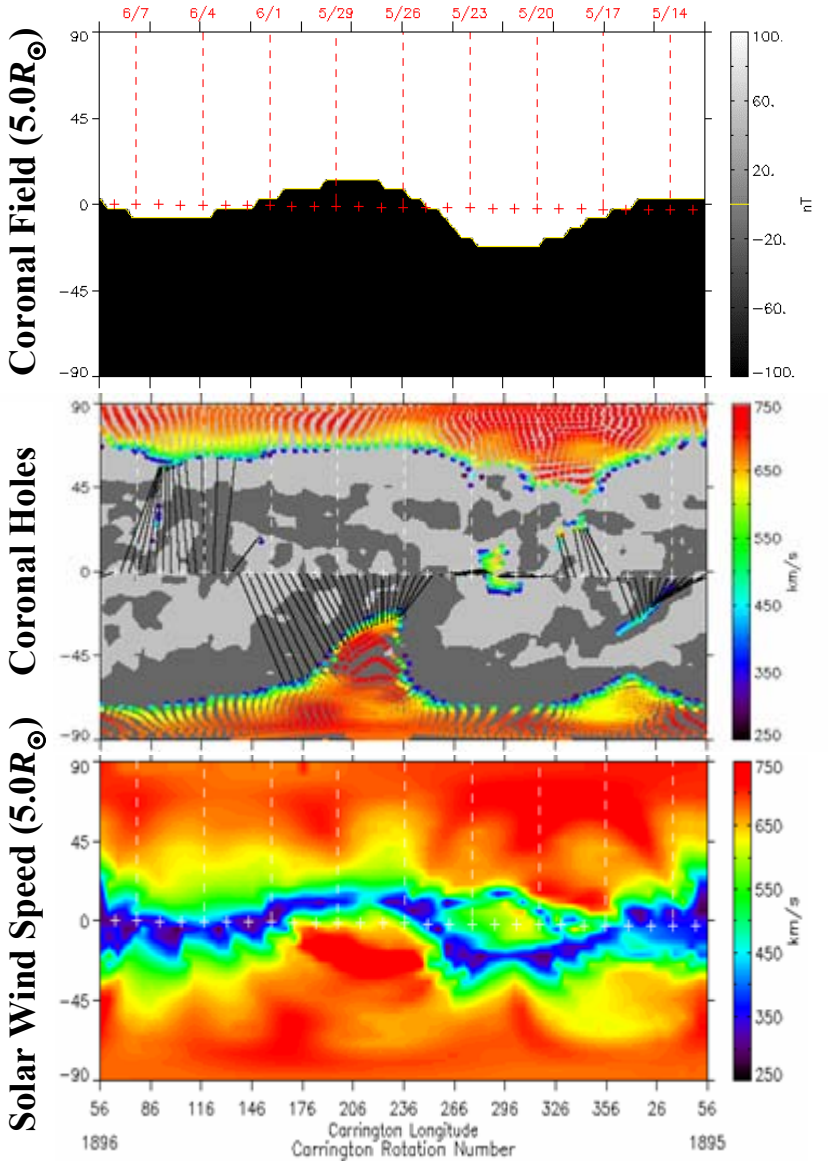
$$V(f_s,\theta_b) = 250 + \frac{650}{(1+f_s)^{2/7}}\left\{1.0 - 0.8e^{-\left(\theta_b/3\right)^{7/4}}\right\}^3 \text{ km s}^{-1}$$

Where:

f_s = Magnetic field expansion factor

θ_b = Minimum angular distance that an open field footpoint lies from nearest coronal hole boundary (i.e., Angular depth inside a coronal hole)

Model Output



1-DMK Solar Wind Predictions

- Provides Solar Wind parameter predictions 1-7 days in advance
  - Radial Speed
  - IMF Polarity
  - Footpoint location of the source of the solar wind back at the Sun
  - Footpoint field strength of the solar wind source region
  - Other parameters could be included.

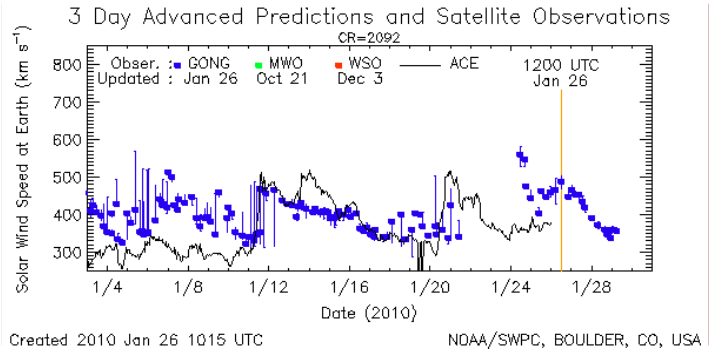
Real-Time WSA Solar Wind Predictions Available at NOAA/SWPC

The Wang-Sheeley Model

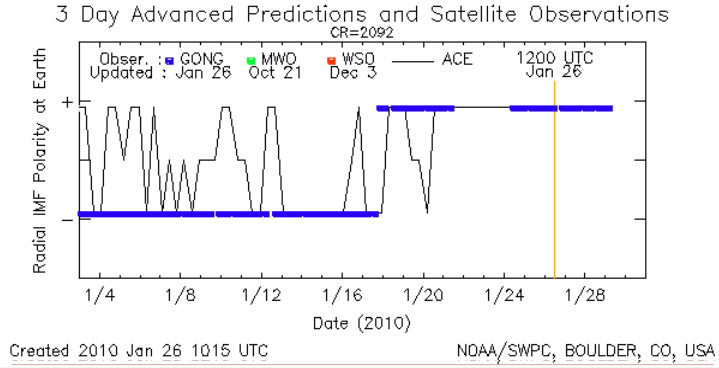
Presented by NOAA/Space Environment Center and the Office of Naval Research (ONR)

The Wang-Sheeley Model predicts the background solar wind speed and the interplanetary magnetic field (IMF) polarity at earth, two important parameters required for predicting geomagnetic activity.

Predicted Solar Wind Speed at Earth



Predicted Interplanetary Magnetic Field (IMF) Polarity at Earth



http://www.swpc.noaa.gov/ws

Model also runs in real time at:

1) Sac Peak in support of the Air Force Weather Agency (AFWA).
2) Community Coordinated Modeling Center (CCMC).

Delivered to the Centered for Integrated Space Weather Modeling (CISM).

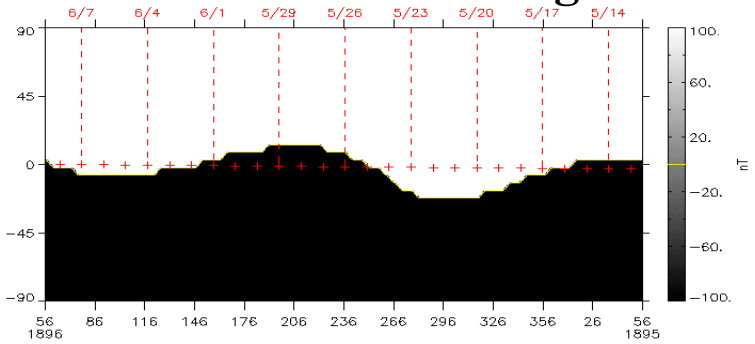
Serves as their baseline model.

WSA has been modified to predict solar wind parameters at other *planets* or *spacecraft* (e.g., STEREO) in the inner heliosphere.

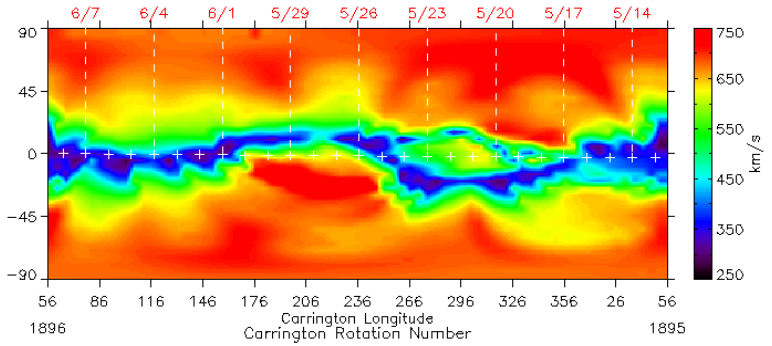
WSA Coronal - ENLIL MHD Solar Wind

Output of WSA MODEL
(R = 21.5 *Rs*)

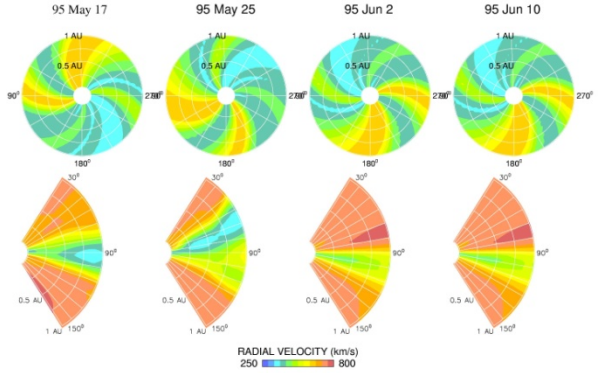
Coronal Field Strength



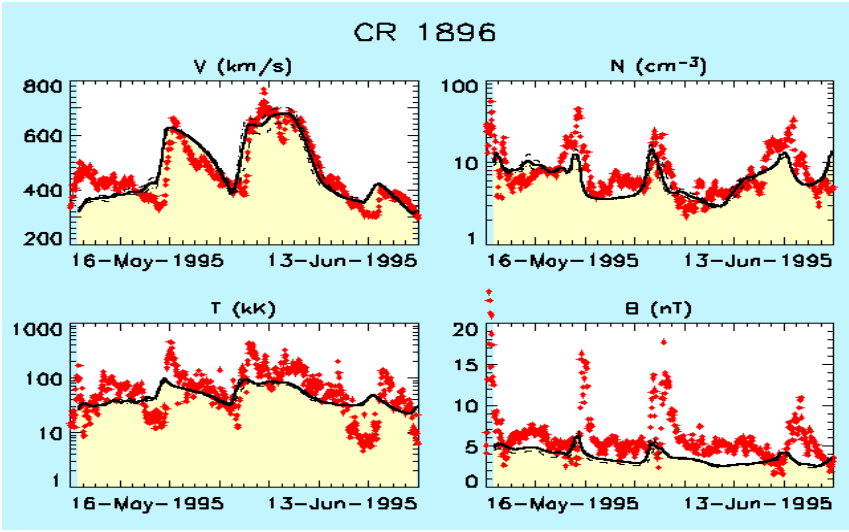
Solar Wind Speed



ENLIL 3D MHD Solar Wind Model

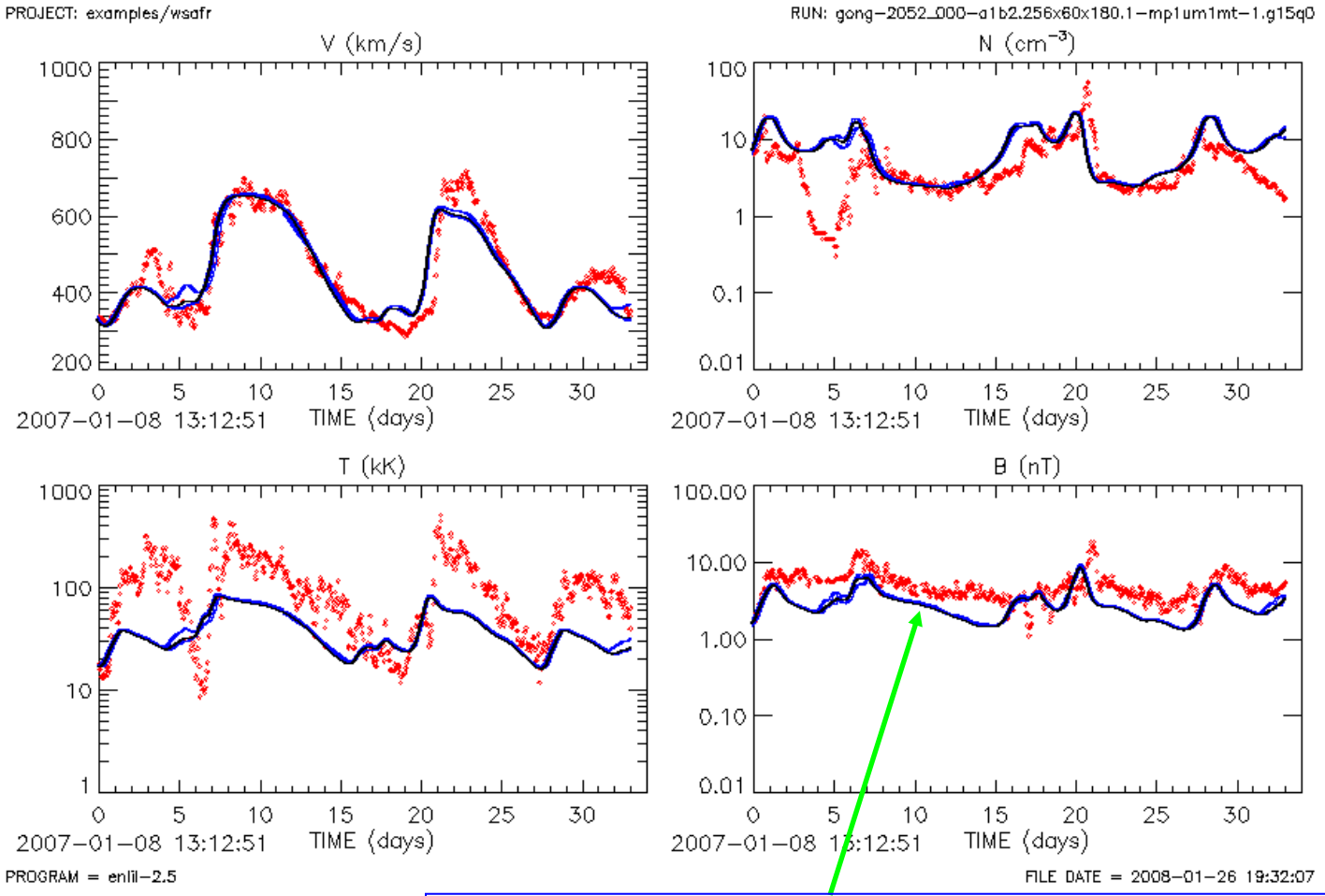


Output of ENLIL MODEL at 1AU



CISM
Center for Integrated Space Weather Modeling

WSA-ENLIL Solar Wind Predictions Compared with ACE Observations at L1



Odstrcil

GONG has a known issue with their fluxes that is currently being looked into.

Current Status of WSA

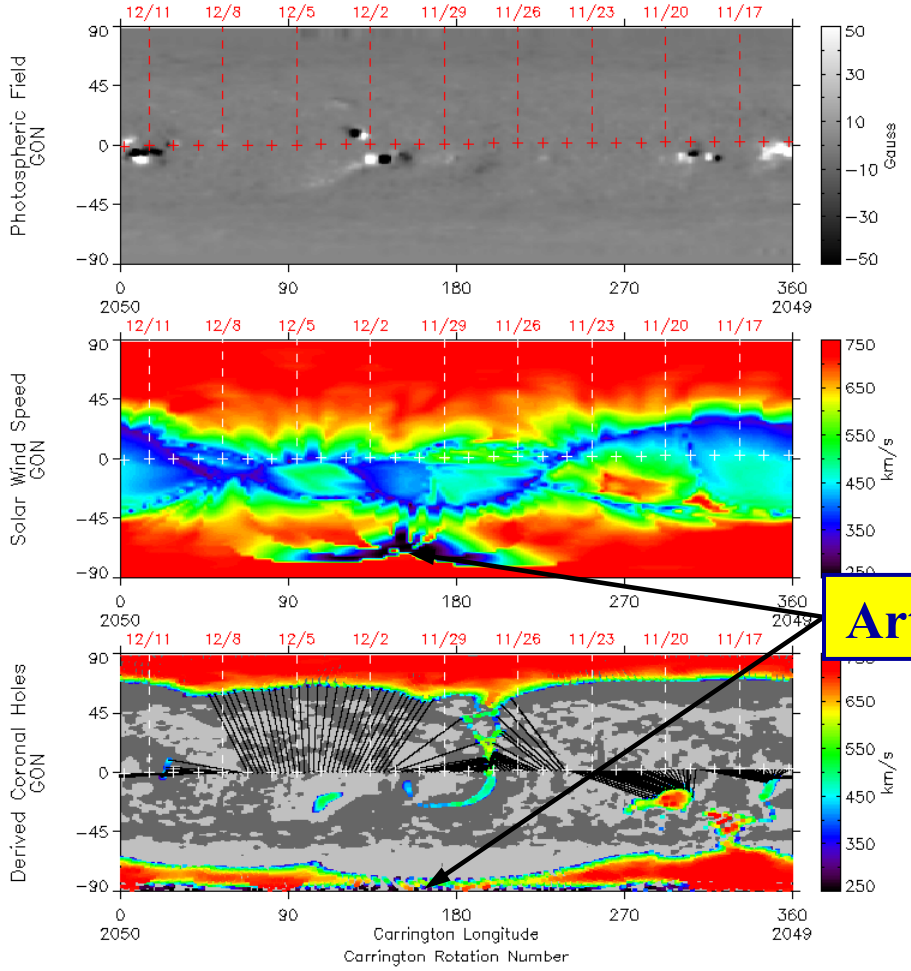
- **WSA Version 2.1 now available & will be transferred to the CCMC soon.**

- **Major Changes**
  - **Code modified to allow field lines to be traced down to the photosphere starting at arbitrary points on the outer boundary**
    - **Files containing the points to be traced (i.e., other than those at cell centers) are read in by the code and no longer "hardwired" within the model**

  - **Code modified to allow field lines to be traced in both directions (i.e., outside in and inside out)**
    - **Eliminates problem of the model occasionally miss-identifying cells with open field lines as being closed**
      - **Grid cells with open fields occasionally missed when tracing down to the photosphere**
      - ***Especially a problem at the poles***

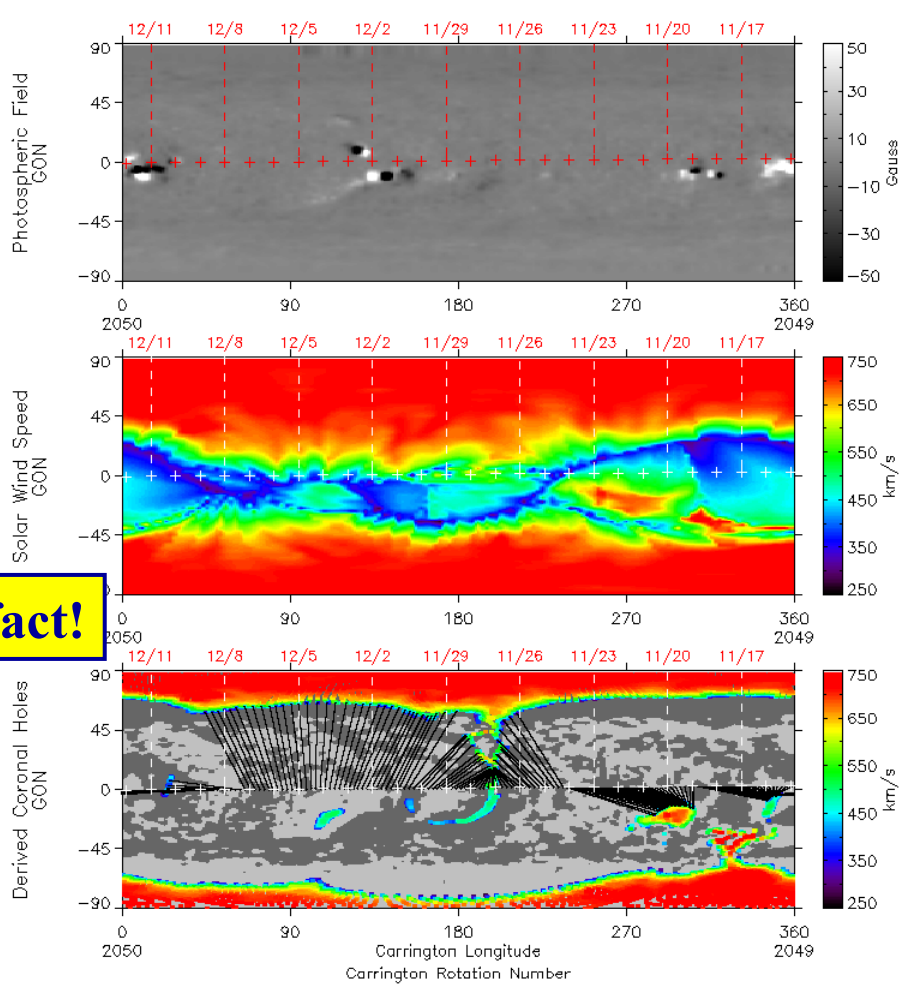
WSA Model Results And Field Line Tracing

WSA OUTPUT
Field Line Tracing: Inward Only



Artifact!

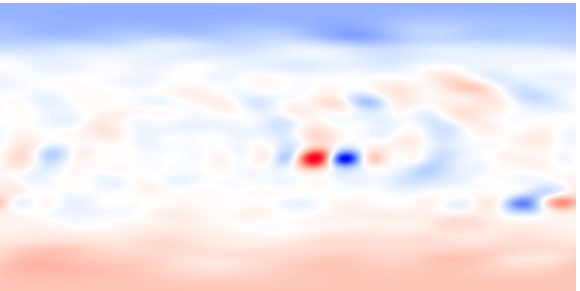
WSA OUTPUT
Field Line Tracing: Both Directions



Upcoming improvements

- PFSS + SCS code in the process of being decoupled and modularized
  - A simple "switch" will allow one to use the
    - PFSS model only
    - PFSS+SCS model combination

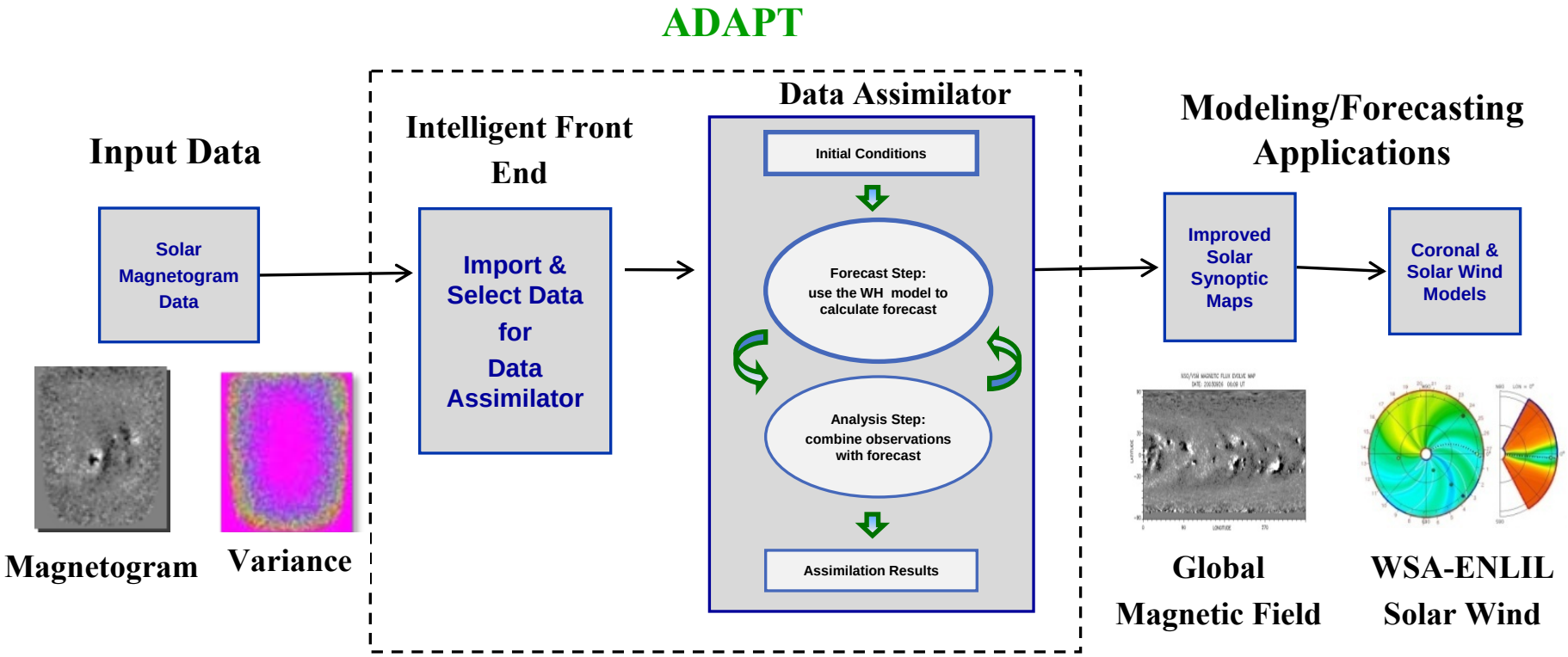
- Planned enhancements of the WSA inner heliospheric component.
  - Model being modified to predict IMF magnitude as well as B_x and B_y components
  - Working on incorporating electron density data into the model, which will allow it to predict density at L1 (Work done in association with R. Frazin, U. of Mich.)
  - PSI has incorporated WSA coronal model within their CORHEL model.
    - We have CORHEL at AFRL and have successful installed it on our 80 node computer cluster
  - Have an UNM student lined up to begin working with the code



Smoothed synoptic map used to drive CORHEL

Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model

Motivation: Global estimates of the solar photospheric magnetic field distribution serve as primary input to all coronal and solar wind models.



Approach: ADAPT incorporates rigorous data assimilation methods into the NSO Worden & Harvey (WH) time-dependant solar photospheric magnetic field flux transport model.

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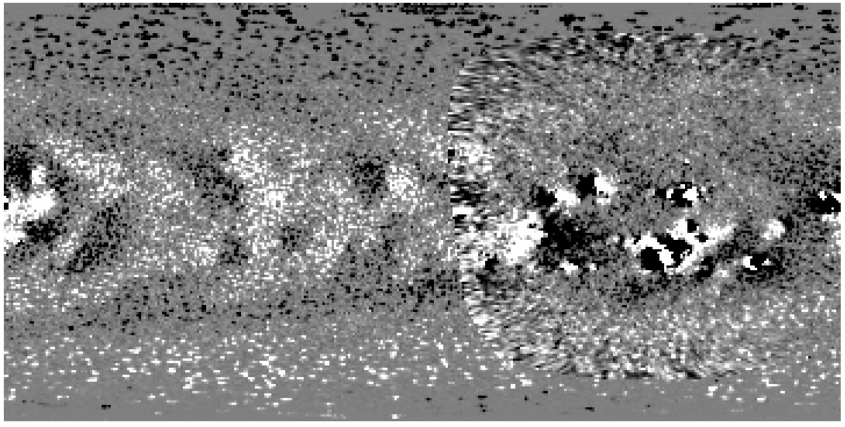
NSO National Solar Observatory

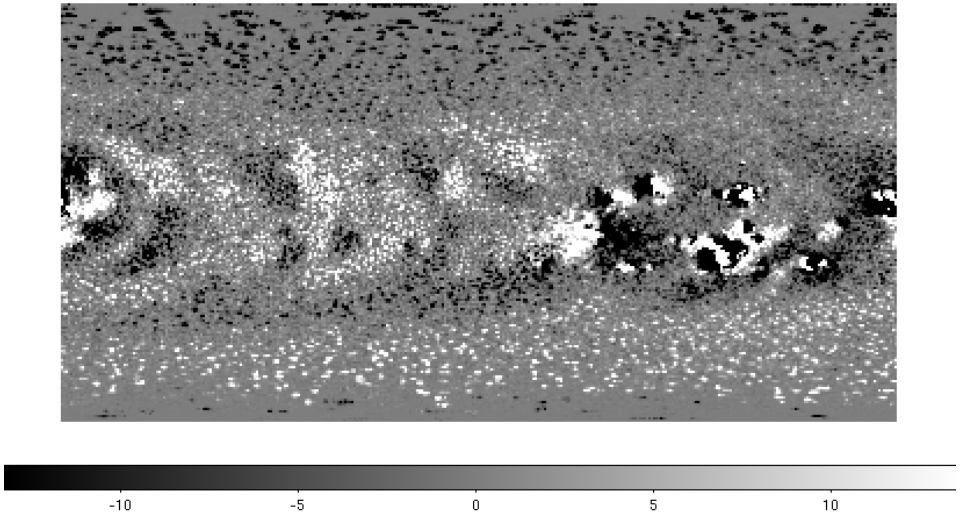
Original Worden & Harvey vs. ADAPT Photospheric Field Maps

Result: Improved, high quality "snapshots" of the global magnetic field.

Worden & Harvey "Old Method"



ADAPT Method



Global solar magnetic maps using the original flux transport code (Left) and the ADAPT ensemble least squares method (Right). Note the obvious boundaries between the newly merged vs. older "data" in the left-hand map which are largely missing in the right-hand one.

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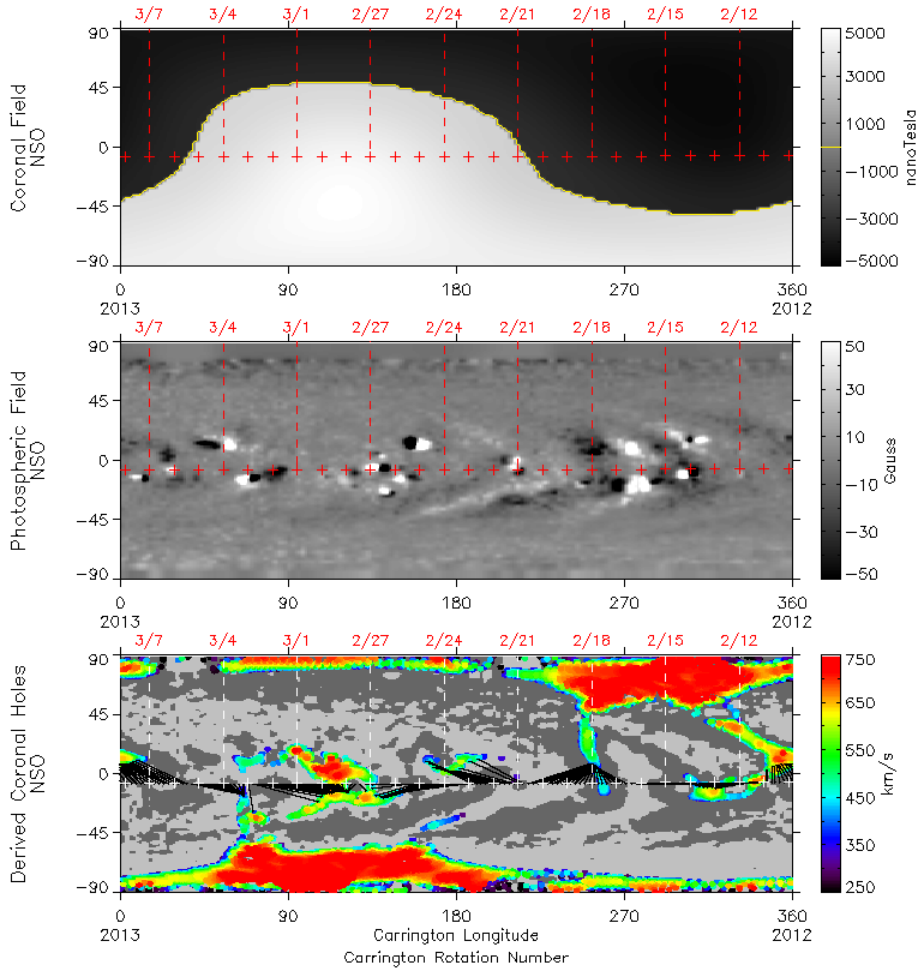
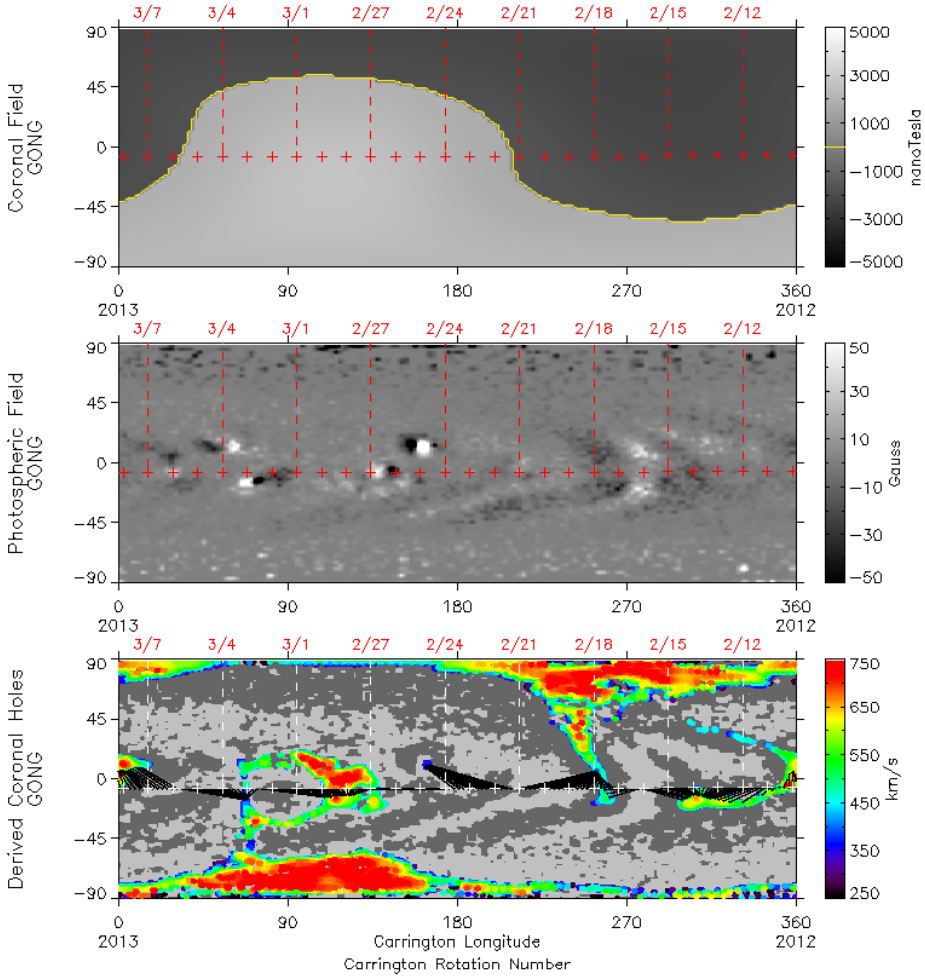
WSA Model Results Using a Traditional Carrington vs. ADAPT Model Map

NSO Carrington Map



ADAPT Map



WSA - Coronal hole Analysis Tool (CAT)

Purpose – Allows forecasters to

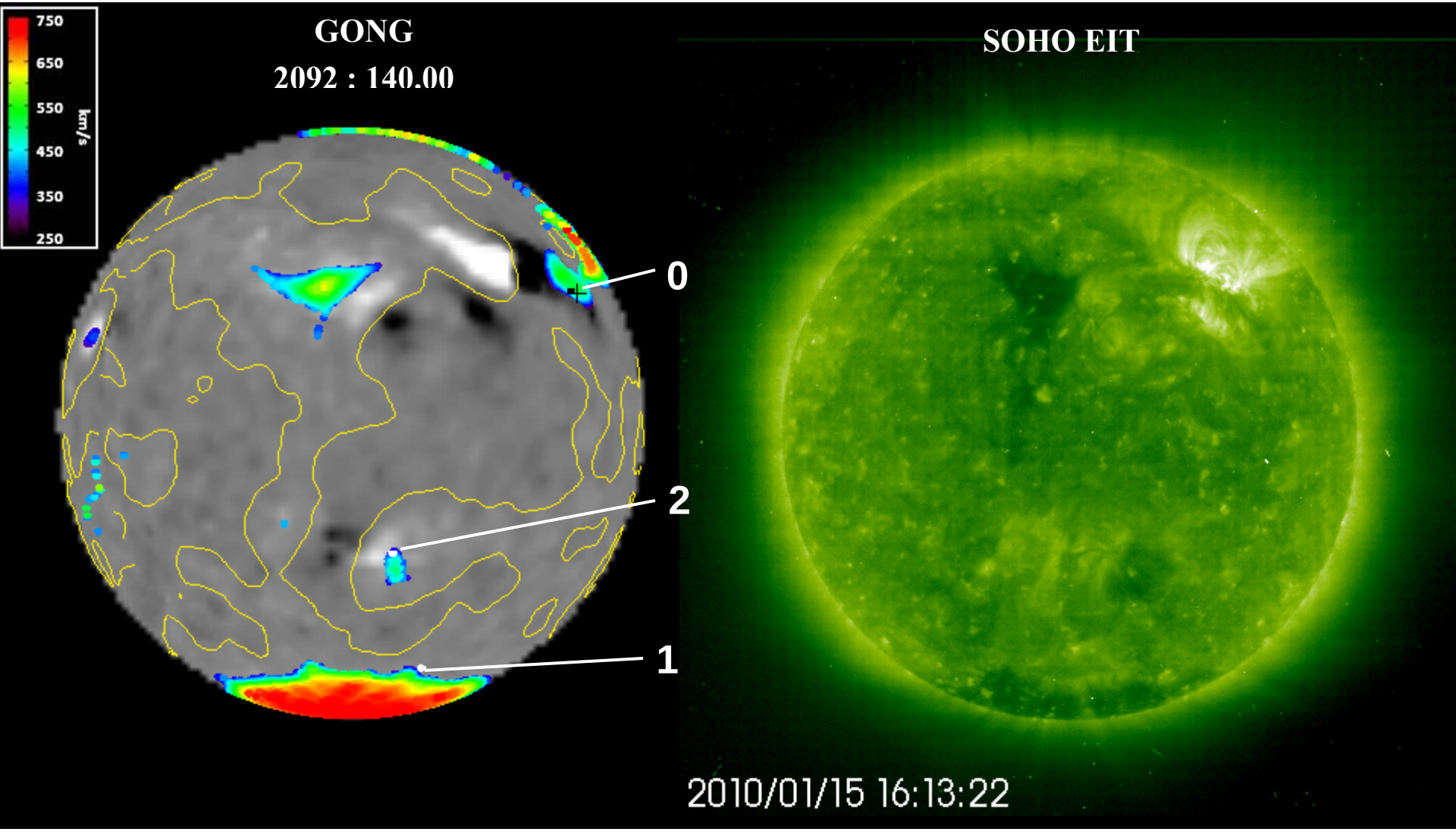
- Readily indentify the source regions back at the Sun of the solar wind observed near Earth.
- Determine how well the coronal hole shapes, sizes, and positions as predicted by the Wang Sheeley Arge (WSA) model agree with direct observations.

Overview – Provides

- A quick-look comparison between coronal hole predictions from WSA with those directly observed (e.g., SOHO/EIT).
- 3 day predictions of the solar source regions of the ambient solar wind observed at Earth.
- The neutral lines separating positive and negative magnetic field polarity on the disk.

WSA Model
Coronal hole Analysis Tool (CAT)

AFRL –Space Weather Forecasting Laboratory (SWFL)



Summary

- ✓ **Overview of the WSA model presented**
  - **Data flow diagram described and consists of**
    - **Synoptic map Pre-processor**
    - **Synoptic map Interpolator**
    - **PFSS+SCS codes**
    - **1-D Kinematic propagation code**
- ✓ **WSA CISM Version 2.1**
- **Allows field lines to be traced down to the photosphere starting at arbitrary points on outer boundary**
  - **Traces field lines in both directions (i.e., outside in and inside out)**
- ✓ **Planned upgrades**
  - **PFSS + SCS code to be decoupled and modularized**
  - **Ability to predict IMF magnitude as well as B_x and B_y**
  - **Ability to predict density**
- ✓ **WSA now part of CORHEL**
- ✓ **ADAPT & WSA-CAT tool may be of future interest to the CCMC and the community.**
- ✓ **WSA Version 2.1 will be available at the CCMC soon**

Data Assimilation with EnLS

- Currently, new observations are data assimilated using an ensemble least-squares (EnLS) estimation:

$$X_a = X_f + \omega (y - X_f),$$

where X_a, X_f, ω and y represent the analysis, forecast (background), weight, and observation values respectively. The weight, ω, is defined as:

$$\omega = \sigma_f^2 / (\sigma_f^2 + \sigma_y^2),$$

where σ_f^2 and σ_y^2 are the variances of the model ensemble and observed data respectively.

- To account for new active region flux emergence, the model variance is increased, such that ω ranges from 0.7 to 0.9, for spatial regions where:
  - the observed flux value is greater than 100 Gauss, and
  - the absolute value of the innovation, $| y - H(x_f)|$, is greater than 5 times $(\sigma_f + \sigma_y)$, where H is the observation operator.

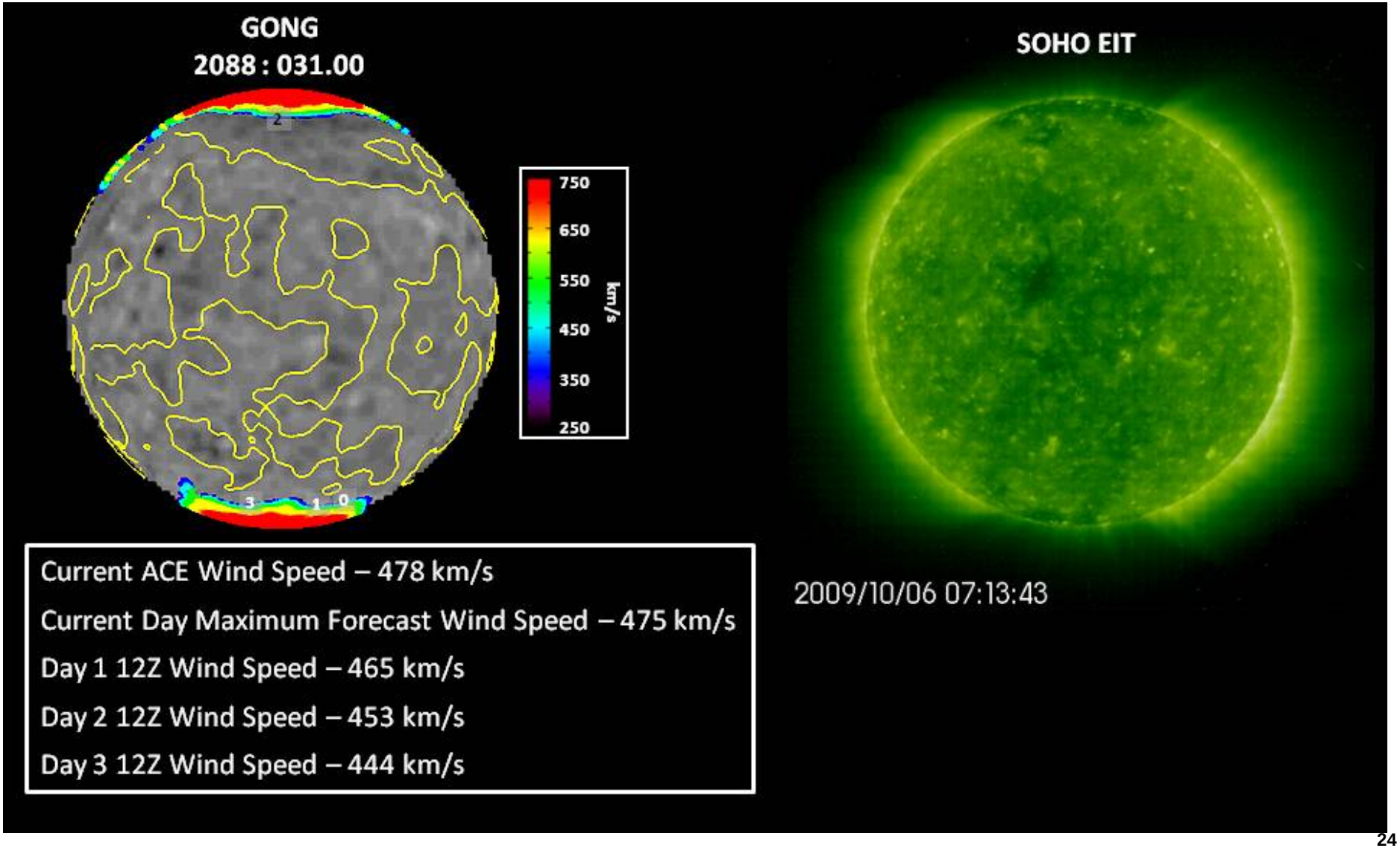
Contents of PFSS+SCS Output Files

Model results provided in the Output FITS files

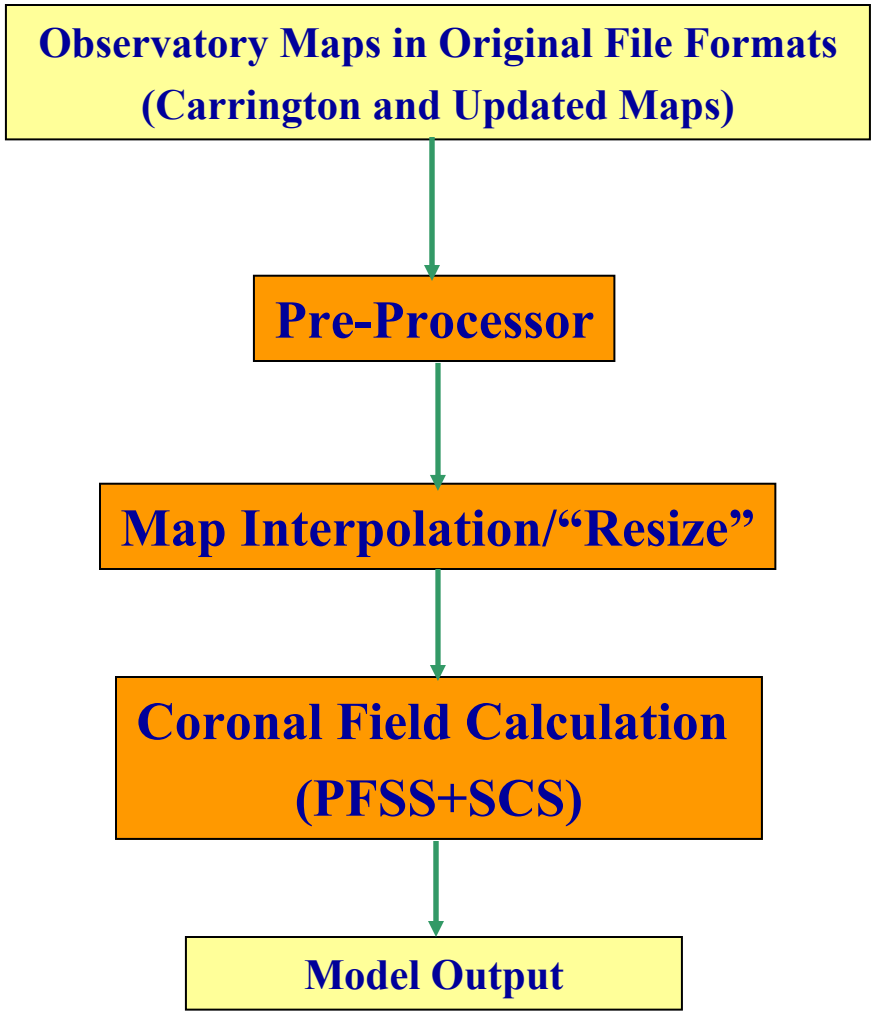
- **Extension = 0**
  - **Source surface field at outer boundary of model (nT)**
  - **Flux tube expansion factor evaluated at the source surface**
  - **Co-latitude of open field footpoints at photosphere (rad)**
  - **Longitude of the photospheric footpoint (rad)**
  - **Photospheric Field (G)**
  - **Angular distance from each open field footpoint to nearest coronal hole boundary (deg)**
  - **Open (1) and closed (0) regions on the photosphere**
- **Extension = 1**
  - **Same as above except now just for the sub-earth track**
- **Extension = 2**
  - **Latitude and longitude values for sub-earth track**
- **Extension = 3**
  - **PFSS coefficients**
- **Extensions = 4-6 can include the 3D magnetic field values (e.g., from 1 to 5-21.5Rs)**

Wang Sheeley Arge Model
Coronal hole Analysis Tool (CAT)

Sample Output



WSA Data Flow Diagram



- Code written in
  1. Fortran 90
  2. Perl
  3. IDL
- Tested and successfully runs using multiple versions of Fortran (g95, gfortran, Lahey, etc.)
- Requires cfitsio

Coronal Field Calculation (cont.)

- Field line tracing provides
  - Expansion factor (quantifies degree of field line divergence)
  - Radial field (magnitude and polarity) at outer coronal boundary
  - Latitude, longitude, and magnitude & polarity of radial field of the associated photospheric field footpoint
  - Angular distance from each photospheric field footpoint to the nearest coronal hole boundary