Solar Wind Structure in the Heliosphere: A Solar Perspective of Space Weather

Bala Poduval

Bala Poduval presented at MIT Haystack Observatory, Westford, MA , April 23, 2008

Solar Wind

is the expansion of the solar corona out into the heliosphere, carrying the coronal magnetic field along, forming the interplanetary magnetic field (IMF)

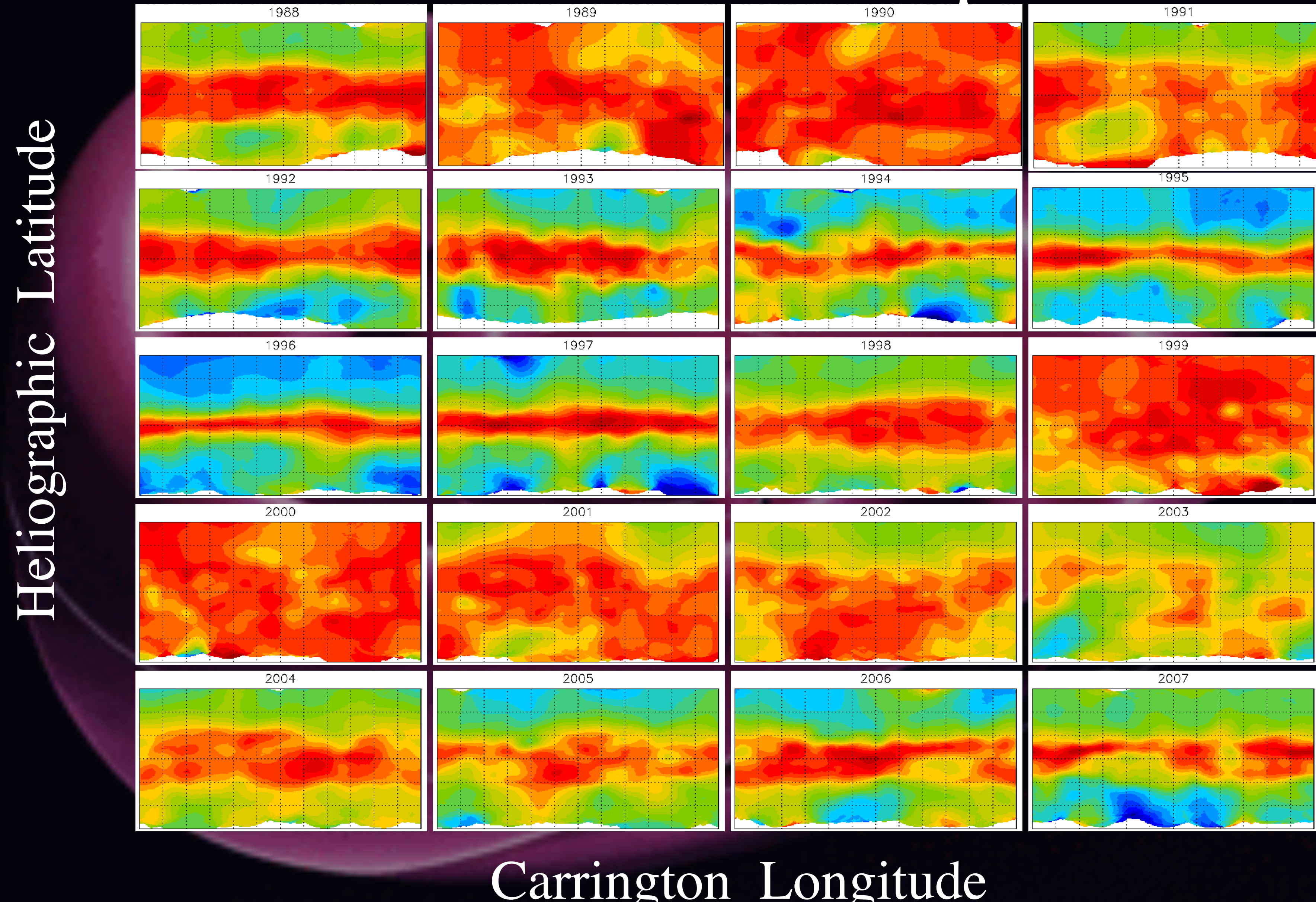
Slow wind

streamer belt
closed field regions

Fast wind

coronal holes
open field regions

IPS V - Maps



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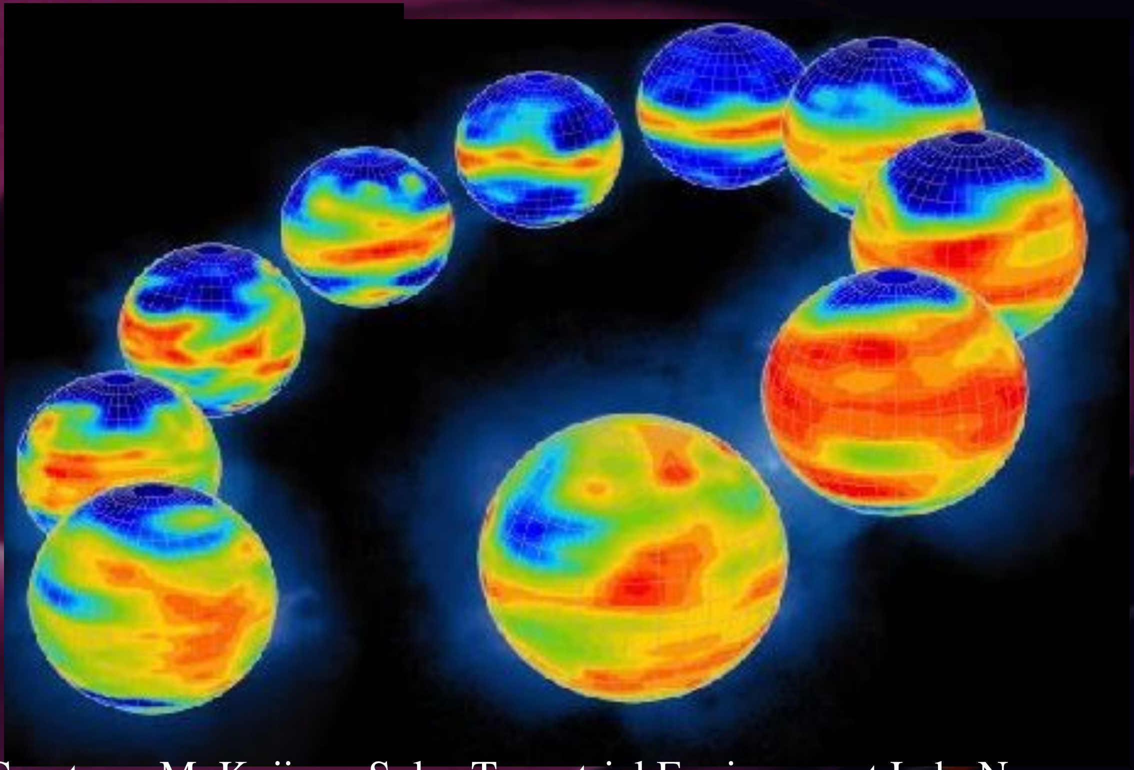
Solar Cycle Variations in Solar Wind

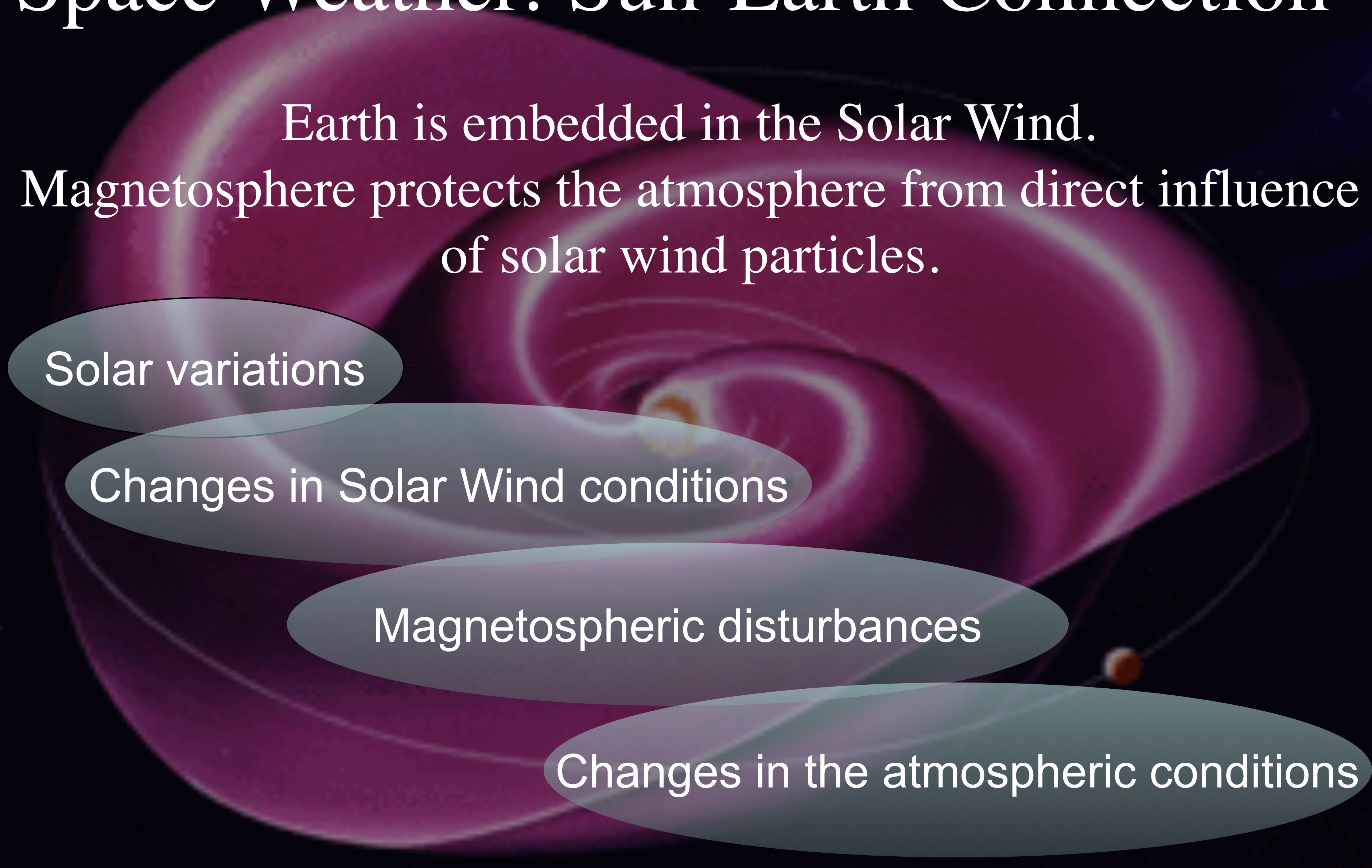
Blue – fast wind
Red – slow wind



Courtesy: M. Kojima, Solar-Terrestrial Environment Lab, Nagoya, Japan.

Space Weather: Sun-Earth Connection

Earth is embedded in the Solar Wind.
Magnetosphere protects the atmosphere from direct influence of solar wind particles.



Space Weather: Sun-Earth Connection

solar wind interacts with geomagnetic field causing various space weather phenomena

correlations between high speed solar wind streams and geomagnetic storms and other related events are well established

solar flares and coronal mass ejections (CMEs) are transient events that cause severe damages to satellites in space, wireless communications and other technological systems.

space weather prediction

to know the changing space weather conditions well ahead of time,

to protect these technological systems

Solar flares and CMEs are transient events. Their occurrence depends on the phase of the Solar cycle. The solar wind and the IMF are always present and variations in their properties could affect space weather adversely.

The prediction of the ambient solar wind will be discussed here.

Coronal Models

Coronal heating and solar wind acceleration: enigma

Coronal magnetic field plays a determining role in the structure and properties of solar wind.

Few direct measurements of coronal magnetic field.

Photospheric field measurements: line-of-sight component.

Potential Field Source Surface Model

Schatten, Wilcox and Ness, 1969
Altschuler and Newkirk, 1969

Assumptions

little current flows between photosphere and source surface

coronal magnetic field can be derived from a potential obeying LaPlace's equation

at the source surface all field lines are radial

PFSS Model: Parameters

Height of source surface : 2.5 R_{sun}

Radius of the inner sphere : 1.0 R_{sun}

Number of multipole components in spherical harmonic expansion

N_{max} : 9, 10, … …90

WSO Synoptic data : 22

Kitt Peak data : 90

Flux Expansion and Solar Wind

Levine, Altschuler and Harvey (1977)

noted

inverse correlation between solar wind speed observed at 1 AU and rate of flux expansion between photosphere and source surface (PFSS model)

Flux Expansion and Solar Wind

Flux Tube Expansion Factor (FTE),

$$f = [R_{sun}/R_{ss}]^2 \ [B_r(\theta_{sun}, \Phi_{sun})/B_r(\theta_{ss}, \Phi_{ss})]$$

R_{sun}	: photospheric radius
$B_r(\theta_{sun},\Phi_{sun})$	: photospheric magnetic field
R_{ss}	: source surface radius
$B_r(\theta_{ss},\Phi_{ss})$	: source surface magnetic field

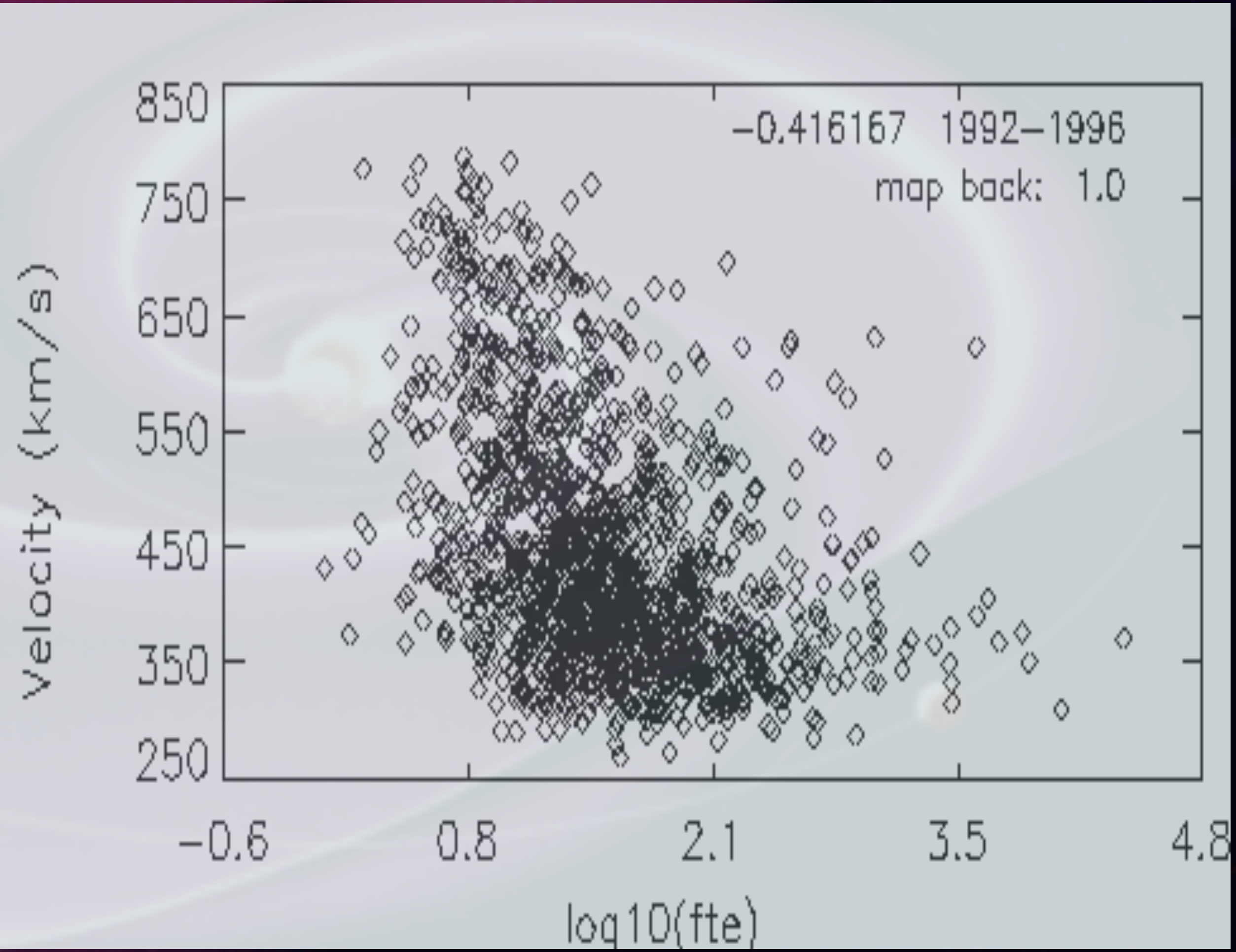
Flux Expansion and Solar Wind

Wang and Sheeley (1990; 1994;1997) Confirmed the inverse correlation

Speed	**FTE**
< 450	> 20
450-550	10-20
550-650	8-10
650-750	4.5-8
> 750	< 4.5

Scatter Plot: FTE Vs SWS

used daily averaged values of solar wind speed



Solar Wind Prediction

Arge and Pizzo (2000)

$$V_{sw} = 267.5 + 410.0/f^{(1.0/2.5)}$$

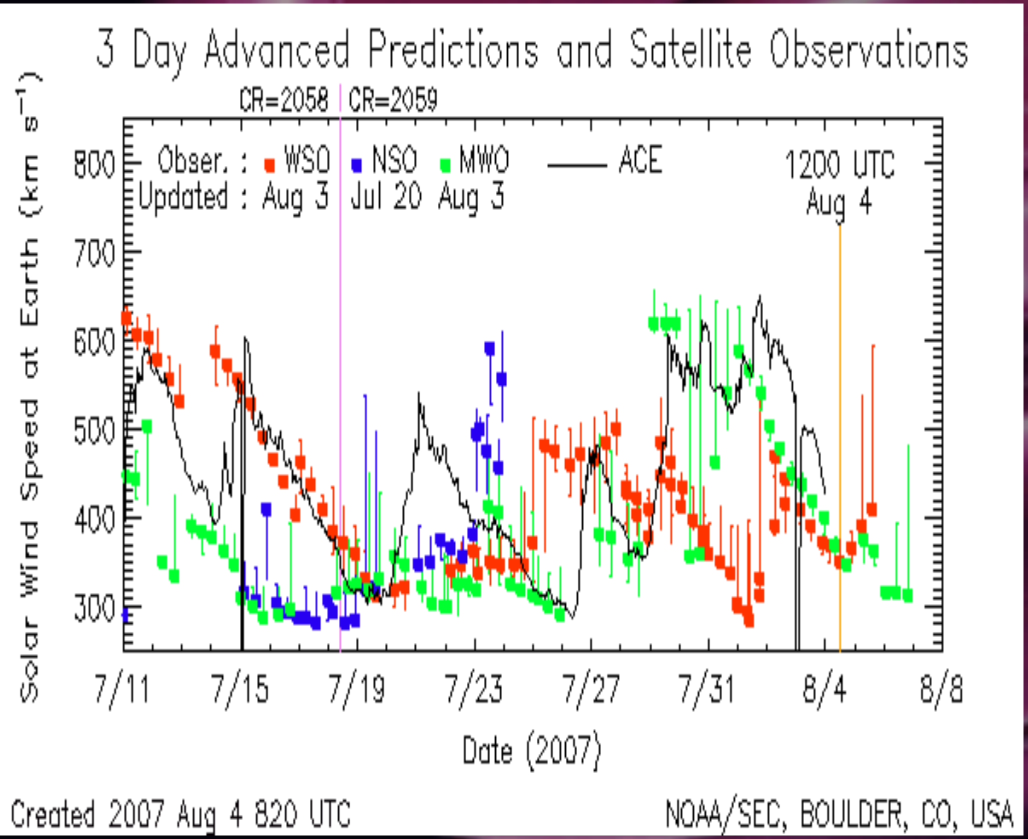
f => FTE calculated using PFSS model

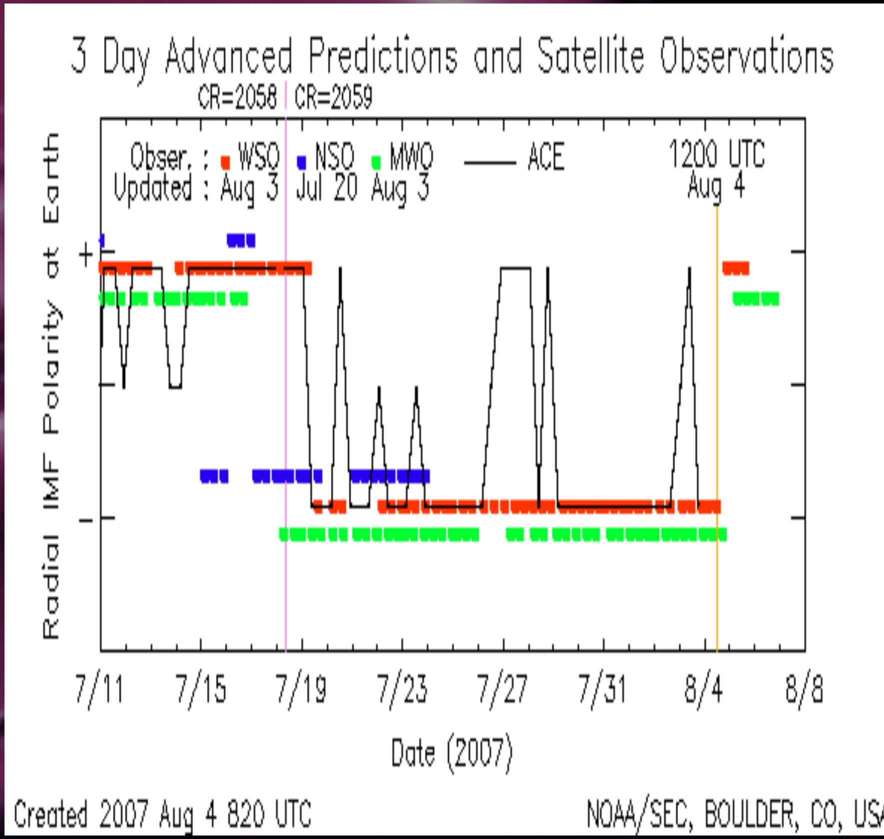
NOAA/SEC – Wang Sheeley Arge Model

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

ambient solar wind speed.

IMF polarity





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Discrepancy - Causes

- Quality and resolution of photospheric data.
- Interaction between slow and fast streams.
- Transient events PFSS model cannot handle.
- Mapping the solar wind back to solar surface.
- Limitations of PFSS model itself.

Arge and Pizzo (2000)

- improved photospheric field data by applying various corrections and using daily updated data
- allowed stream-stream interaction

discrepancies still exist

PFSS Model: Limitations

- very sensitive to rapid field evolutions,
- magnetic field predicted for mid- and high latitudes does not agree with observations,
- potential field approximation not strictly valid for solar corona,
- location of source surface, 2.5 Rsun, much lower than Alfvén critical point.

we investigated the sources of errors in:

- the computation of FTE,
- inverse mapping,
- identification of the footpoints of the solar wind sources on the solar surface.

Computation of correlation between FTE and SWS involves:

1. determination of coronal sources of solar wind (inverse mapping),

$$\boldsymbol{\theta}_0 = \boldsymbol{\theta}_R \; ; \quad \boldsymbol{\varphi}_0 = \boldsymbol{\varphi}_R + \Omega R \,/\, V_R$$

θ_0, φ_0 – latitude and longitude at $R = R_{sun}$,

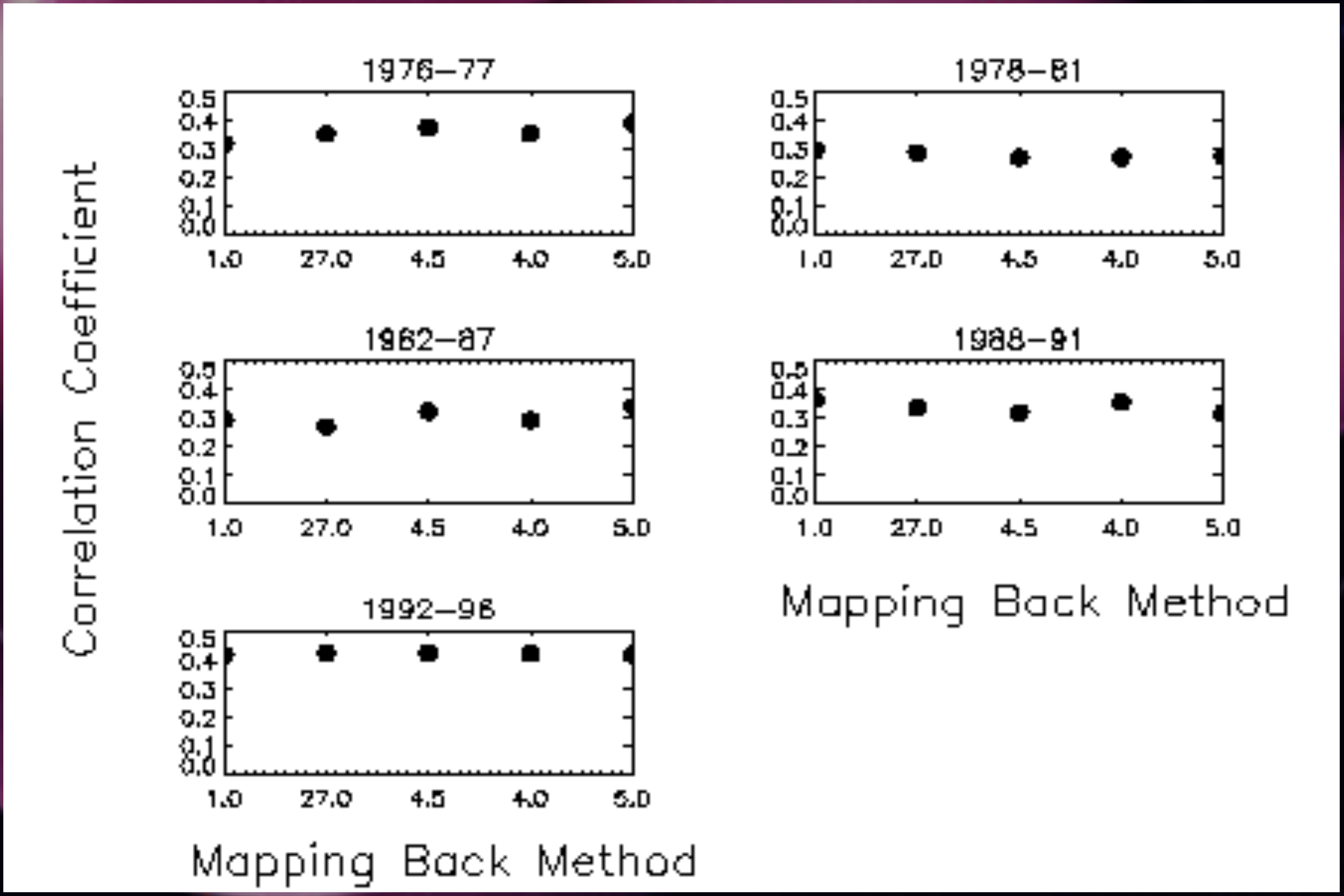
θ_R, φ_R – the same at distance R from the Sun,

Ω – angular rotation of the Sun,

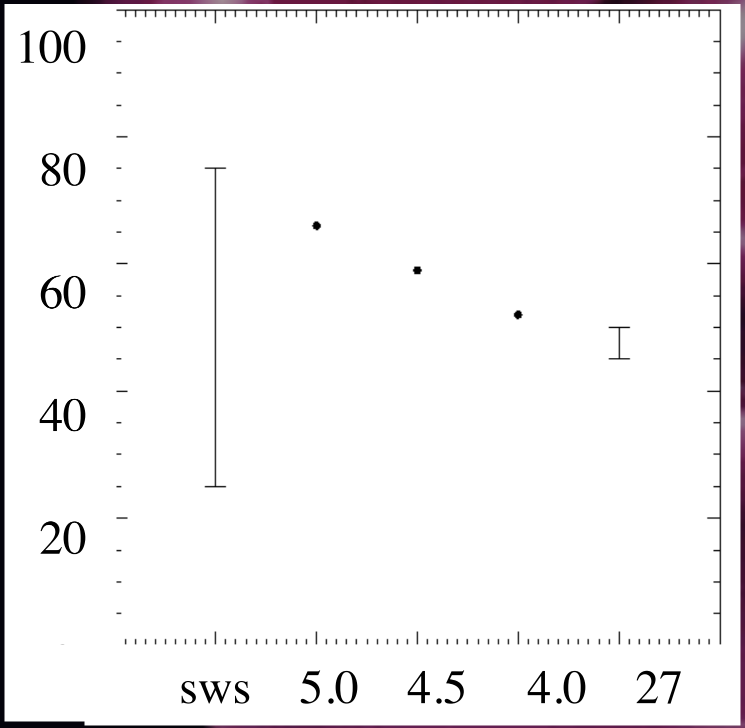
V_R – the solar wind speed observed at R,

2. identification of photospheric footpoints of these sources by tracing along the magnetic field lines.

Inverse Mapping
Correlation Coefficient



Inverse mapping: range in the heliographic longitude



sws: observed daily averaged values;

longitude range 25 - 75°; slow (300 km/s) and fast (900 km/s) wind are separated by 50°.

5.0 days (345 km/s): longitude 65°,

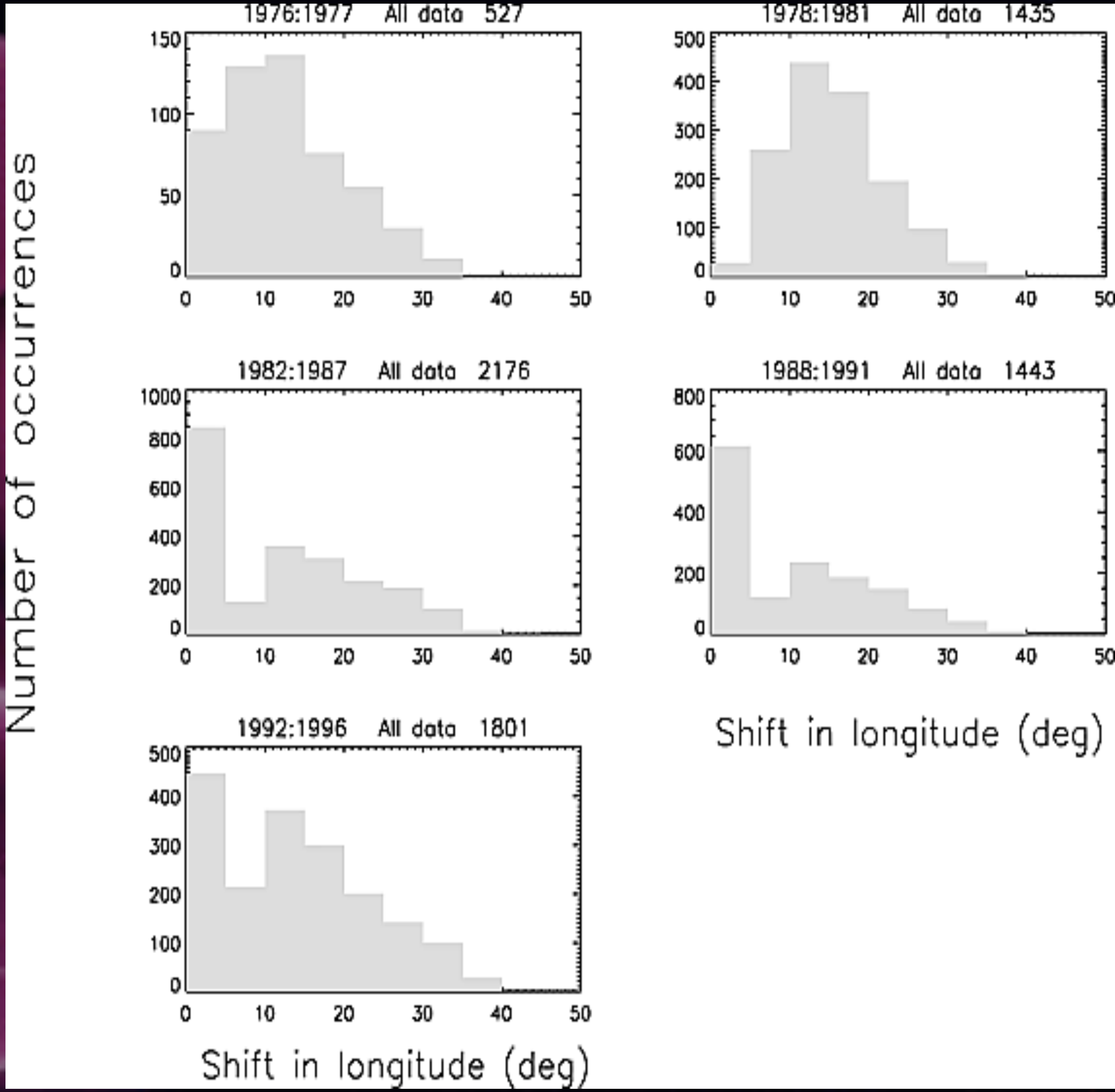
4.5 days: longitude 59°

4.0 days: longitude 52 °,

27: running ave.; longitude range 45 - 50°

difference in location: 10 - 40°; ave. 25°

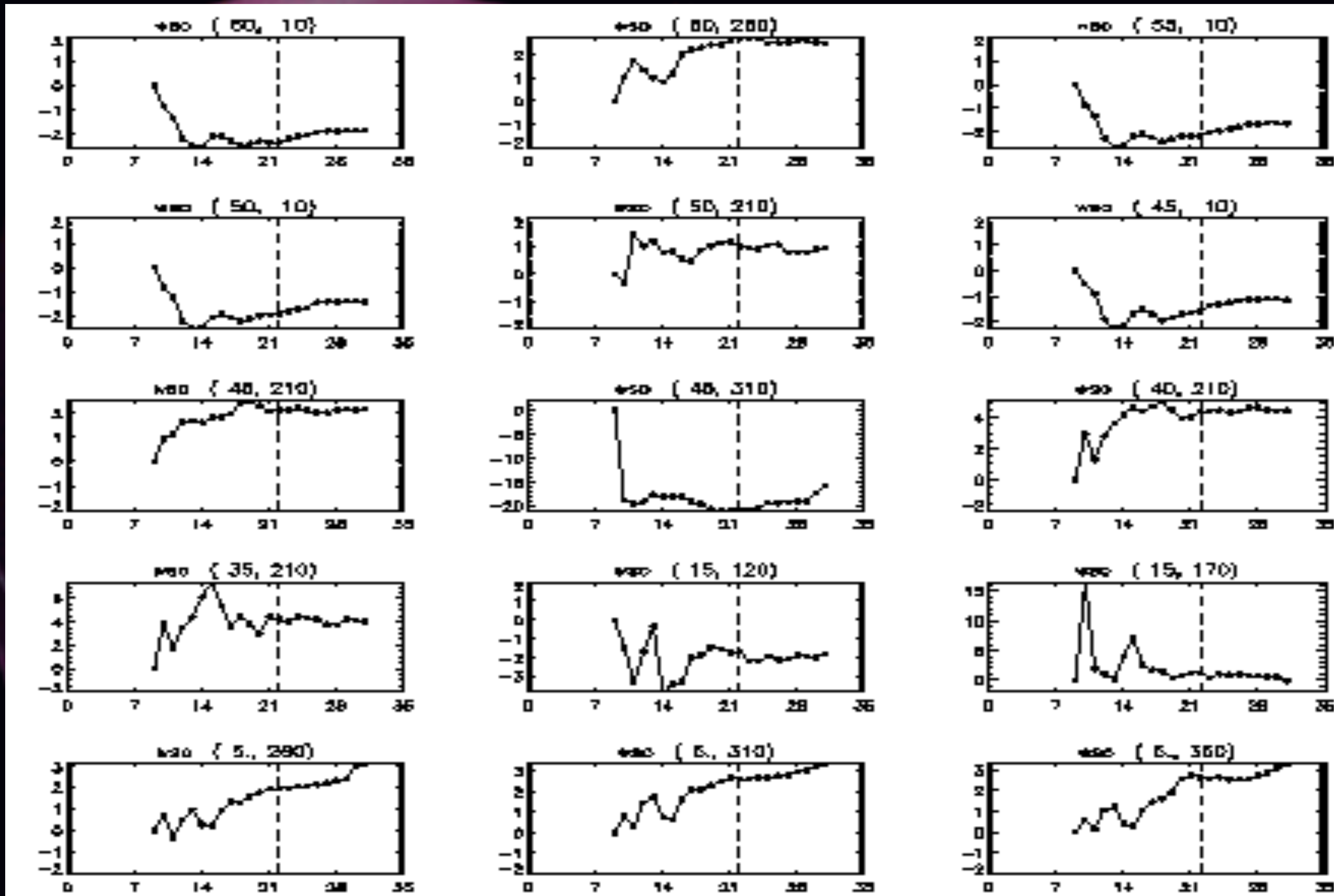
Histogram of shifts in longitude of the coronal sources of solar wind for different inverse mapping techniques. The shifts are the difference from the longitude obtained using the daily values of solar wind speed.



In order to compute FTE, the coronal sources of solar wind need to be traced back to the photosphere to determine the foot points.

This procedure is sensitive to many parameters and the most important one is N_{max}, the number of multipole components used in the spherical harmonic expansion.

Foot Points and N_{max}: Latitude

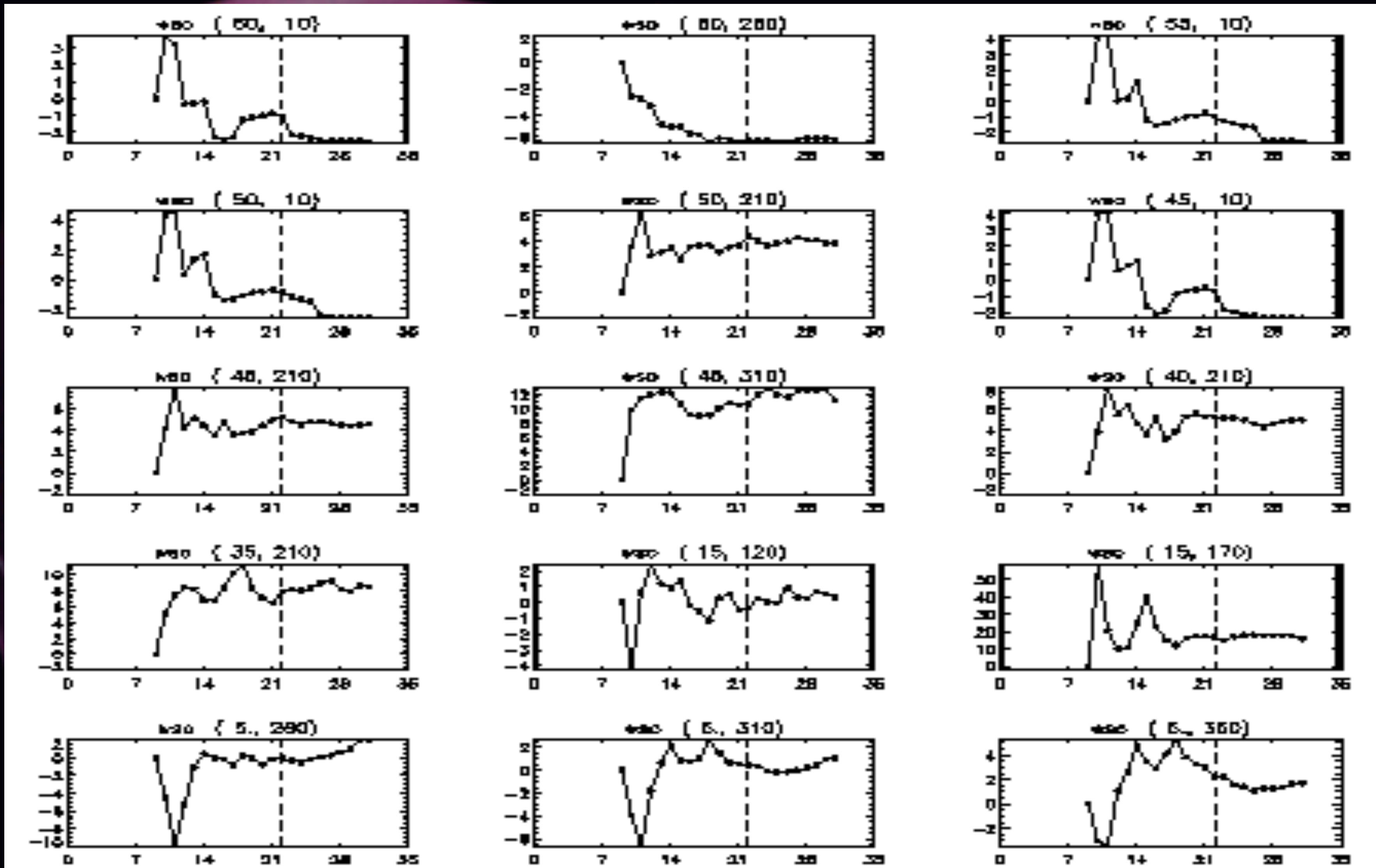


$\theta(N_{max}) - \theta(N_{max} = 9)$

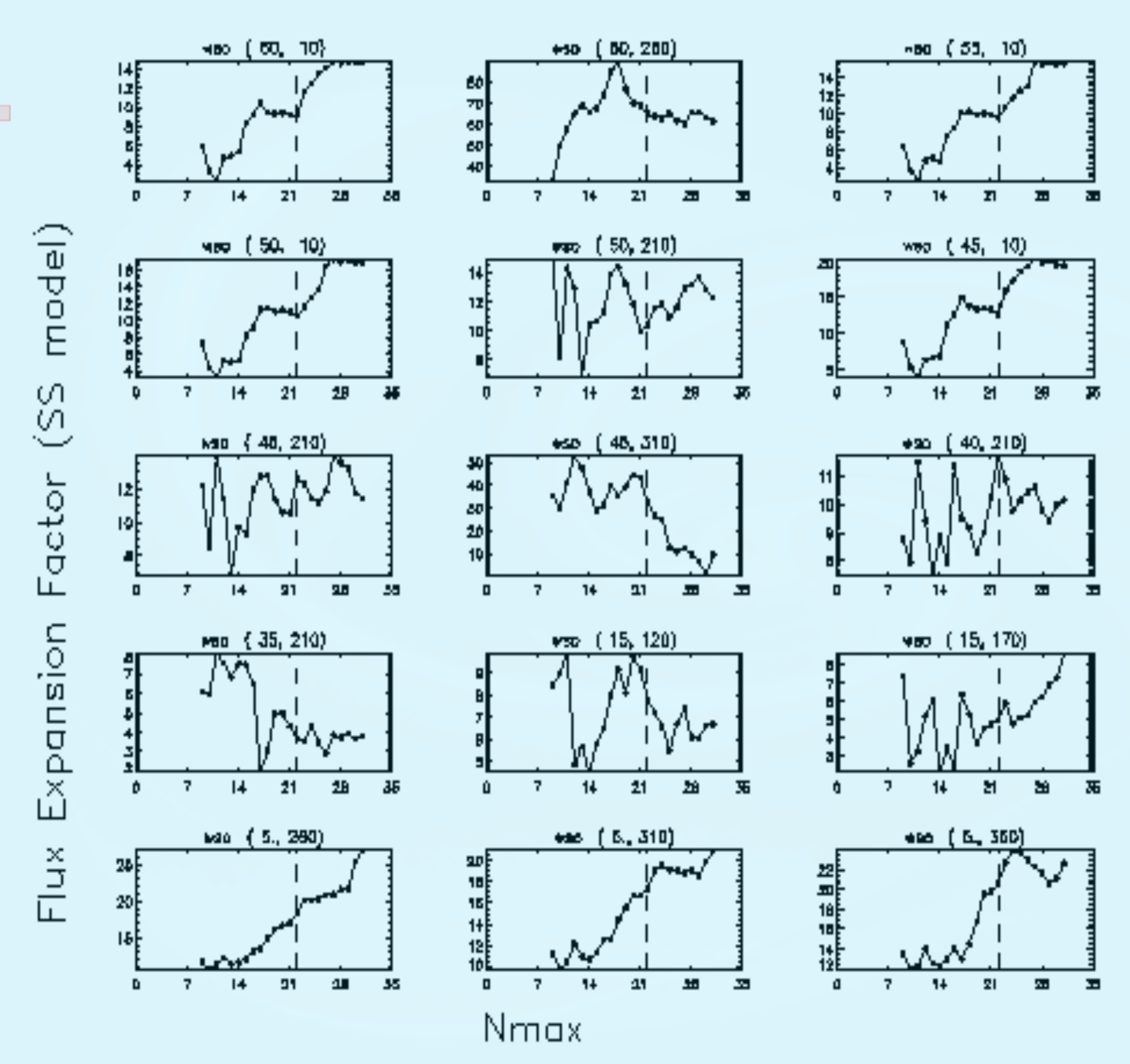
N_{max}

Foot Points and N_{max}: Longitude

$\Phi(N_{max}) - \Phi(N_{max} = 9)$



N_{max}



Variation of FTE with N_{max} used in PFSS model

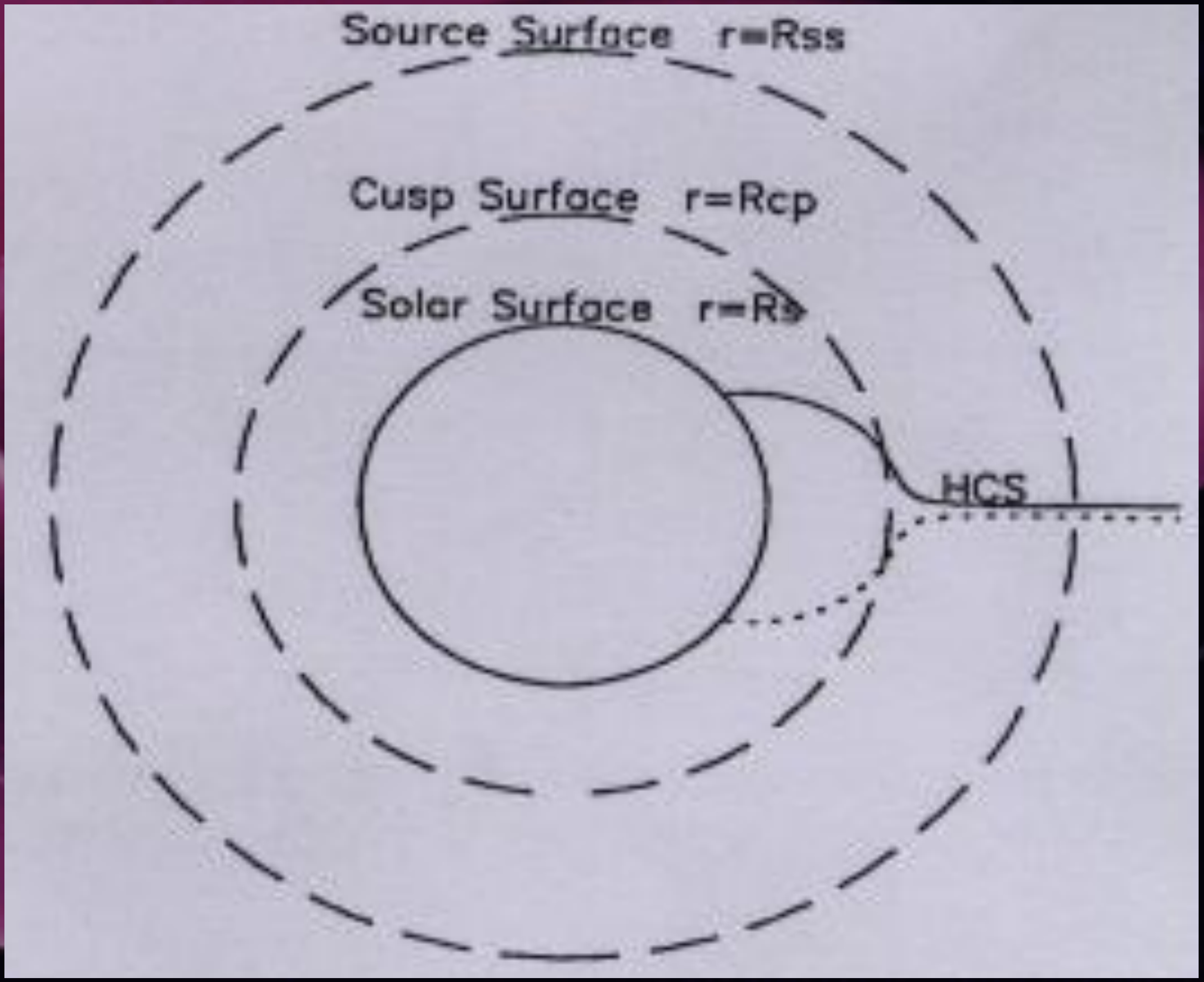
Current Sheet Source Surface Model

Advantages over PFSS model

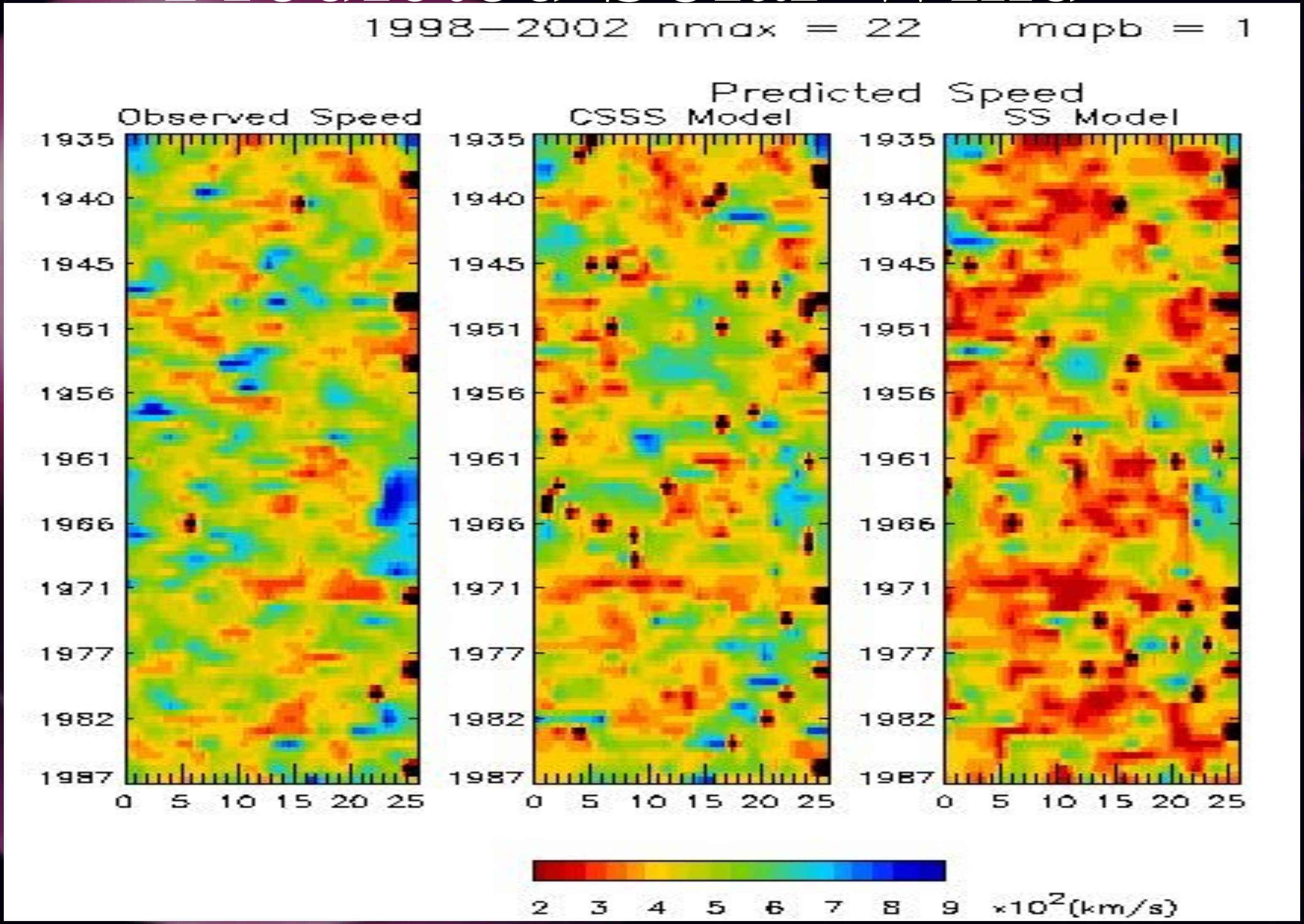
- cusp surface: field lines are open but <u>not</u> necessarily radial; includes effects of streamer current sheets.
- source surface: placed near the Alfvén critical point.

uses source surface technique to include effects of volume currents beyond source surface.

Current Sheet Source Surface Model



Predicted Solar Wind



Concluding Remarks

The PFSS Model has a number of drawbacks in the prediction of solar wind conditions at Earth.

The CSSS model shows better prediction an has a number of advantages over PFSS model.

Calls for an alternate method or improvement of the existing one.

The Earth is embedded in solar wind, the outward expanding solar corona. However, the magnetosphere protects the Earth from the direct interaction of the harmful particles and plasma of the solar wind. The slow solar wind found near the solar equatorial regions have typical velocities less than 450 km/s while the fast wind, those observed in the mid- and high-latitudes, especially near the polar regions, vary in the range 500-900 km/s. This is the typical structure during solar activity minimum. As the solar activity increases the structure becomes complex with slow and fast wind distributed randomly in the heliosphere. These changing solar wind conditions or Space Weather, can cause damages to spacecraft, wireless communications and other technological systems on Earth and space. To prevent this, a knowledge of the space weather conditions well ahead of time is necessary. I will be presenting the state-of-the-art prediction scheme and its limitations, bringing out the need for a better technique to handle the space weather forecast.

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