



# Air Force Research Laboratory



***Integrity ★ Service ★ Excellence***

## WSA Model Update

**Community Coordinated  
Modeling Center Workshop**

**April 12, 2016**

**Annapolis, Maryland**

**C. Nick Arge<sup>1</sup>, David MacKenzie<sup>2</sup>,  
& Kathleen Shurkin<sup>3</sup>**

1. AFRL/Space Vehicles Directorate, Kirtland AFB, NM

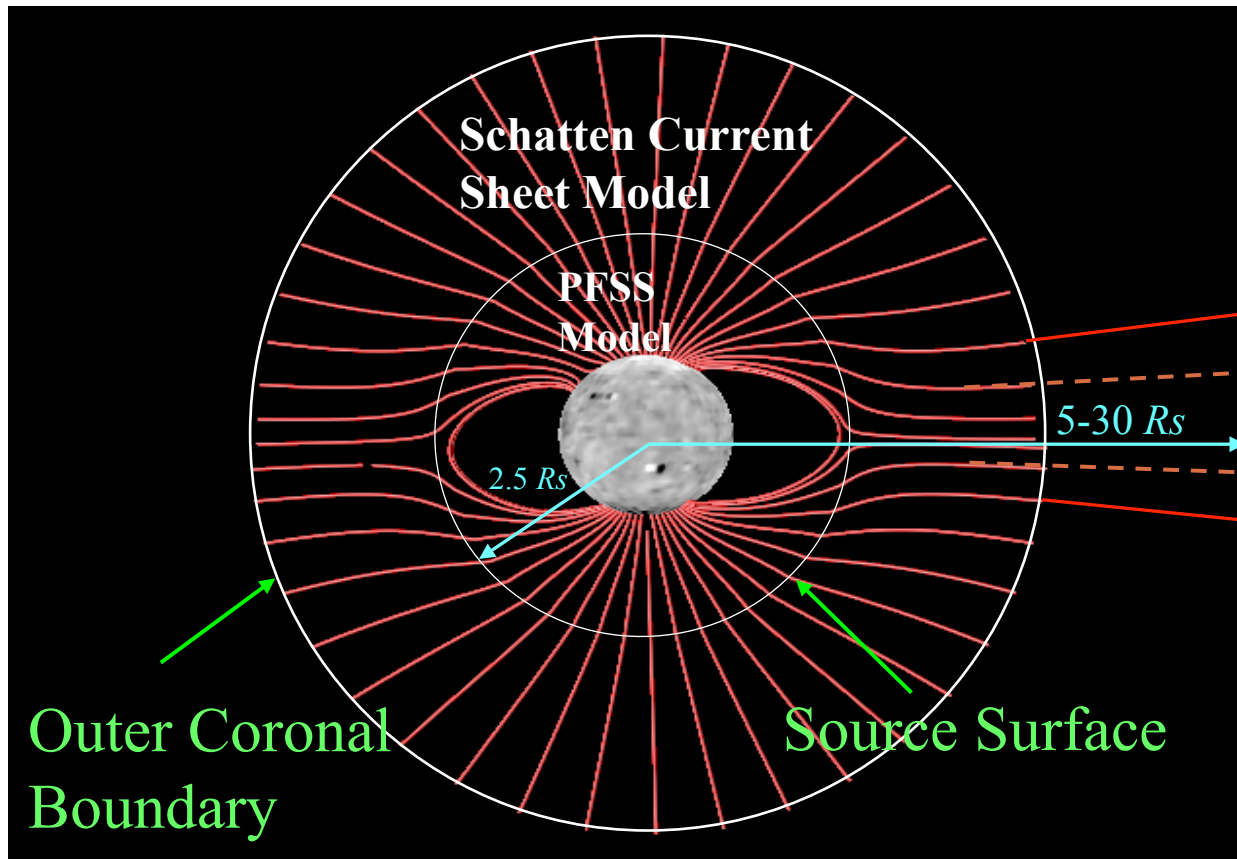
2. Atmospheric and Environmental Research (AER)

3. Boston College





# Wang-Sheeley-Arge (WSA) Coronal & Solar Wind Model



Solar Wind Models such as:

- 1) WSA 1D Kinematic
- 2) ENLIL
- 3) LFM-Helio
- 4) MS-FLUKSS
- 5) HAF

(5-30 $R_s$  to 1AU)

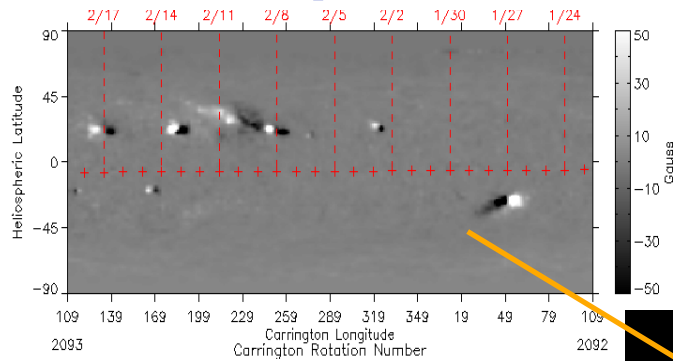
- Wang-Sheeley-Arge (WSA) model - combined empirical and physics based model of the corona and solar wind.
- Improved version of the original Wang & Sheeley model developed at NRL.
- Operational at NOAA/NCEP and NASA/CCMC.



# WSA PFSS+SCS Coronal Solution

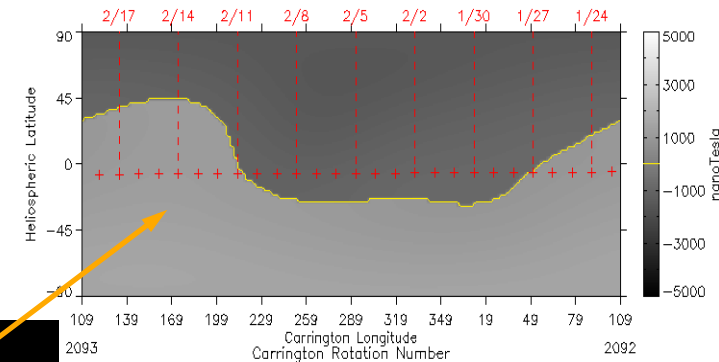


## MODEL INPUT: Observed Photospheric Field



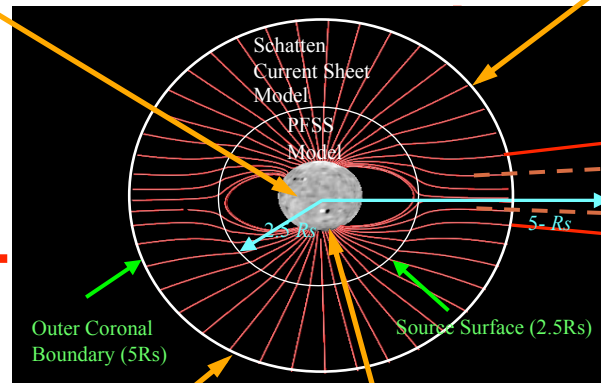
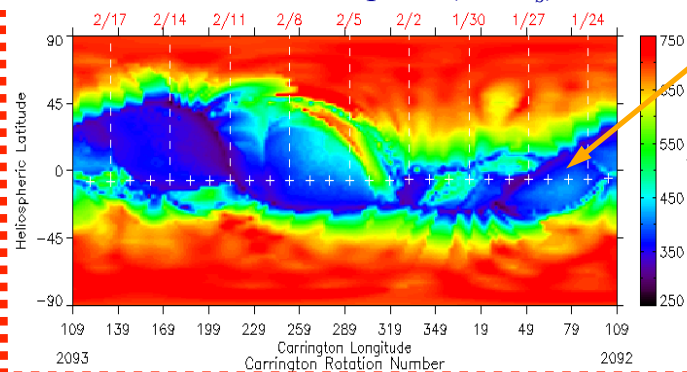
## MODEL OUTPUT

### Field at Outer Coronal Boundary ( $5.0 R_s$ )



## MODEL OUTPUT

### Predicted Solar Wind Speed ( $5.0 R_s$ )

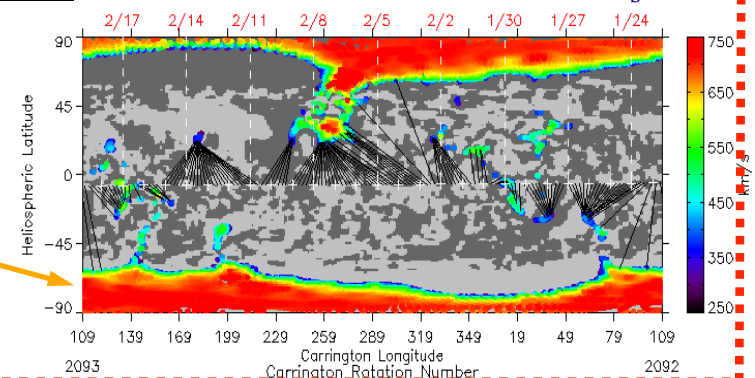


**Solar Wind Model**  
(e.g., WSA 1D Kinematic model, Enlil, LFM-Helio, MS-FLUKSS & HAF)  
( $5-30R_s$  to 1AU)

Open Field Footpoints  
(coronal holes)

## MODEL OUTPUT

### Derived Coronal Holes ( $1.0 R_s$ )





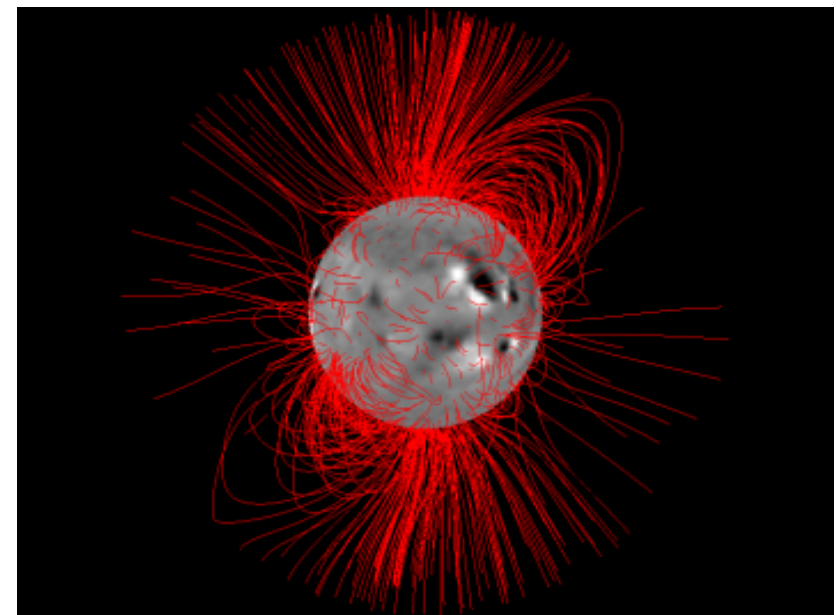
# WSA 4.0 Available Soon!



## Key Features:

1. Field line tracing parallelized
2. Compatible with
  - NSO (VMS, GONG), WSO & MWO
  - ADAPT (VSM, GONG, HMI)
  - Understands multi-realization input files
3. Can be run in the following modes:
  - PFSS
  - Coupled PFSS+Schatten Current Sheet (SCS)
  - Traditional or Improved interface between PFSS & SCS models.
    - Improved: minimizes “kinking” at interface.
4. IDL & Perl scripts replaced with Python
5. Forecasts solar wind speed and IMF polarity at
  - L1, STEREO A & B, Ulysses, & all inner planets
  - Easy to add other positions/satellites
6. Retuning empirical solar wind speed relationship
7. New field line tracing package

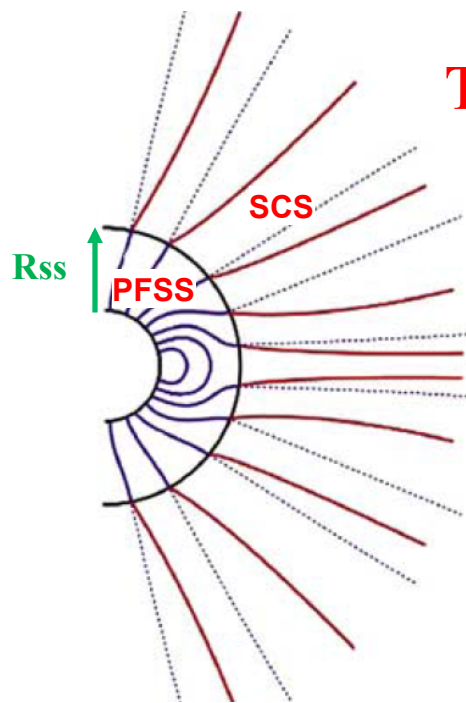
## Wang-Sheeley-Arge (WSA) (Coronal Model)



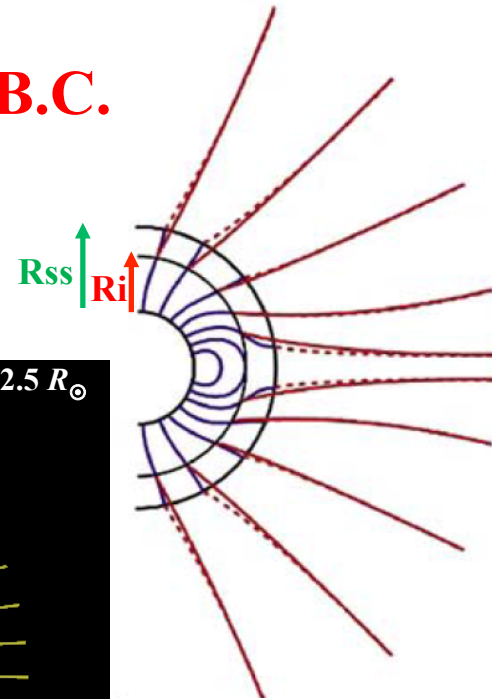
Input: Global maps of photospheric magnetic field  
(e.g., ADAPT)



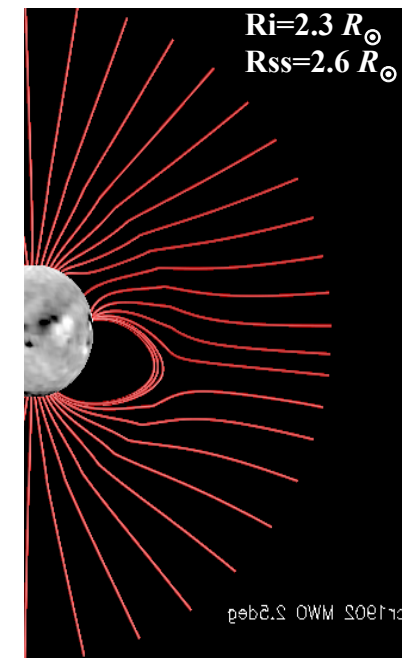
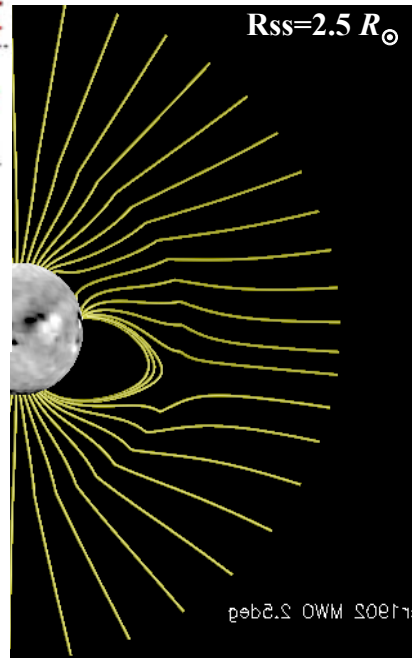
# Improved Interface B.C. Between PFSS & SCS Models



**Traditional B.C.**



**Improved B.C.**



WSA 4.0 allows user to choose between standard interface B.C. (left) and improved one (right)

*McGregor et al., JGR, 2008*

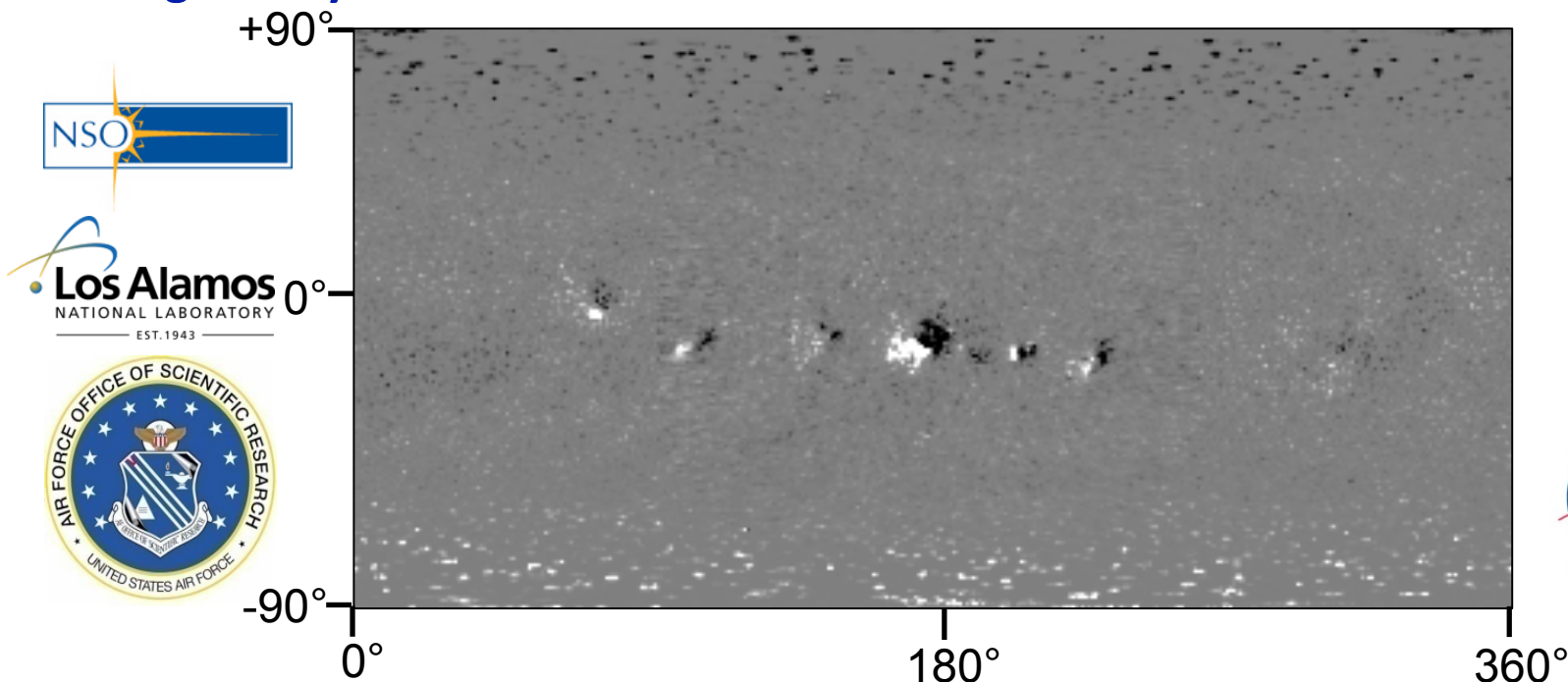




# Air Force Data Assimilative Potospheric Flux Transport (ADAPT) Model



1. Evolves solar magnetic flux using well understood transport processes where measurements are not available.
2. Updates modeled flux with new observations using *data assimilation methods*
  - Rigorously takes into account model & observational uncertainties.



Sun's surface magnetic field (movie length ~60 days)

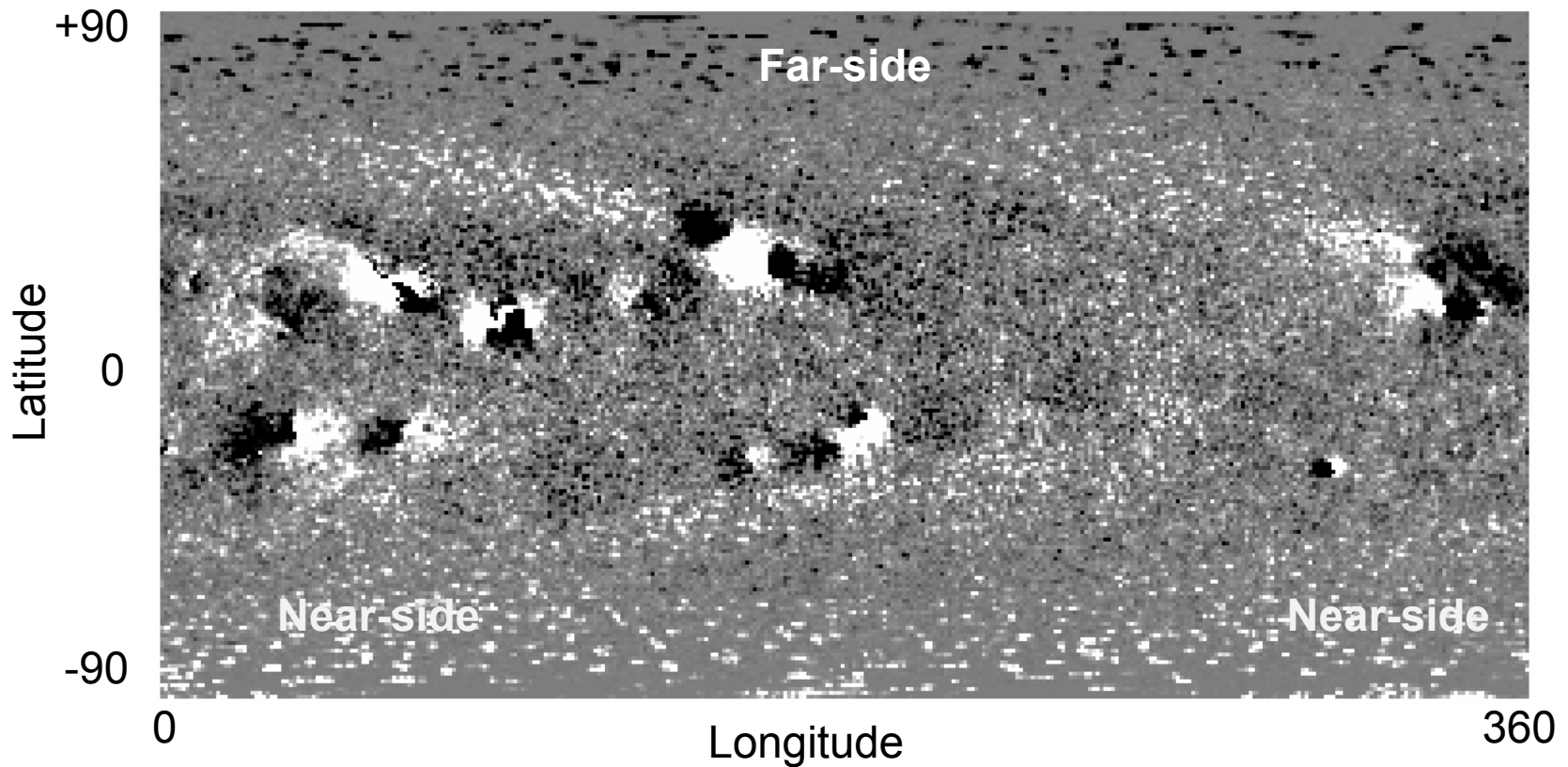
**Provides more realistic estimates of the instantaneous global photospheric magnetic field distribution than those provided by traditional synoptic maps.**



# ADAPT Solution Ensemble

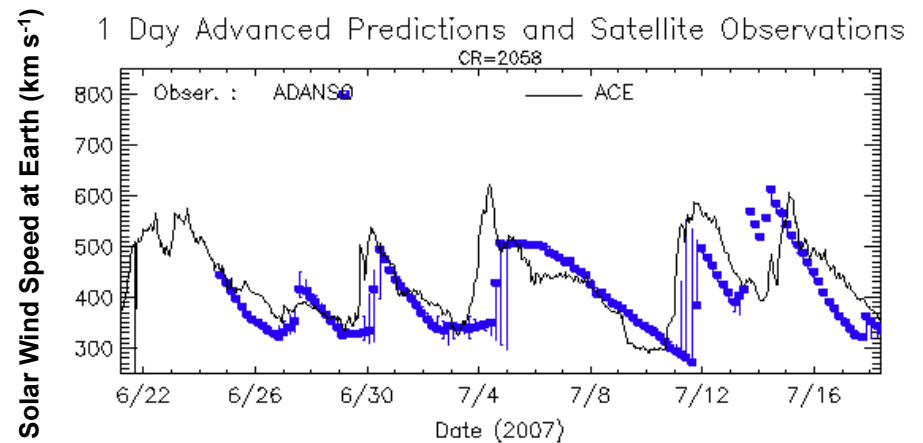
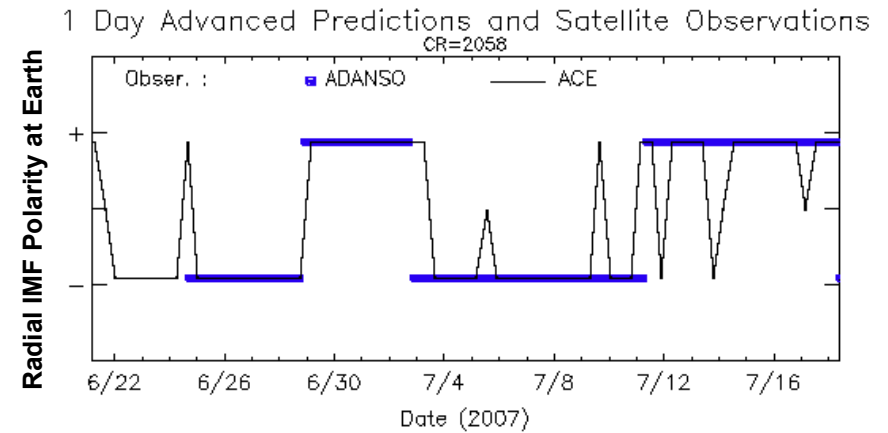
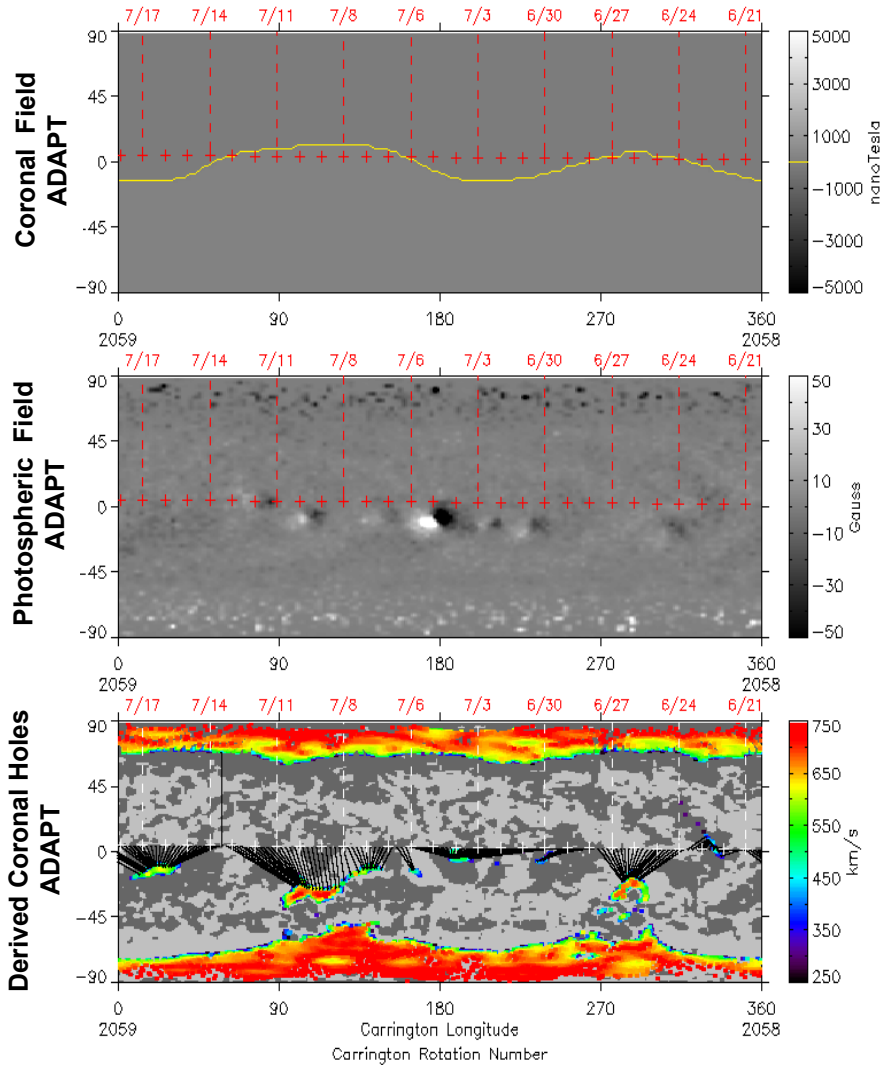


**ADAPT generates an ensemble of global photospheric magnetic field maps for each given moment in time**





# WSA Coronal & Solar Wind Solutions using the 12 ADAPT Realizations for June 21, 2007 (Start of CR2058)

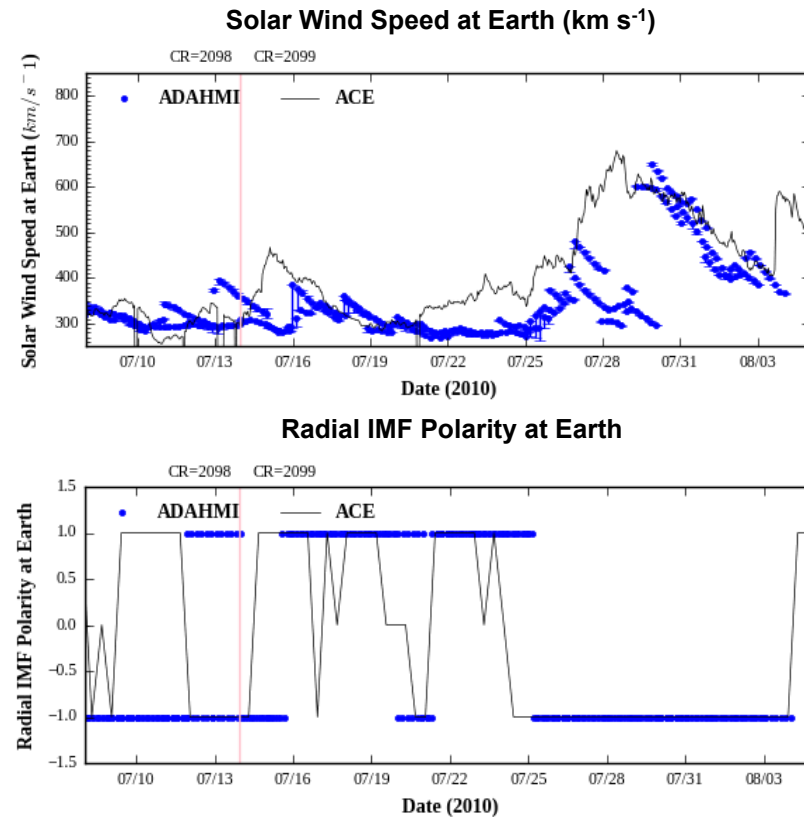
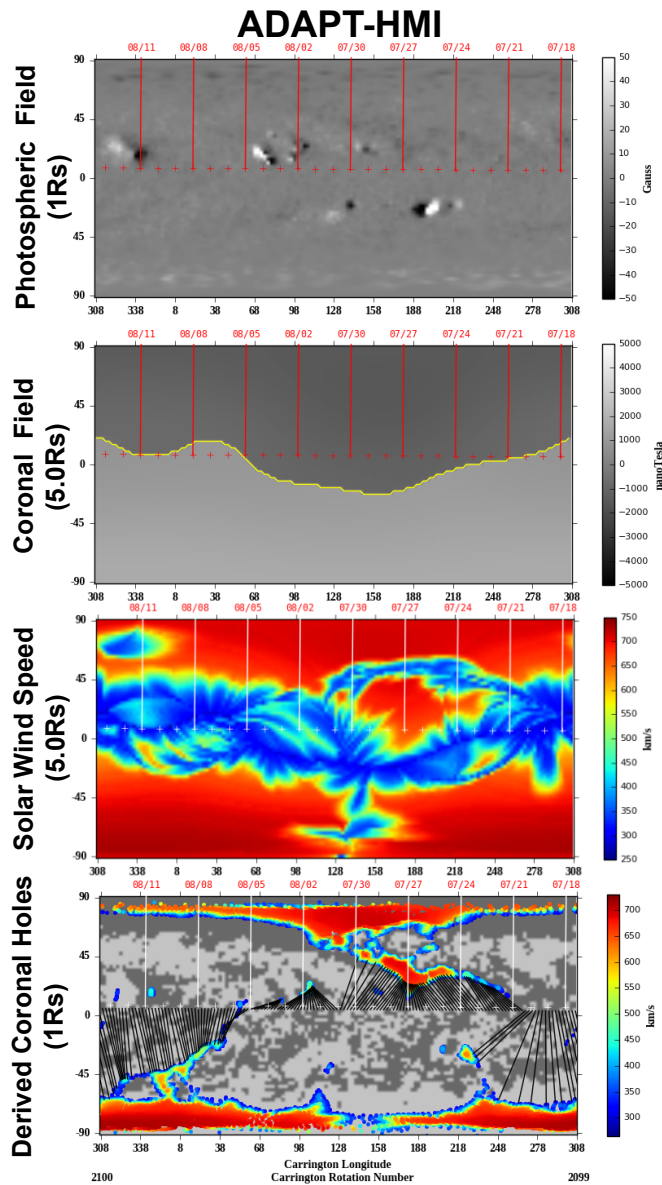






# WSA 4.0 ADAPT-HMI

## Coronal Solutions & Solar Wind Solutions



Created 2016 February 29 1704 UTC

- *ADAPT-HMI maps fully integrated into WSA 4.0*
- *Tuning the solar wind empirical relationship*

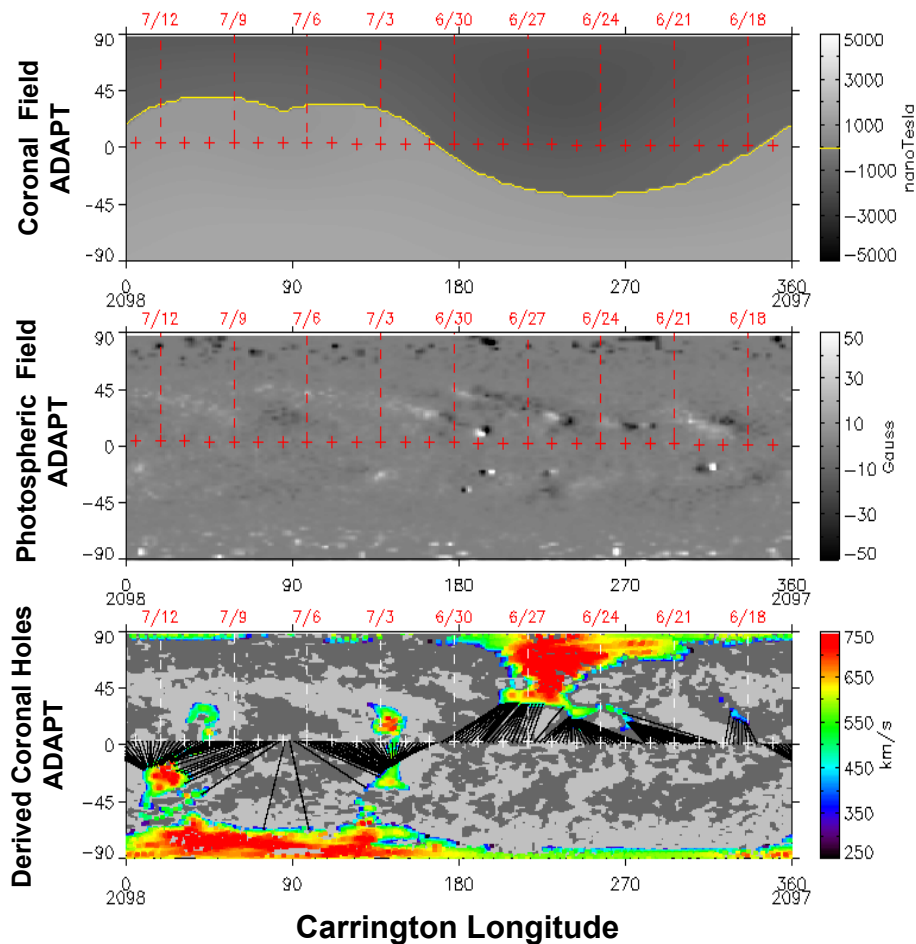




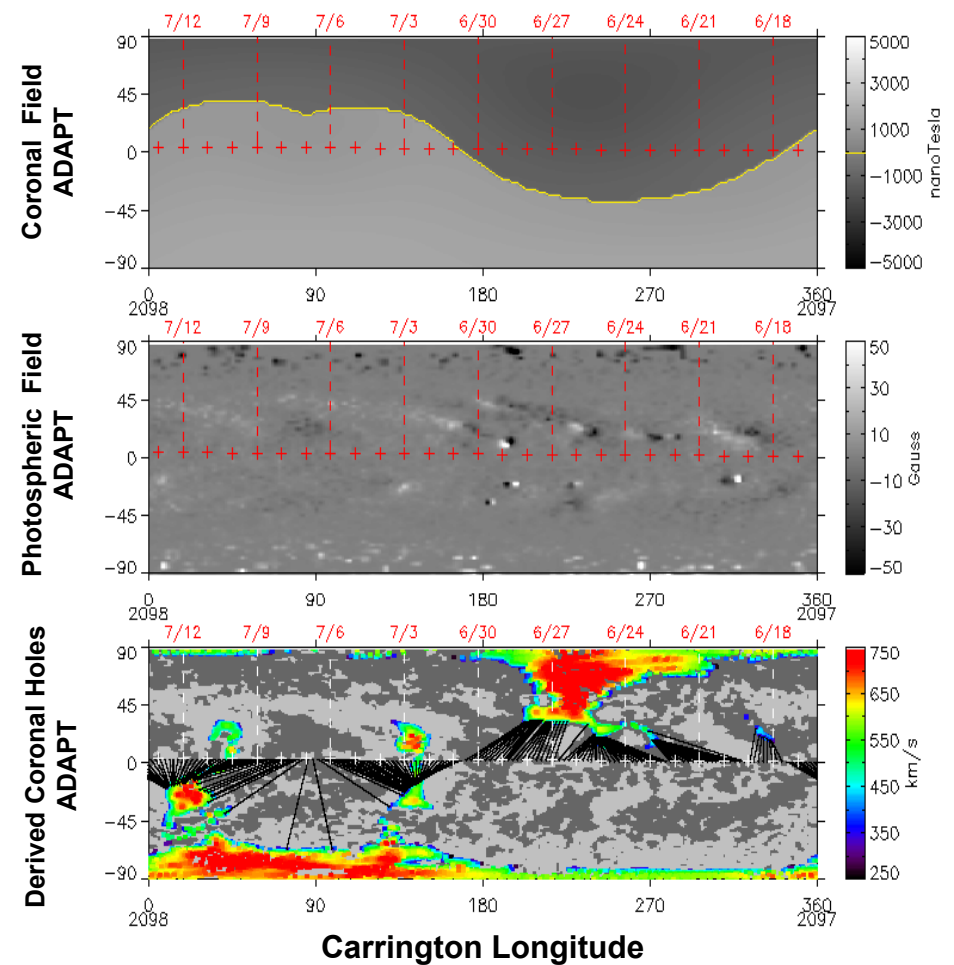
# Time Evolution of the Photosphere & Coronal (With & Without Far-Side Active Region Inserted)



## Without Far-Side Active Region Inserted



## With Far-Side Active Region Inserted



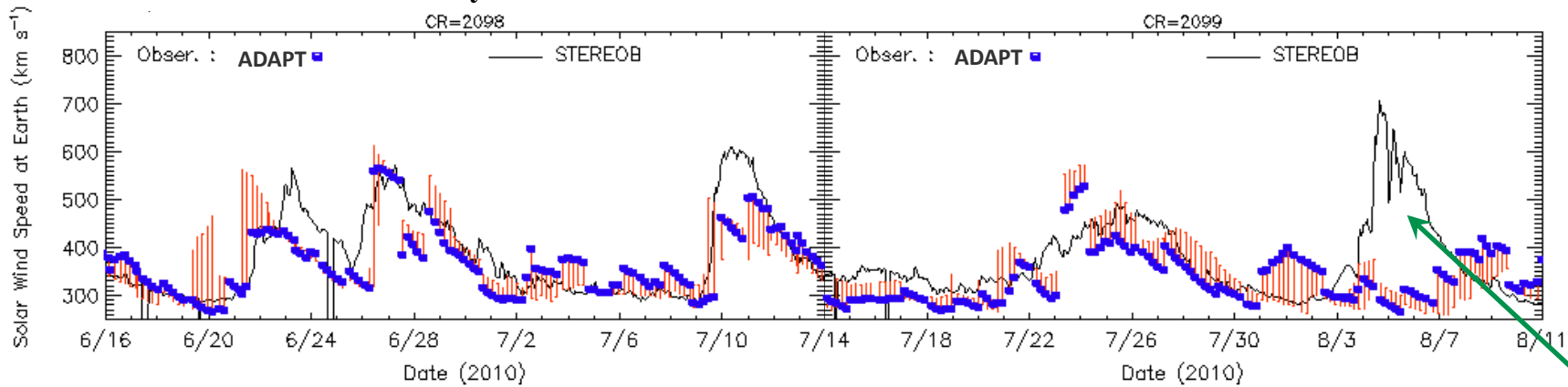


# WSA Solar Wind Speed vs Observations at STEREO B (With & Without Far-Side Active Region Inserted)

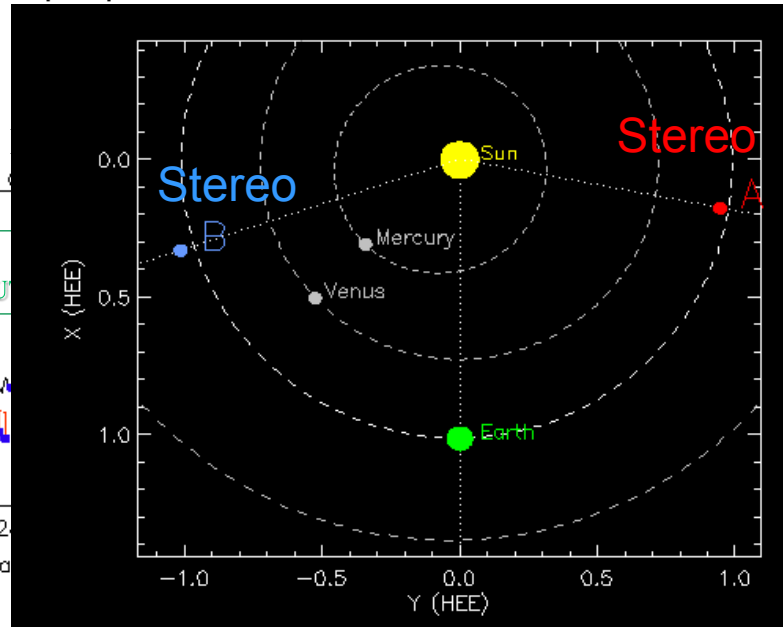
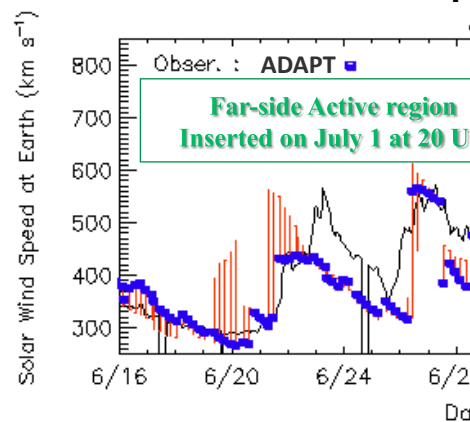


## Without Far-Side Active Region Inserted

### 4 Day Advanced Predictions and STEREO B Observations

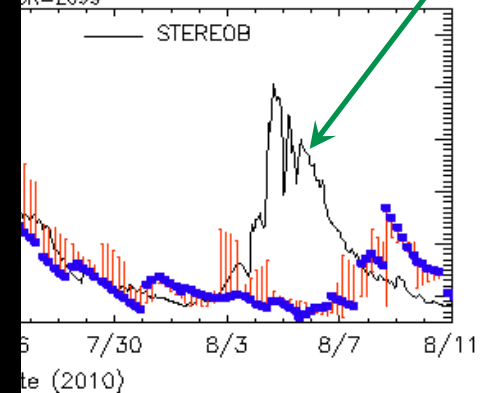


ICME



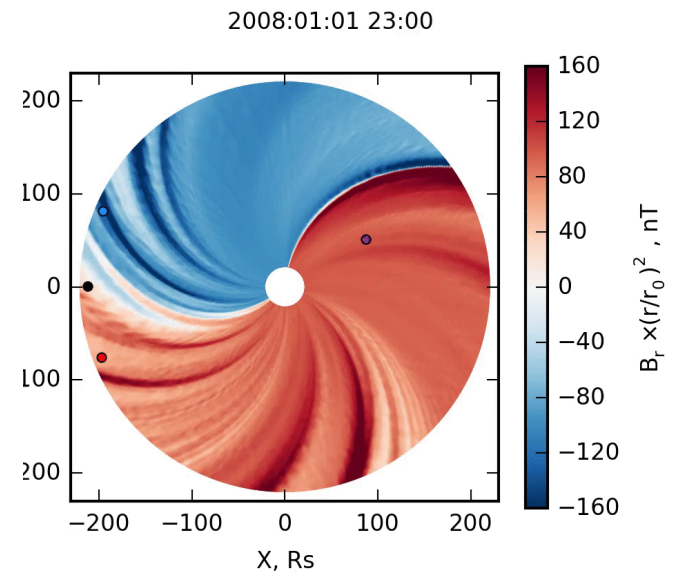
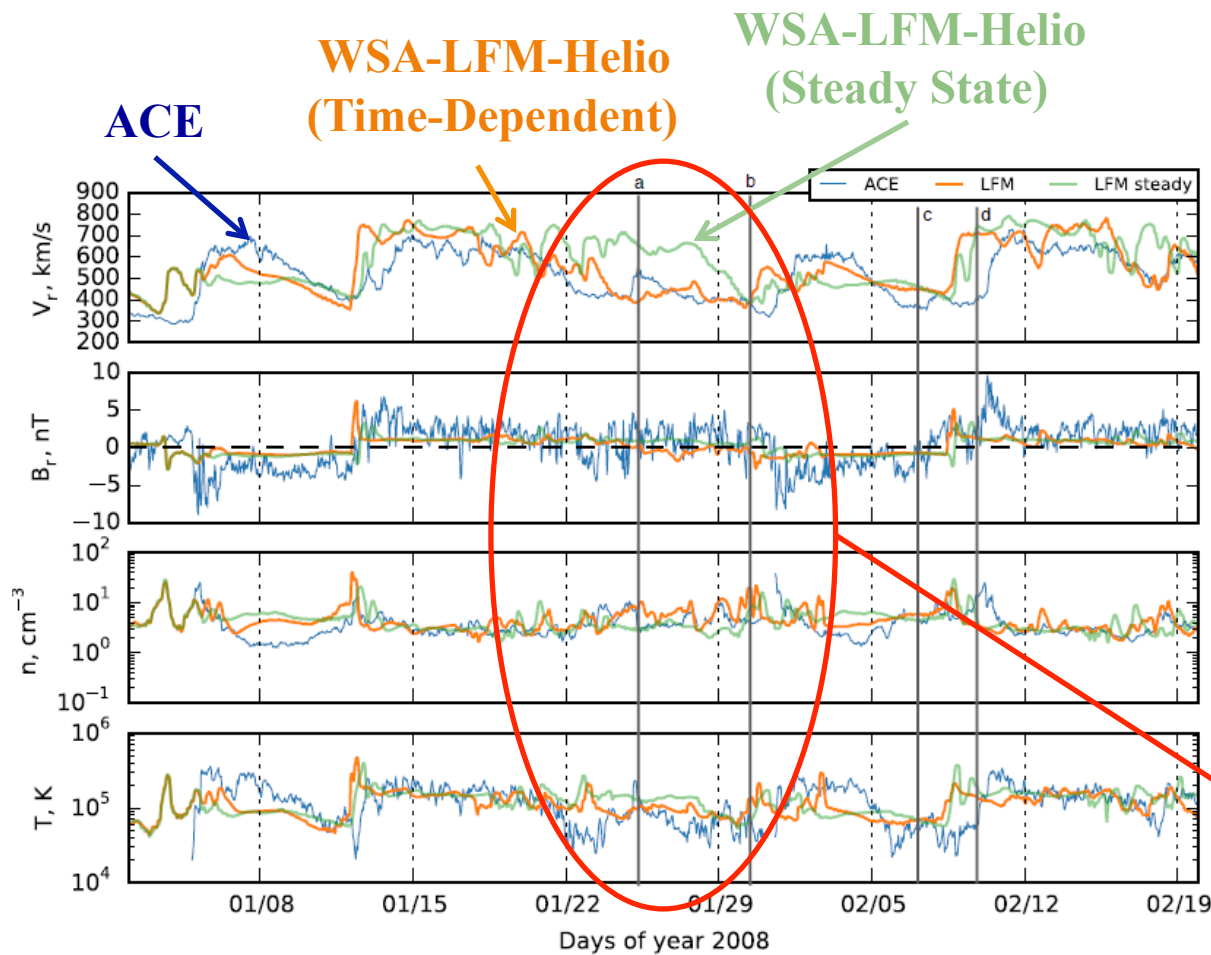
Observations

CR=2099





# ADAPT Driven WSA-LFM+Helio



**Time-Dependent LFM-Helio predicts the solar wind better than steady state solution.**

*Merkin, Lyon, Lario, Arge, & Henney, JGR, 2016 (Accepted)*





# “Time-Dependent” ADAPT-WSA-Enlil

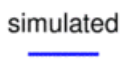
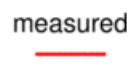
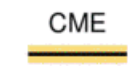
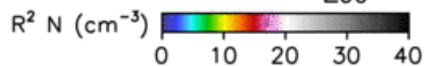
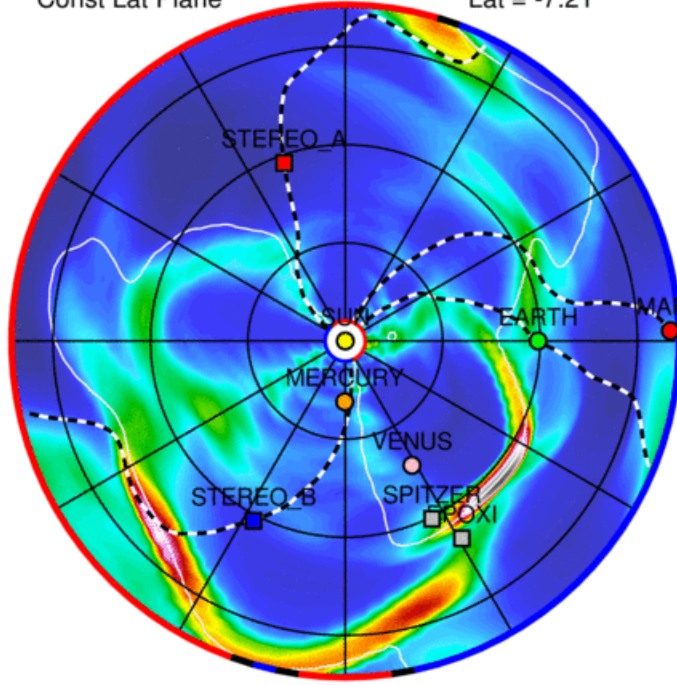


2012-03-01T00:00

Const Lat Plane

W90

Lat = -7.21°

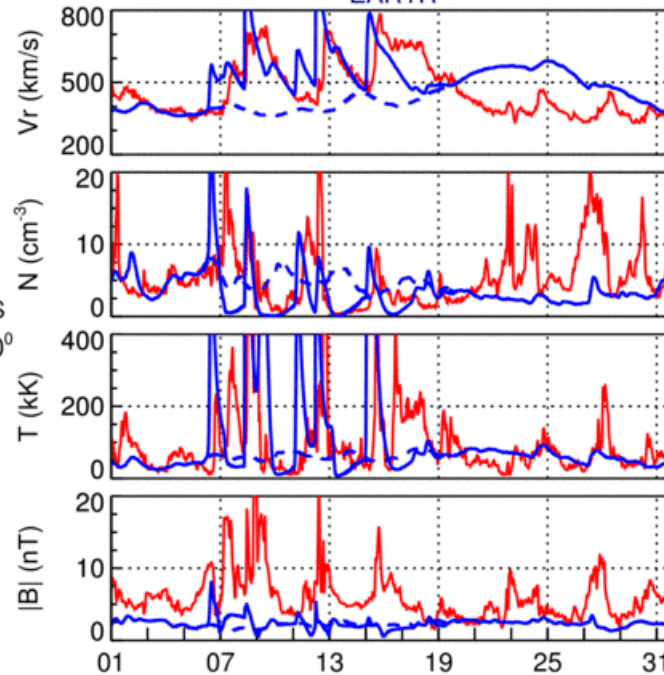


ENLIL-lowres + AGN-WSADA + Cone-SWRC

Courtesy Dusan Odstrcil

2012-03-01T00 + 0.00 days

EARTH



- ACE
- - - ADAPT-WSA-Enlil Forecast
- ADAPT-WSA-Enlil Forecast with CMEs

For discussion of far-side active region impact on modeling see:

Cash, Biesecker, Pizzo, de Koning, Millward, Arge, Henney, & Odstrcil (2015)

*Moving toward time-dependent ADAPT-WSA-Enlil solar wind forecast capability*







# Issues Facing Coronal & Solar Modeling



- Solar community moving toward *true* time-dependent modeling of corona & solar wind
- The global solar photospheric magnetic field distribution serves as primary input to *nearly all* coronal and solar wind models.
- Several *issues* with photospheric magnetic field input driver maps
  - Poles not observed for months at a time
    - Coronal models very sensitive to the polar fields
    - Can Introduce artificial monopoles into maps
  - Traditional magnetograms of the solar far-side not available
    - Helioseismology helping
    - Solar Orbiter will provide some far-side coverage
  - Far-side flux emergence can
    - Change *global* coronal solution
    - Introduce artifacts into the models (e.g., “sudden” appearance of active regions as they rotate on to the solar near-side)
    - Introduce artificial monopoles into maps
- Flux transport models (e.g., ADAPT) ideally suited to drive solar models time-dependently
  - Required because routine global observations of Sun’s magnetic field not available
  - Provide time sequences of the global photospheric magnetic field at cadences required by models.



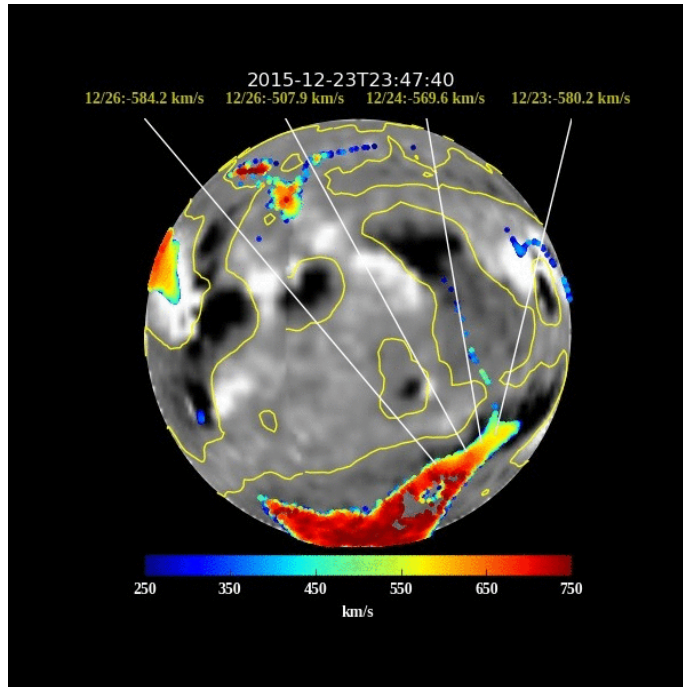
# Summary



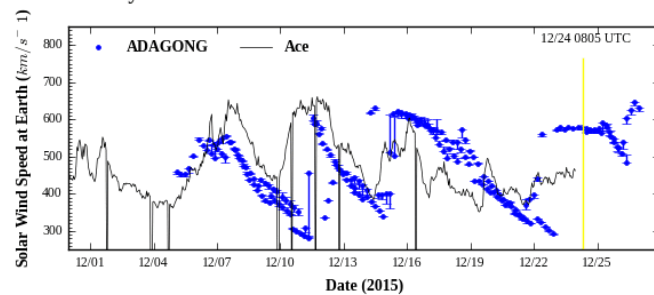
- **Wang-Sheeley-Arge (WSA) model - combined empirical and physics based model of the corona and solar wind.**
  - **Improved version of the original Wang and Sheeley model.**
  - **Operational at NOAA/NCEP and NASA/CCMC.**
- **Key Features:**
  1. **Field line tracing parallelized**
  2. **Compatible with most input photospheric field maps including ADAPT.**
  3. **Can be run in PFSS or coupled PFSS+Schatten Current Sheet (SCS) modes.**
  4. **Optional improved interface between PFSS & SCS models can be employed**
    - **minimizes “kinking” at interface.**
  5. **IDL & Perl scripts replaced with Python**
  6. **Can forecast solar wind speed and IMF polarity at inner planets & most satellites**
    - **Easy now to add other satellites.**
  7. **In the process of retuning empirical solar wind velocity relationship.**
  8. **New field line tracing package.**
  9. **Available soon!**
- **Coronal & solar wind modelers face new challenges**
  1. **when moving to time-dependent modeling.**
  2. **contending with high cadence, high resolution, multi-realization input maps.**



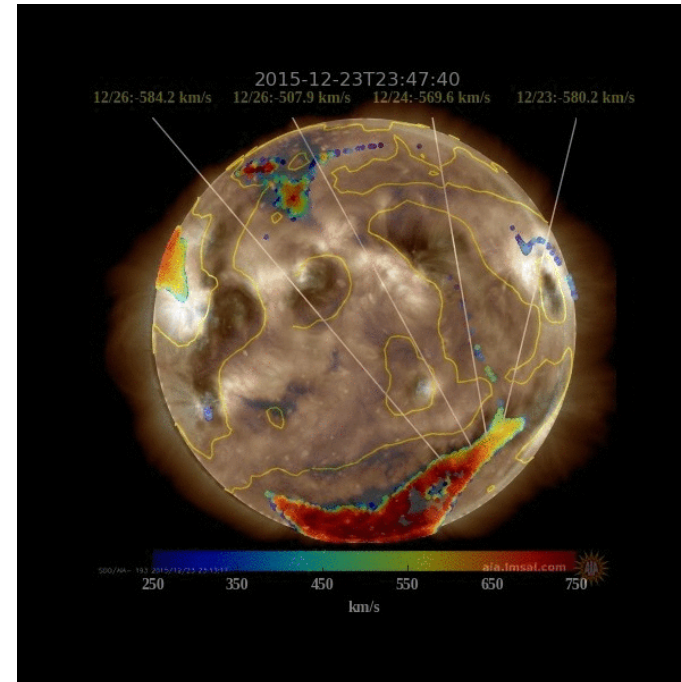
# ADAPT-Driven WSA Coronal & Solar Wind Predictions



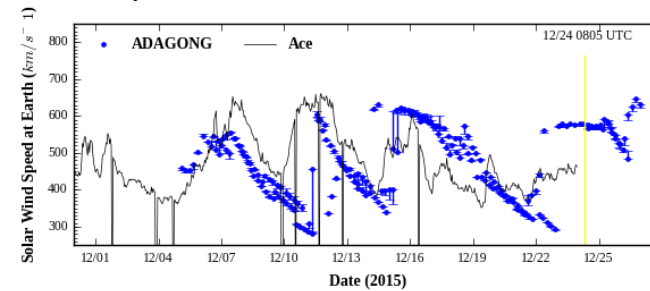
3 Day Advanced Predictions and Satellite Observations



Created 2015 December 24 0805 UTC



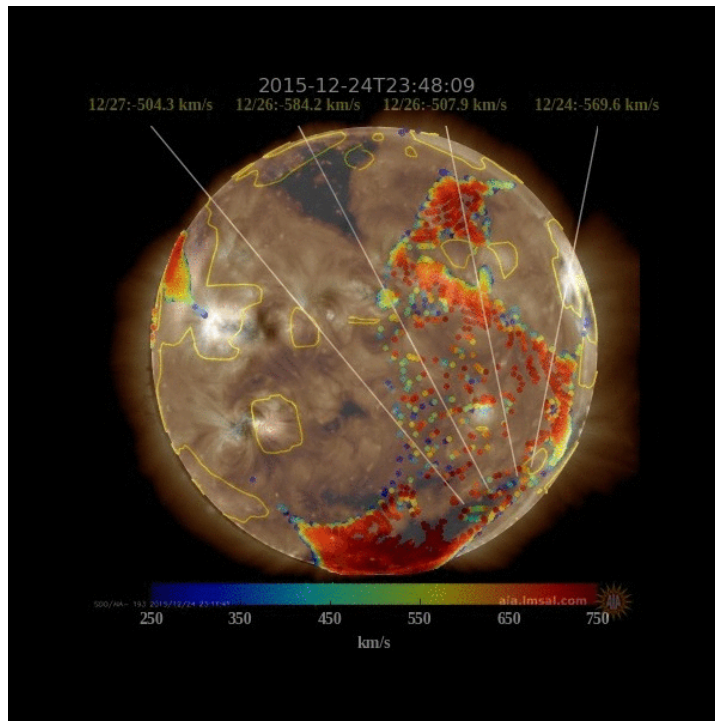
3 Day Advanced Predictions and Satellite Observations



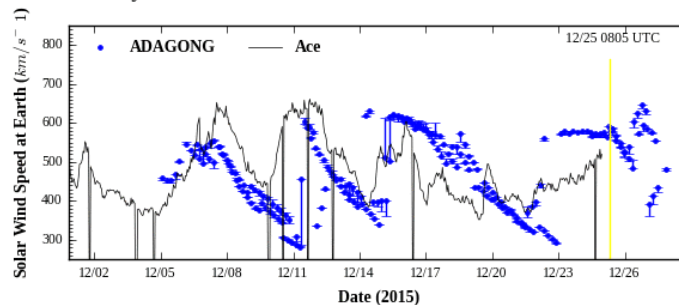
Created 2015 December 24 0805 UTC



# ADAPT-Driven WSA Solar Wind Predictions (What can happen when things go wrong!)



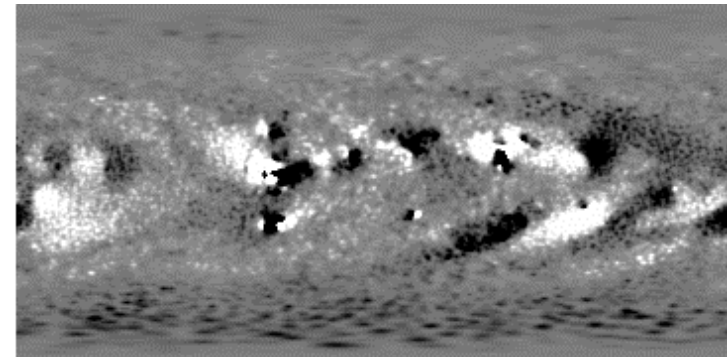
3 Day Advanced Predictions and Satellite Observations



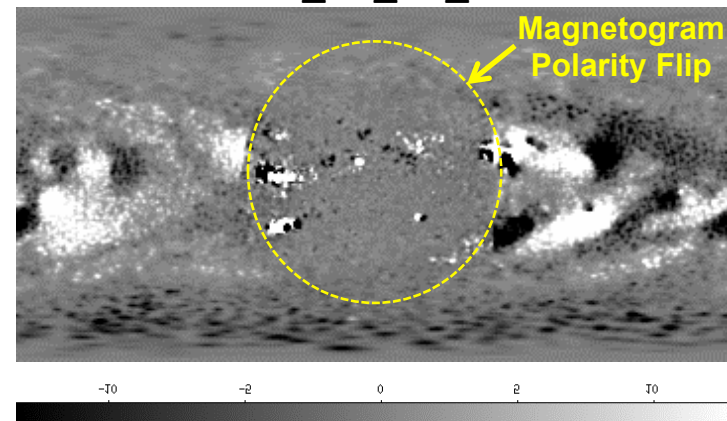
Created 2015 December 25 0805 UTC

## ADAPT-GONG Map

2015\_12\_24\_04hr

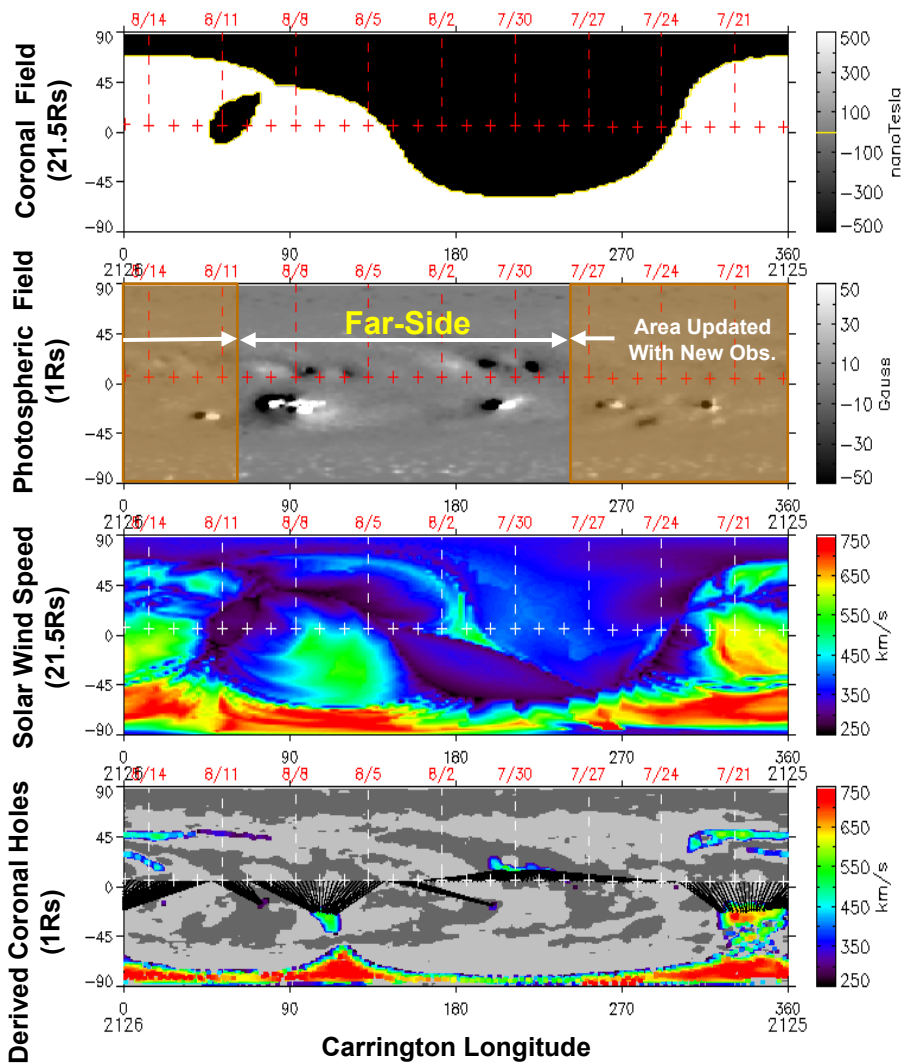


2015\_12\_24\_08hr

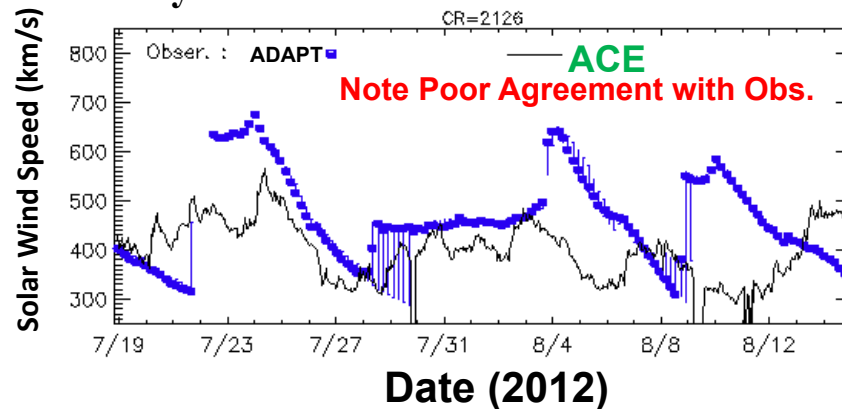




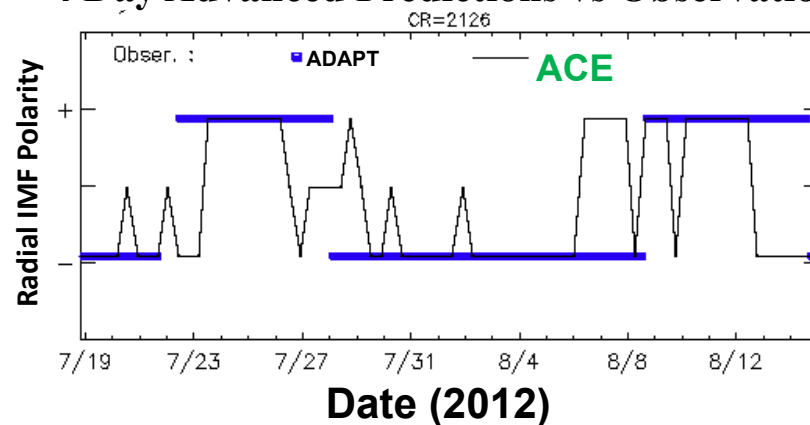
# WSA Coronal and Solar Wind Predictions Using *July 21, 2012* ADAPT Map as Input to WSA



## 4 Day Advanced Predictions vs Observations



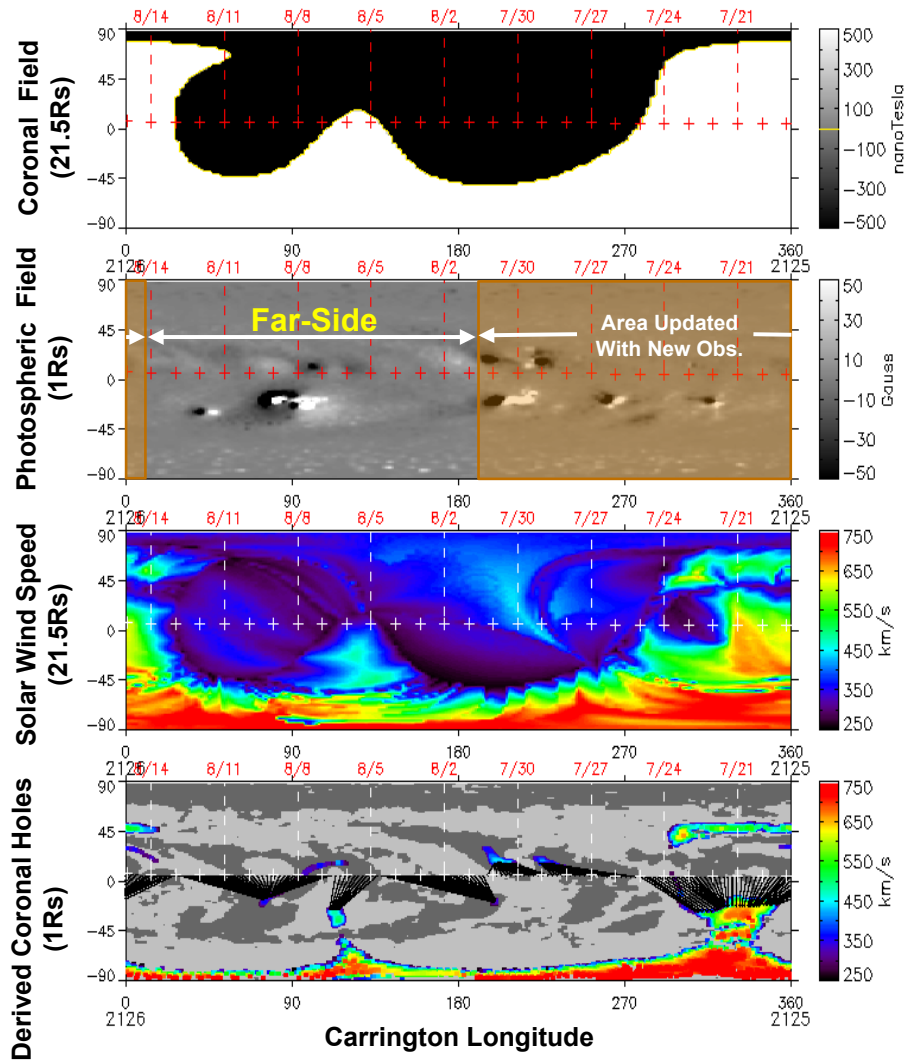
## 4 Day Advanced Predictions vs Observations



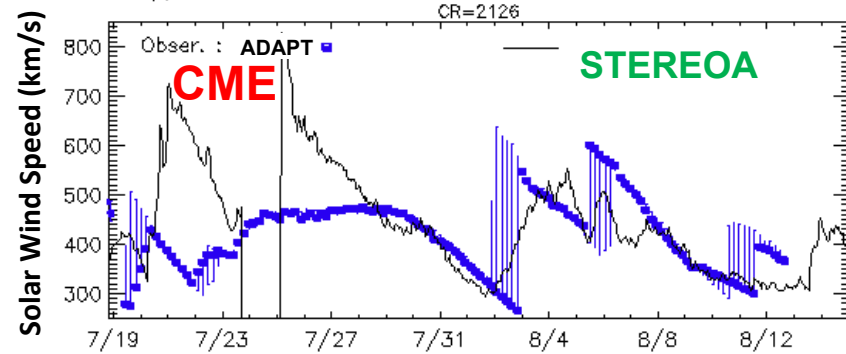




# WSA Coronal and Solar Wind Predictions Using *July 25, 2012* ADAPT Map as Input to WSA

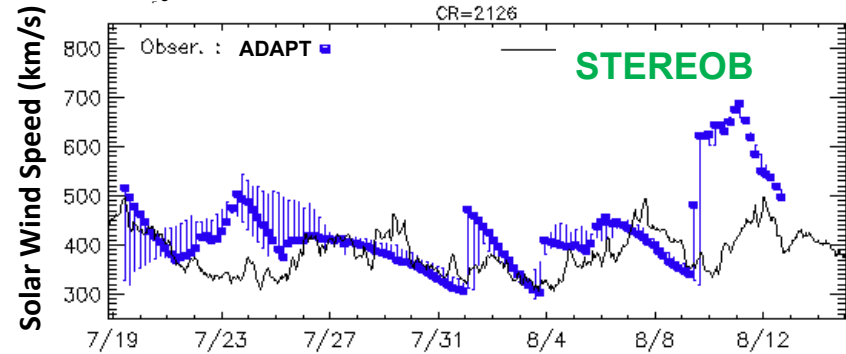


## 4 Day Advanced Predictions vs Observations



Updated 7-26-2013 Date (2012)

## 4 Day Advanced Predictions vs Observations



Updated 7-25-2013 Date (2012)