



# AFRL

THE AIR FORCE RESEARCH LABORATORY  
LEAD | DISCOVER | DEVELOP | DELIVER



## WSA at the CCMC

C. “Nick” Arge

*Space Vehicles Directorate/Air Force Research Laboratory*

4th CCMC Community Workshop  
Arecibo Observatory, Puerto Rico  
November 6, 2007



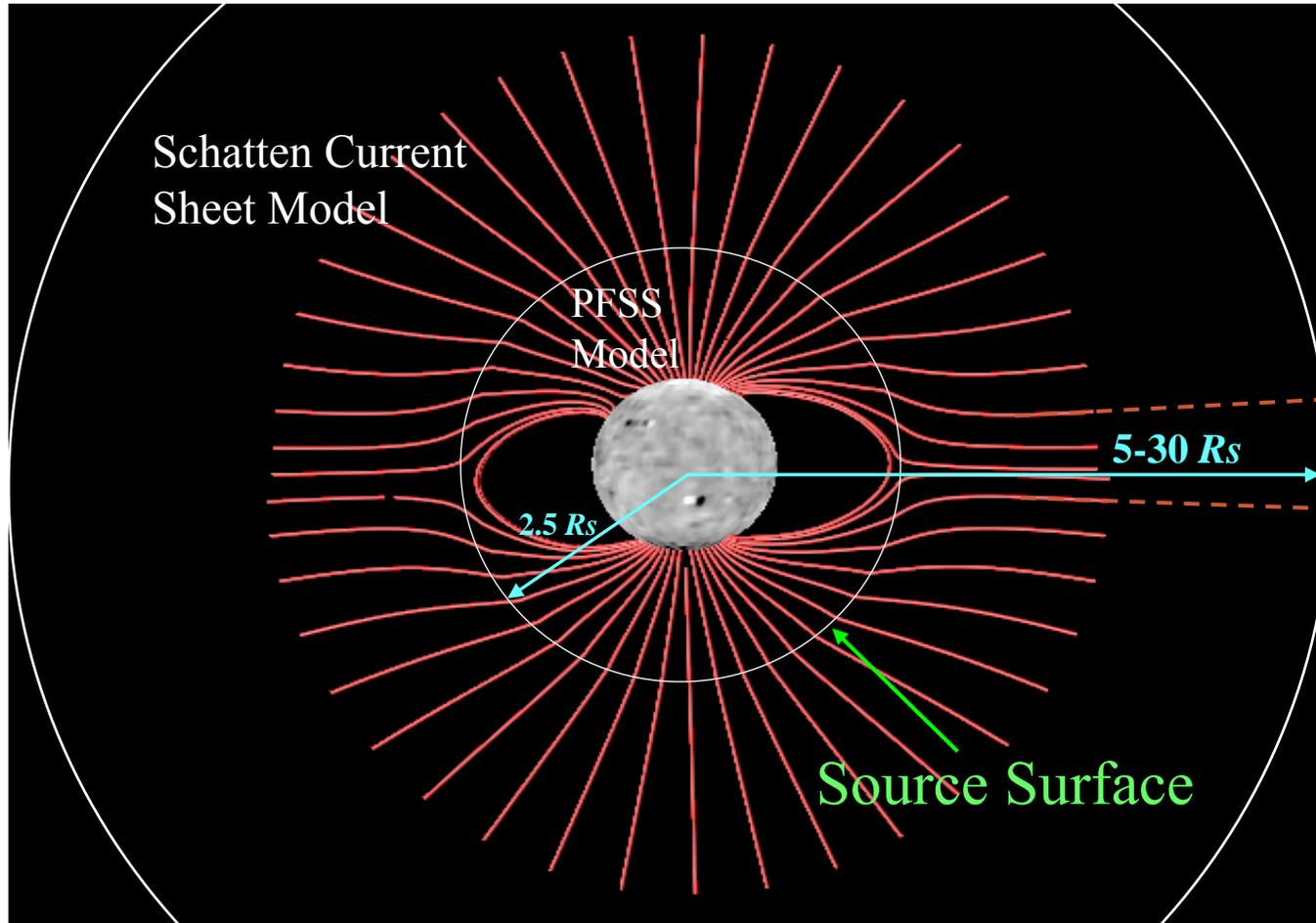
# Overview



- ✓ **Brief summary of the WSA model.**
- ✓ **Present status of WSA at the CCMC (and CISM & SWPC).**
- ✓ **Future upgrades of WSA to be handed off to the CCMC.**
- ✓ **New/additional data sources.**
- ✓ **Calibration of WSA+ENLIL.**
- ✓ **Summary.**



# WSA Coronal & Solar Wind Model



Solar Wind Model  
(e.g., WSA 1D  
Kinematic  
model, ENLIL,  
HAF)  
(5-30 $R_s$  to 1AU)



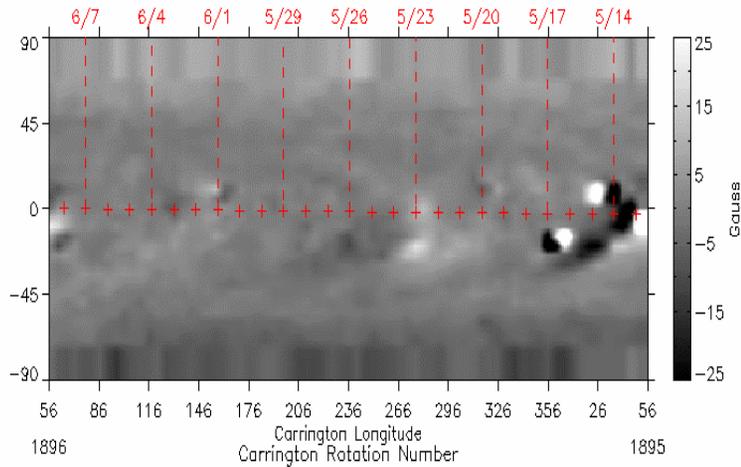
Plot courtesy Sarah McGregor (BU/CISM)



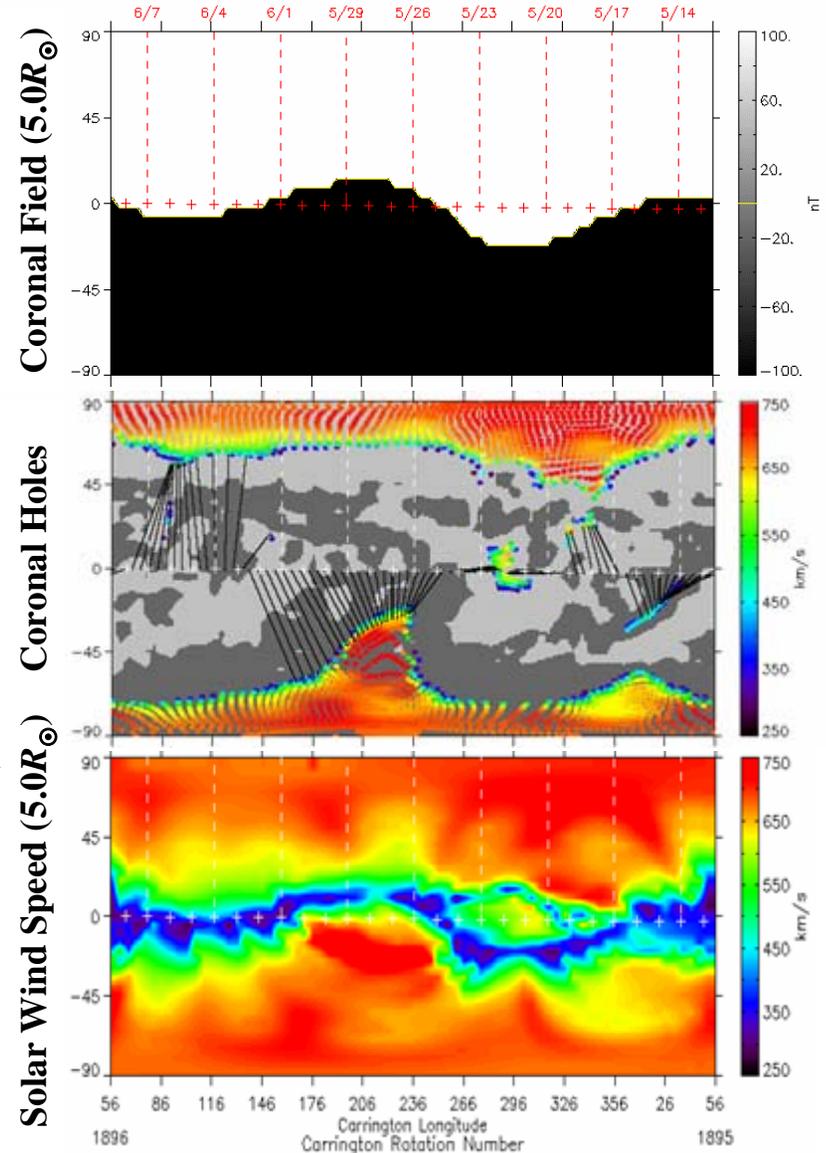
# WSA Model Coronal Input/Output

## Model Input

Observed Photospheric Field from Mt Wilson Solar Observatory



## Model Output



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

Where:

$f_s$  = Magnetic field expansion factor.

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

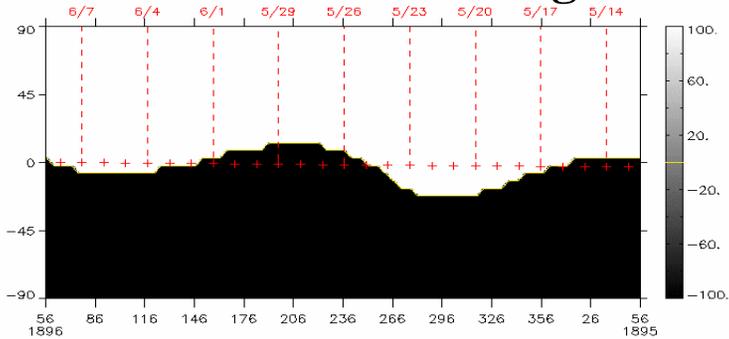


# WSA Coronal - ENLIL MHD Solar Wind Model Coupling (A Joint AFRL-CISM Effort)

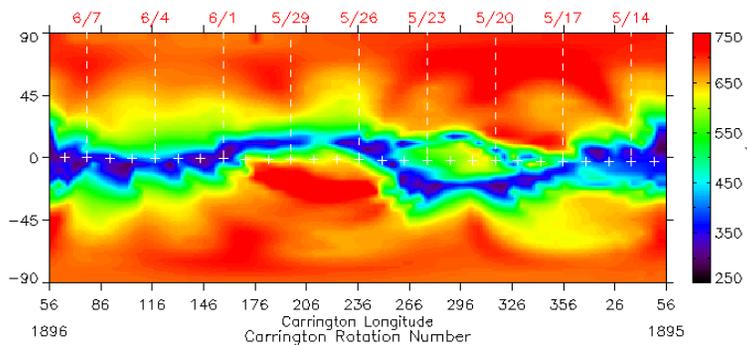


## Output of WSA MODEL ( $R = 21.5 R_{\odot}$ )

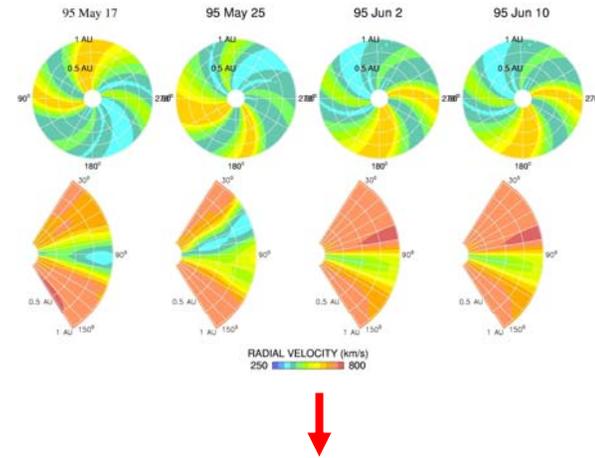
### Coronal Field Strength



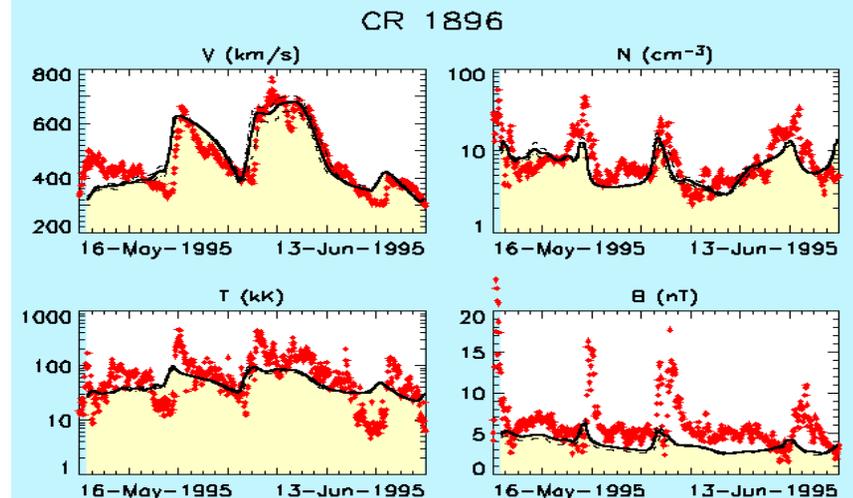
### Solar Wind Speed



## ENLIL 3D MHD Solar Wind Model



## Output of ENLIL MODEL at 1AU





# *Brief Summary of the Status of WSA at the CCMC (and CISM & SWPC)*



WSA CISM Version 1.4.2 now at the CCMC.

- Simple script written and automated (for the CCMC) that routinely retrieves the daily updated and Carrington synoptic maps from
  1. Mount Wilson (MWO)
  2. Kitt Peak (NSO)and then runs them through the WSA code.
- Script is very simple and *does not* evaluate the quality of the data being retrieved.
  - e.g., doesn't detect gaps in the maps etc.
- Version currently used as input to ENLIL.



# Summary of the Status of WSA at the CCMC (and CISM & SWPC) continued



- Coronal results for each WSA run are now available in a *single* FITS file with multiple extensions and detailed headers.
  - 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 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 could include the 3D magnetic field values (e.g., from 1 to 5-21.5Rs)



# Sample Header File From New WSA Output Files in FITS Format



```
SIMPLE =          T / file does conform to FITS standard
BITPIX =         -32 / number of bits per data pixel
NAXIS =           3 / number of data axes
NAXIS1 =          72 / length of data axis 1
NAXIS2 =          36 / length of data axis 2
NAXIS3 =           7 / length of data axis 3
EXTEND =          T / FITS dataset may contain extensions
COMMENT FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT  and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
DATE = '2007-10-31T17:13:10' / file creation date (YYYY-MM-DDThh:mm:ss UT)
OBSER = 'gon ' / Observatory
CARROT =          2058 / Carr. Rot. of leading edge of map
CARRLONG=         80 / Long. of leading edge of map
OBSCAR =          2058 / Carr. Rot. of latest magnetogram (CM)
OBSLON =          140 / Long. of latest magnetogram (CM)
OBS TIME = '2007:07:7_19h:04m:18s' / Obs. time of latest magnetogram (CM)
VERSION = 'CS_1.2 ' / TRACER version
RADOUT =          5.00 / Outer boundary radius (Rs)
RADSS =           2.50 / Source Surface radius (Rs)
GRID =            5.00 / Uniform grid res., X = Y (deg)
EDGE =            -0.20 / Edge criteria used for coronal holes
SPHHAR =          36 / Number of spherical harmonics
ENDDATE = '2007: 7:12' / Date of leading longitude
COMMENT Array 1: Source Surface field at RADOUT (nT)
COMMENT Array 2: Flux tube expansion factor eval. at the source surface
COMMENT Array 3: Colat. of open field footpoints at photosphere (rad)
COMMENT Array 4: Long. of the photospheric footpoint (rad)
COMMENT (Take absolute value and add CARRLONG to get correct values)
COMMENT Array 5: Photospheric Field (G)
COMMENT Array 6: Dist. from open field footpoint to nearest coronal bndary (deg)
COMMENT Array 7: Open (1) and closed (0) regions on the photosphere
UNIT1 = 'nT ' / Units of Array 1
UNIT2 = 'dimensionless' / Units of Array 2
UNIT3 = 'radians ' / Units of Array 3
UNIT4 = 'radians ' / Units of Array 4
UNIT5 = 'Gauss ' / Units of Array 5
UNIT6 = 'degrees ' / Units of Array 6
UNIT7 = 'no units' / Units of Array 7
END
```



# *Summary of the Status of WSA at the CCMC (and CISM & SWPC) continued*



WSA CISM Version 1.5 now available (but not at the CCMC yet).

- Includes the ability to run Wilcox (WSO) maps in the model.
  - Includes a routine that assembles the updated synoptic maps from individual WSO magnetograms.
- Otherwise only slightly different from Version 1.4.2 (mainly bug fixes).

Now in the process of replacing the older version of WSA currently running in real-time at SWPC with CISM Version 1.5.

- Will include an advanced routine that does quality control checks on the data.
  - e.g., will know **NOT** to run maps with data gaps through the model.
  - Essentially an upgrade of the quality control routine currently running at SWPC with the old version of WSA.



# Summary of the Status of WSA at the CCMC (and CISM & SWPC) continued



- Will include GONG data and ...
  - NSO/GONG will replace NSO/SOLIS on the real-time SWPC prediction web page, at least for the time being.
    - SOLIS predictions will still be available via SWPC web page and anonymous ftp.
  - MDI will run in a mode similar to that of SOLIS.
  - LMSAL MDI Assimilation Model data to be run at
    - CCMC... Yes
    - SWPC.... ?
- Ultimately a *more manageable* scheme needs to be developed at SWPC (and the CCMC?) to take advantage of the many different data sources.
  - Perhaps run model on all available data sets but only display the most *recent* and *reliable* predictions?



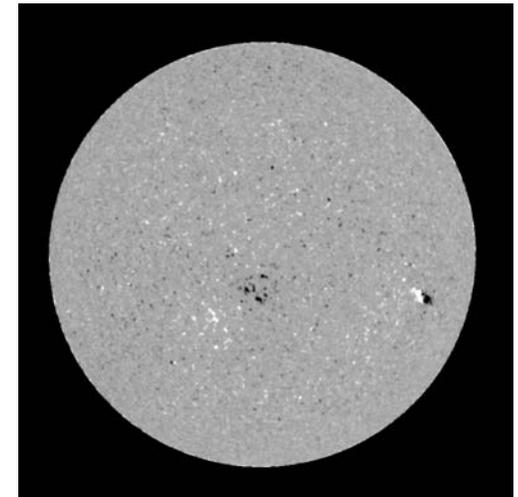
# GONG Magnetograms



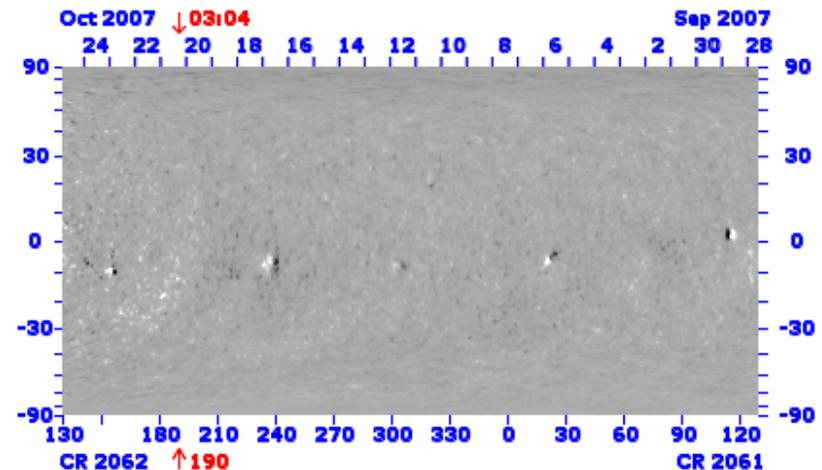
- GONG (Global Oscillations Network Group) obtains 2.5''-pixel *intensity*, *velocity* and *magnetic flux* images every minute from six sites worldwide
- Approximately 90% duty cycle
- *Round-the-clock, high-cadence, low-noise* (~3 G/pixel/min) photospheric line-of-sight *magnetograms*
- GONG is the provider of magnetograms for NASA's STEREO mission.



## GONG Magnetogram



## GONG Synoptic Map

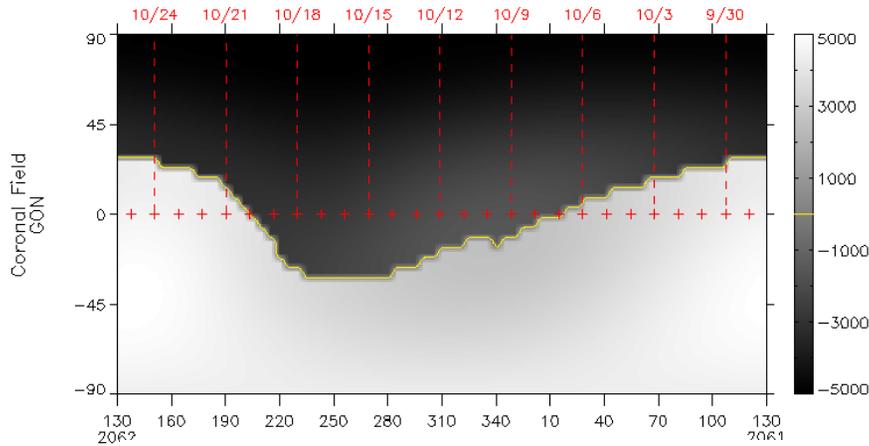




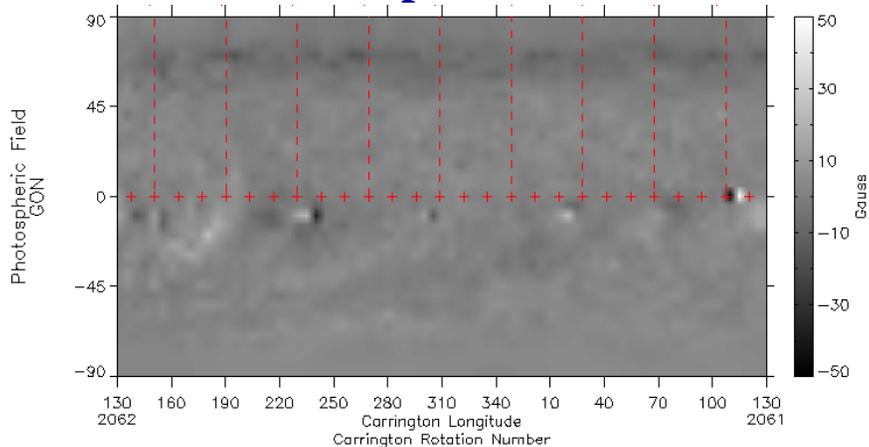
# WSA Output Using GONG



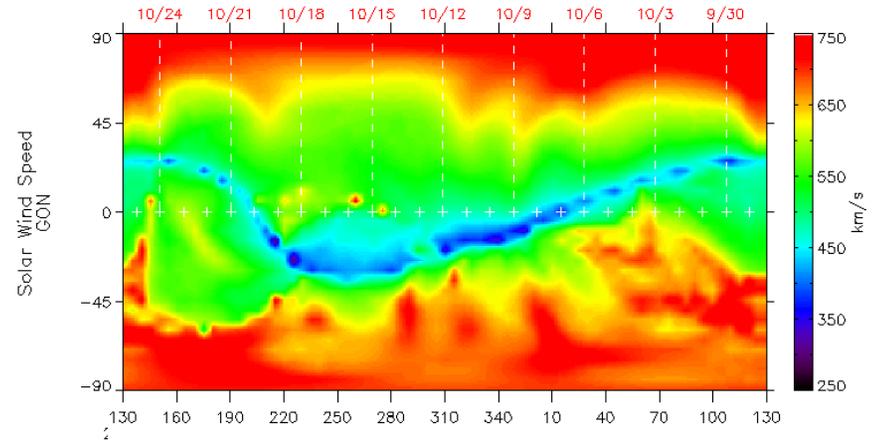
## Outer Coronal Coronal Field ( $5.0 R_{\odot}$ )



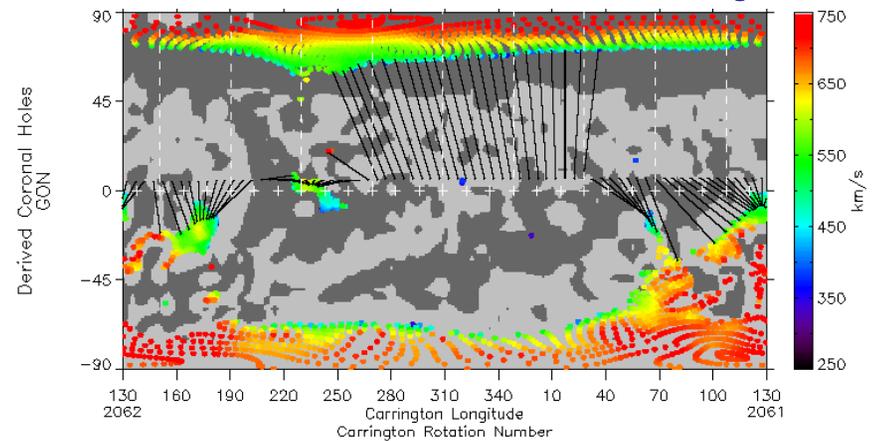
## Photospheric Field



## Predicted Solar Wind Speed ( $5.0 R_{\odot}$ )



## Derived Coronal Holes ( $1.0 R_{\odot}$ )



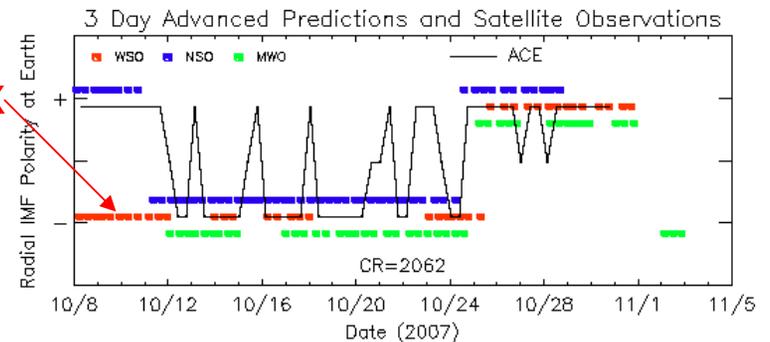
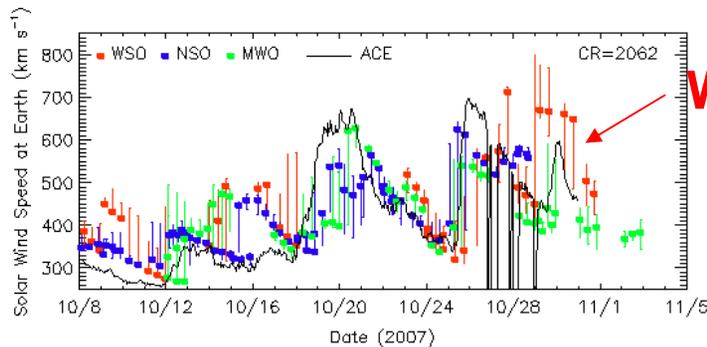
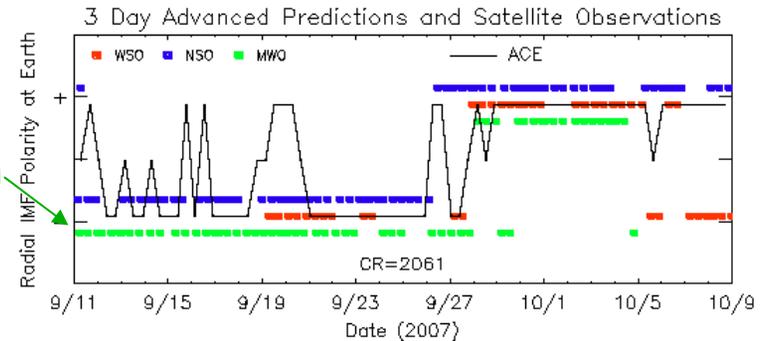
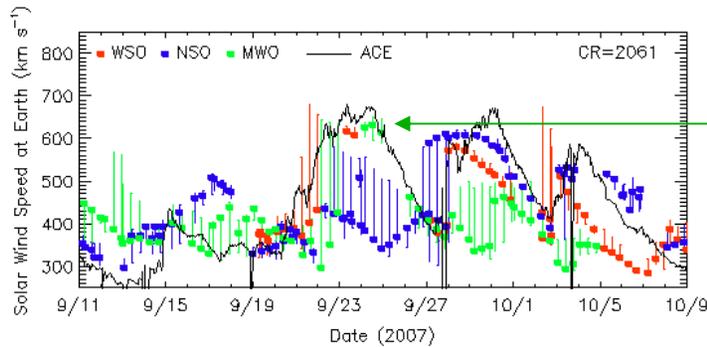
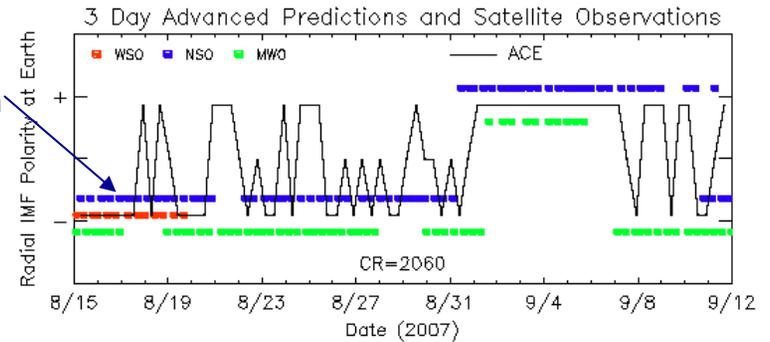
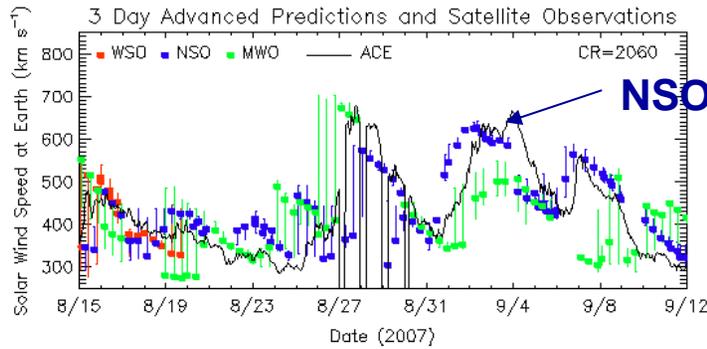


# Real-Time WSA Predictions & Spacecraft Observations



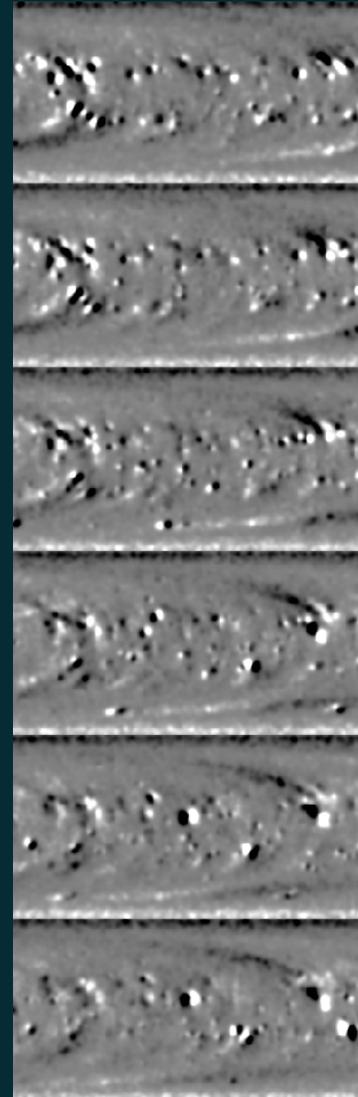
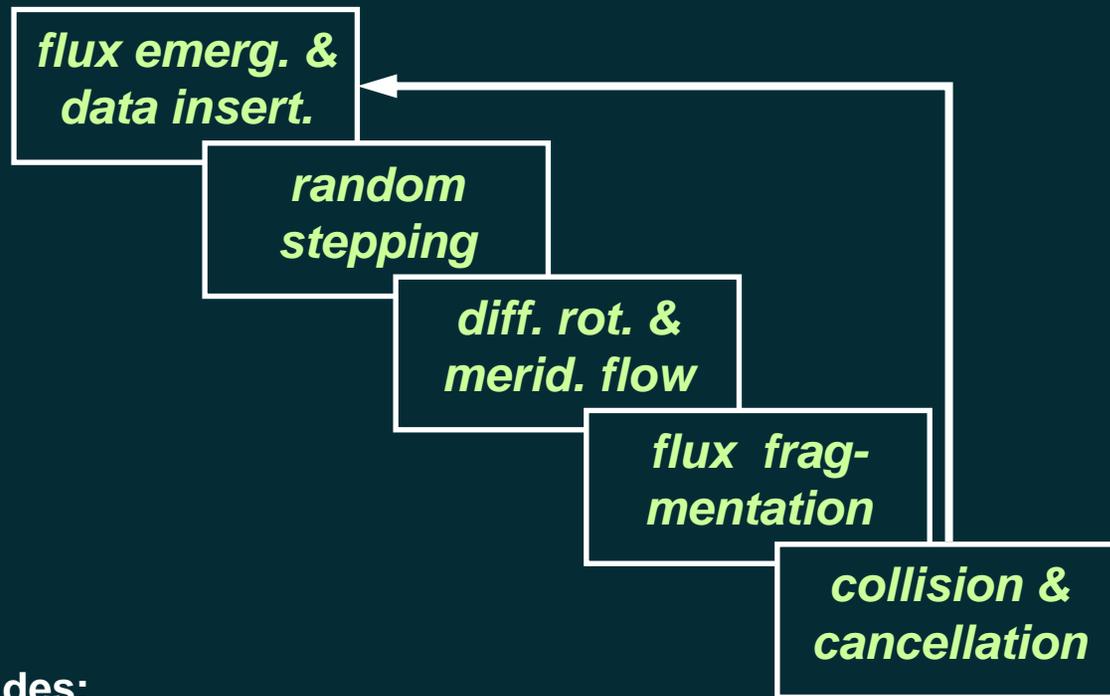
## Solar Wind Speed Predictions & Observations

## IMF Polarity Predictions & Observations





# LMSAL Surface-Flux Transport Model (Marc DeRosa & Karel Schrijver)



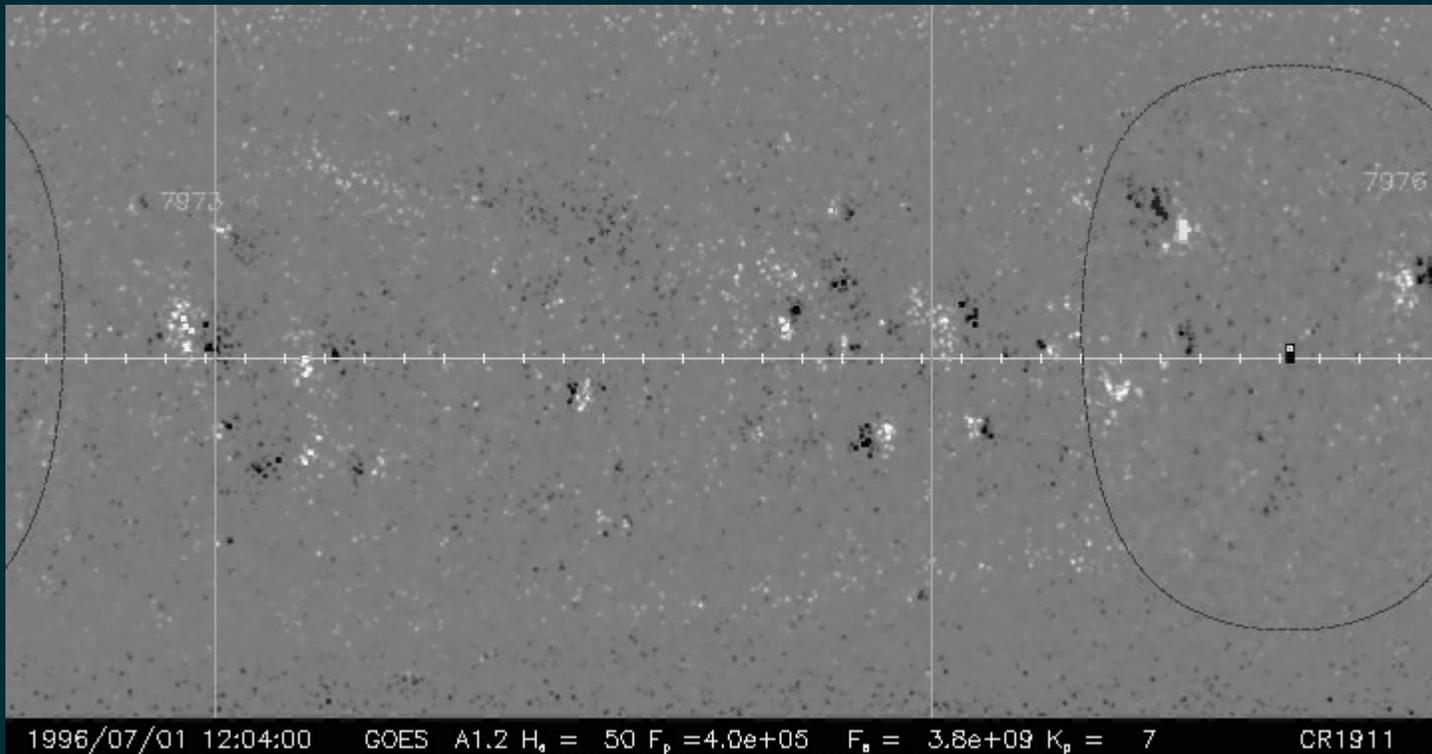
This model includes:

- **active to ephemeral region flux, atomic description** (no grid)
- bipole strengths, emergence latitudes, tilts chosen from empirically determined statistical distribution functions
- **nonlinear magnetoconvective coupling**: nesting, and flux-dependent dispersal coefficient



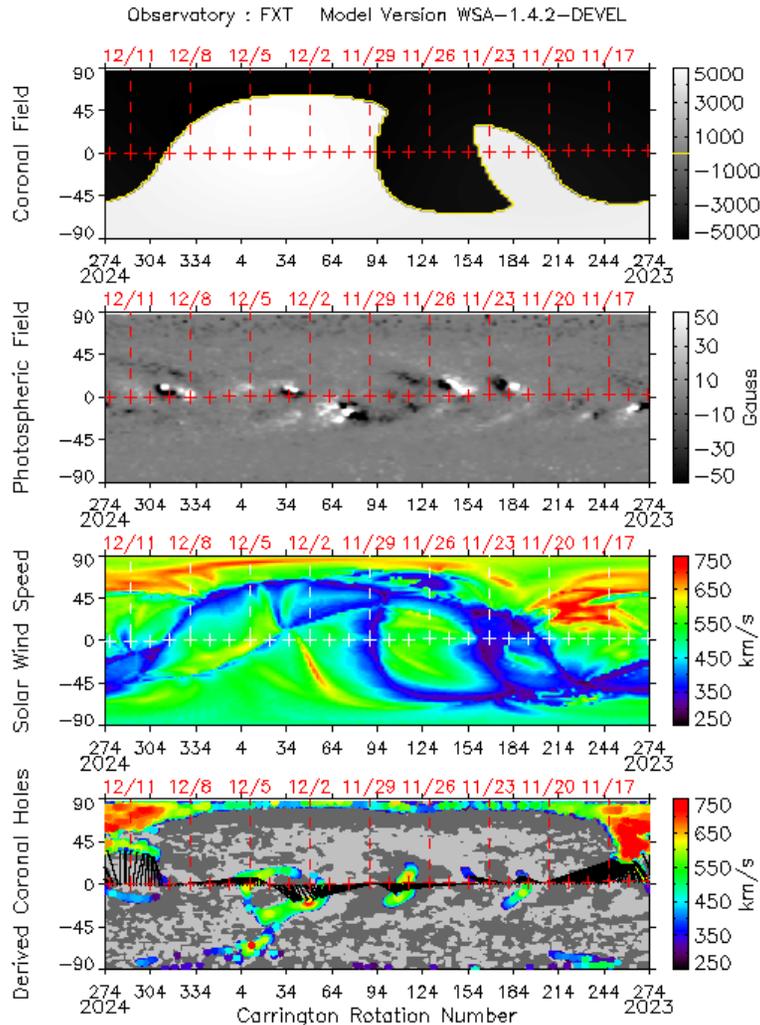
# LMSAL MDI Assimilation Model

(Marc DeRosa & Karel Schrijver)

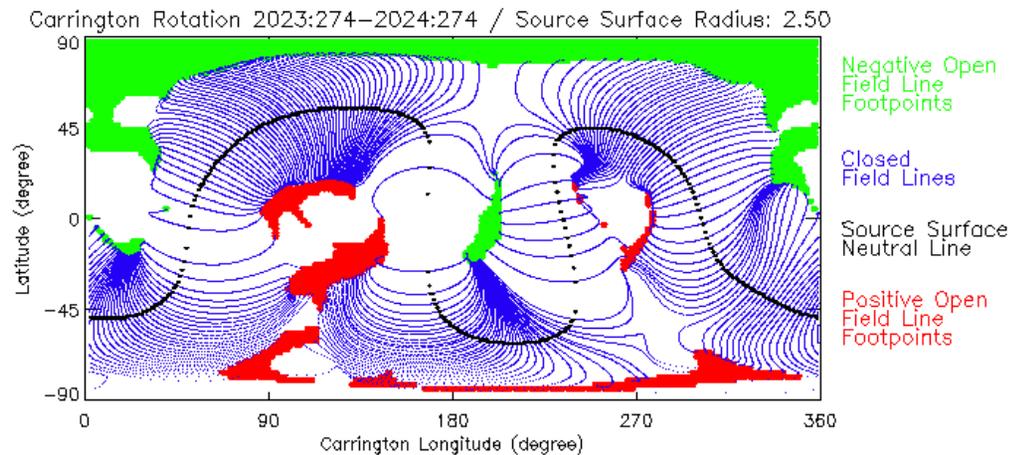




# WSA Output Using LMSAL MDI Assimilation Model Data



## Coronal Output (Luhmann's PFSS Field LINE Plotting Routine)



*Courtesy Macneice & DeRosa*



# Calibration of WSA-ENLIL Velocity Coupling



(S. McGregor, W. J. Hughes, C. N. Arge, M. Owens, & D. Odstrcil)

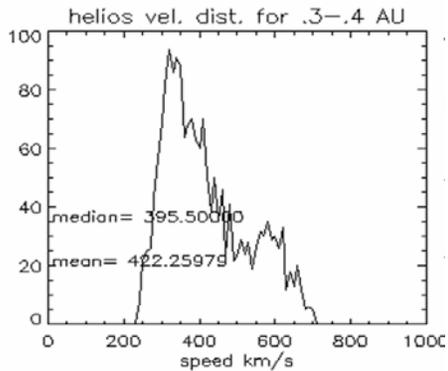
Empirical velocity equation used in WSA tuned to match observations at 1AU

- Solar wind assumed ballistic with an ad hoc mechanism to account for stream interactions (i.e., fast streams cannot by-pass slow streams)
- ⇒ wind can only slow down.

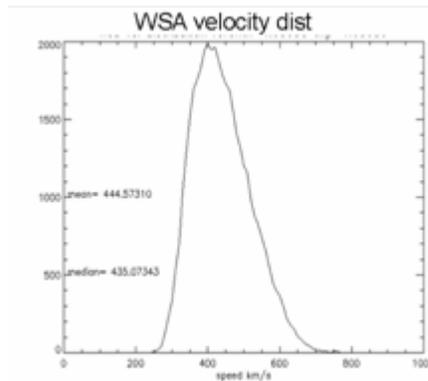
In WSA+ENLIL

- Empirically derived WSA speeds fed into ENLIL at 0.1 AU can both *decelerate* AND *accelerate*.
- ⇒ Empirical velocity equation needs to be *recalibrated* for WSA+ENLIL

HELIOS observations used to re-calibrate equation for in-situ observations made during solar minimum (1974-1976) and when located between 0.3-0.4 AU.



Helios Velocity Occurrence Distribution: 1974-1976



Velocity Occurrence Distribution for (old) WSA at .1AU

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





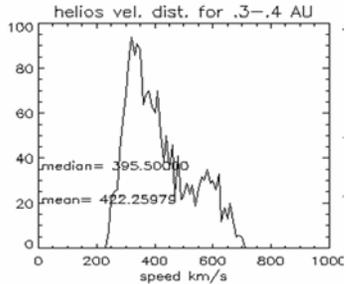
# Calibration of WSA-ENLIL Velocity Coupling ...Continued



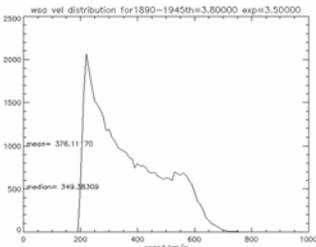
Using observed velocity occurrence distribution and

1. Helios 1 & 2 showed minimum solar wind speeds of ~200 km.
2. Most of the slow solar wind originates from with  $\sim 5.7^\circ$  of the coronal boundary. (Riley et al., 2003)
3. Coronal hole boundary later producing speeds between 600-750 km/s is  $4^\circ$  wide. (Schwadron, 2005)

Permits empirical velocity equation to be modified to better agree with HELIOS observations.

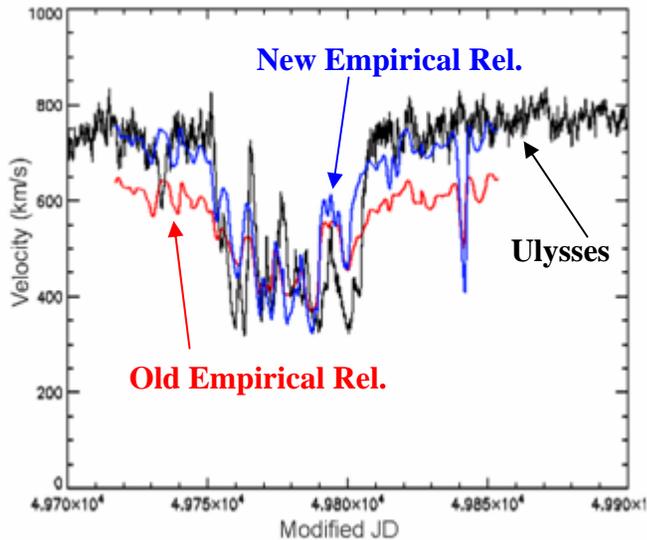


Helios Velocity Occurrence Distribution: 1974-1976

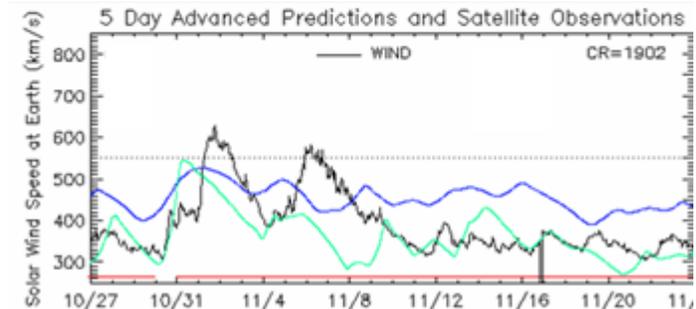
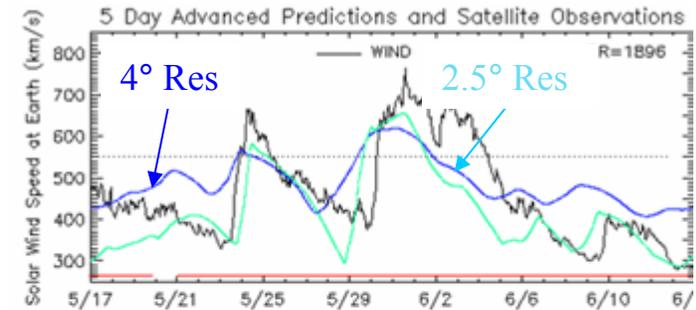


New Velocity Occurrence Distribution for WSA at .1AU

Ulysses first fast latitude scan in 1995



WSA+ENLIL Using New Empirical Relationship





# Summary



## ✓ WSA Version 1.4.2 at the CCMC.

- Automated for the CCMC so that it routinely retrieves Carrington and daily updated synoptic maps from
  - Mount Wilson (MWO).
  - Kitt Peak (NSO).and then runs them through the WSA code.
- Other Observatory data tested in model but not yet standard CCMC products.
- Version currently used as input to ENLIL.

## ✓ WSA Version 1.5 now available at CISM.

- Includes the ability to run Wilcox (WSO) maps in the model.
- In the process of replacing the older version of WSA currently running in real-time at SWPC with Version 1.5.
  - Will include an advanced routine that does quality control checks on the data.
- Will be provided to the CCMC.

## ✓ WSA+ENLIL predictions improved by

- Using Helios observations (between 0.3-0.4 AU) to better calibrate the empirical WSA velocity relationship.
- Increasing resolution of the model.