

Using World Interplanetary Scintillation Systems for Space Weather Predictions



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<http://ips.ucsd.edu/>

Space Weather Predictions using IPS

Introduction:

IPS Space Weather Predictions

IPS Tomographic Analyses:

ISEE, Japan; The UCSD iterative kinematic prediction technique; Used primarily with ISEE observations, Other data sets can fill in; Used in space weather prediction elsewhere including at the CCMC, the KSWC, Jeju; RAL, UK; used at NICT, Japan.

IPS tomographic analysis displays:

Combined analysis from multiple IPS data sets, 3D-MHD forward modeling.

Magnetic field component forward-modeling – Br, Bt:

Part of the model package developed at UCSD.

Interesting Developments:

Bn determination via a simple technique (under development)

Space Weather Predictions using IPS

Thomson Scattering Analysis (Data Fitting Model at the CCMC)

Space Weather Predictions using IPS

The Solar Mass
Ejection Imager
(SMEI)

Jackson, B.V., et al., 2004, *Solar Phys.*, 225, 177

Launch 6 January 2003

Closure 28 Sept 2011



**Interplanetary Scintillation (IPS)
Analysis
(Data Fitting Model at the CCMC)**

↓ 1 gigabyte/day; total ~4 terabytes

Simultaneous images
from the three SMEI
cameras.

Space Weather Predictions using IPS

DATA

IPS Heliospheric Analyses ISEE (STELab)



ISEE IPS array near Mt. Fuji

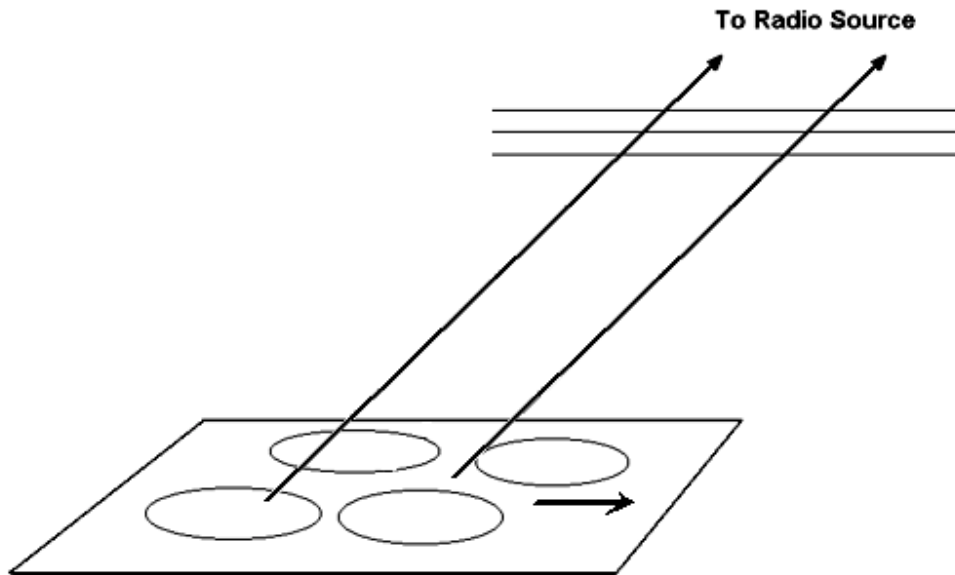


ISEE IPS array systems

Space Weather Predictions using IPS

DATA

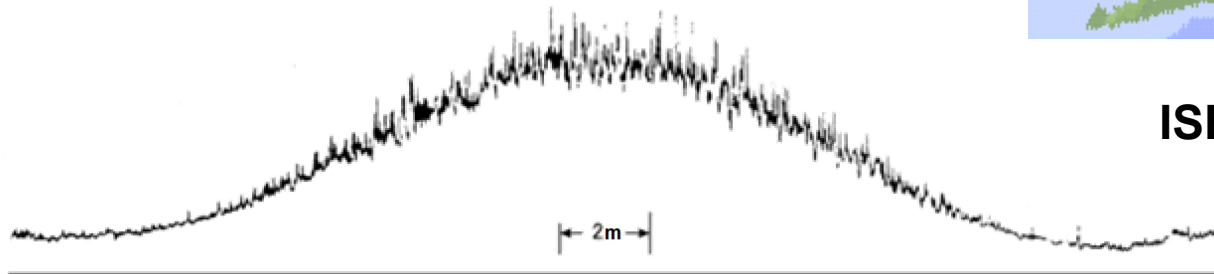
IPS Heliospheric Analyses ISEE (STELab)



IPS line-of-sight response



ISEE IPS array systems



Space Weather Predictions using IPS

Current ISEE Toyokawa IPS System



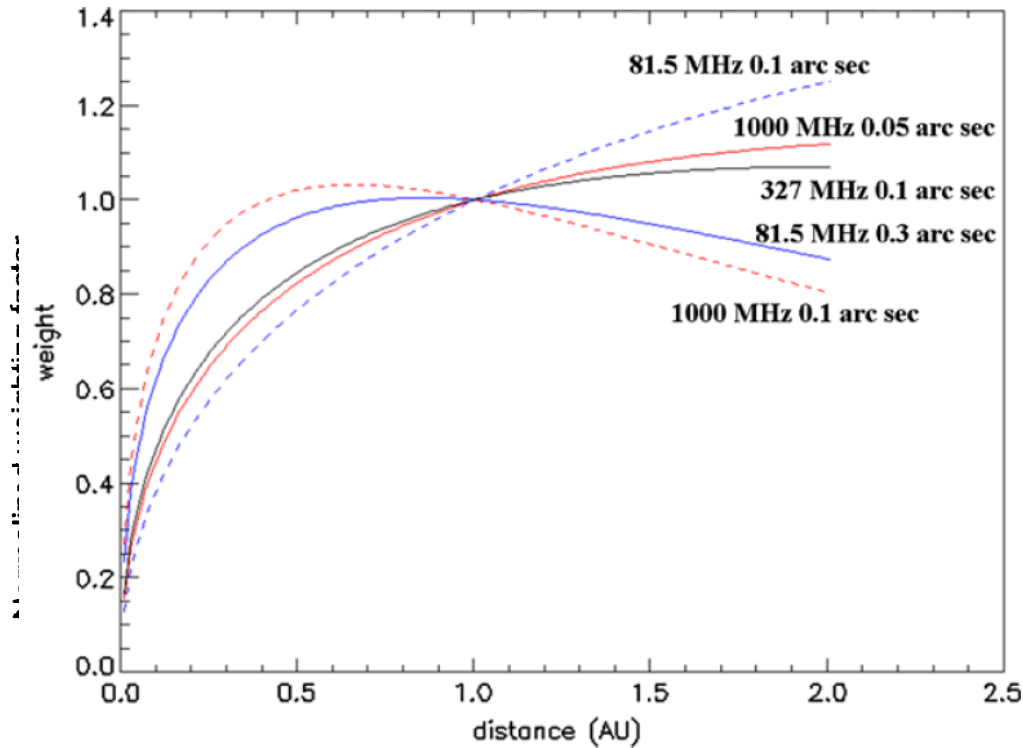
**ISEE IPS array in Toyokawa
(3,432 m² array now operates well – year-round operation began in 2011)**

Space Weather Predictions using IPS

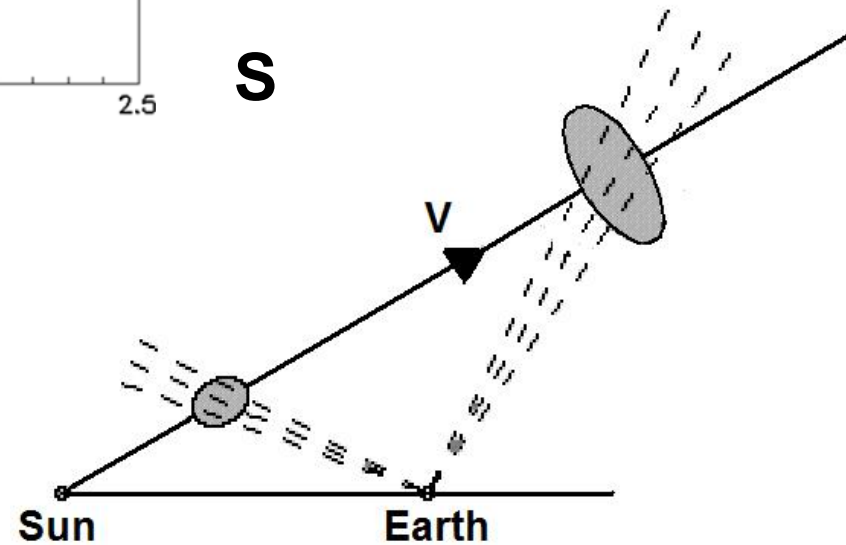
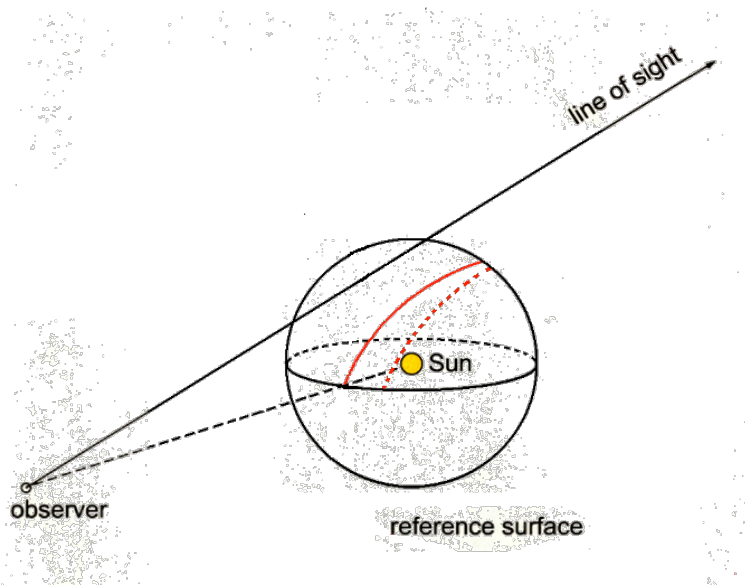
UCSD IPS Predictions

ns using IPS

2008, *Adv. in Geosciences*, 21, 339-360.



meric C.A.T. analyses:
 line-of-sight distribution
 sky location to form the
 surface of the 3D
 ruction.

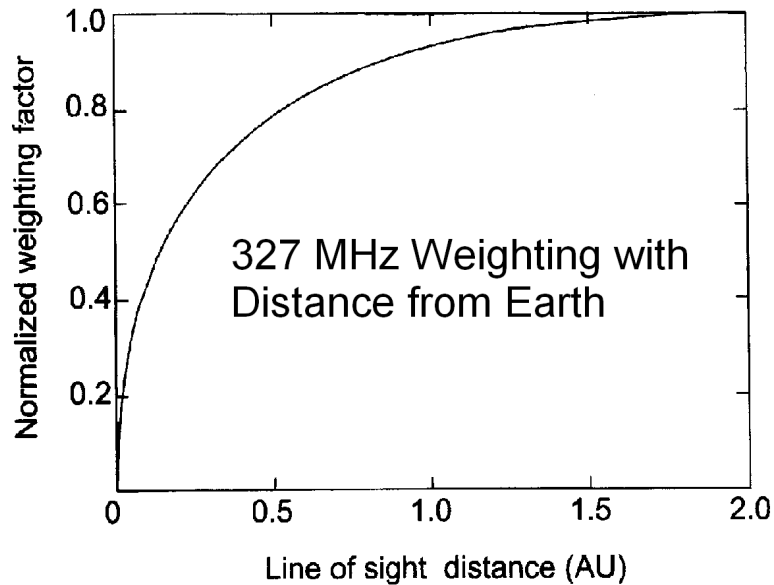


Sample outward motion
 over time

Space Weather Predictions using IPS

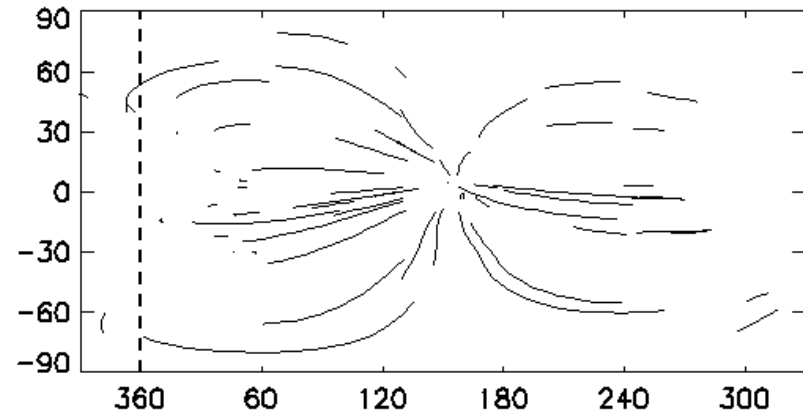
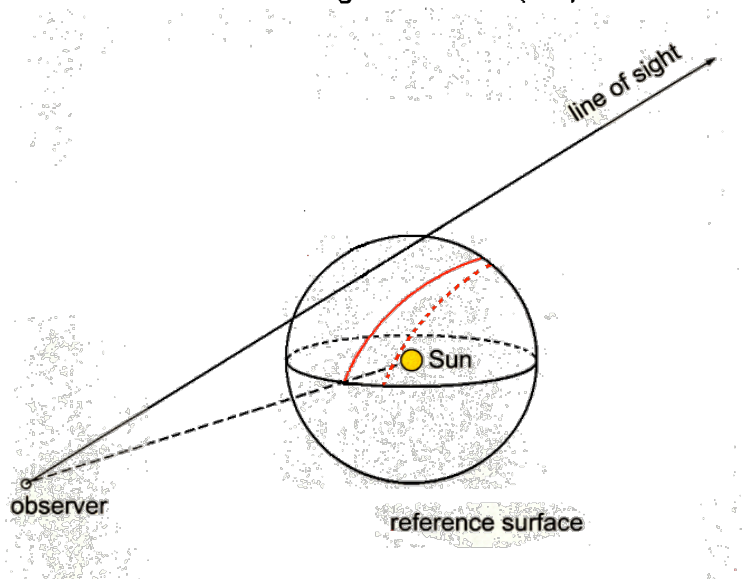
IPS line-of-sight response

Jackson, B.V., et al., 2008, *Adv. in Geosciences*, 21, 339-360.



**Heliospheric C.A.T. analyses:
example line-of-sight distribution
for each sky location to form the
source surface of the 3D
reconstruction.**

ISEE IPS



13 July 2000

Space Weather Predictions using IPS

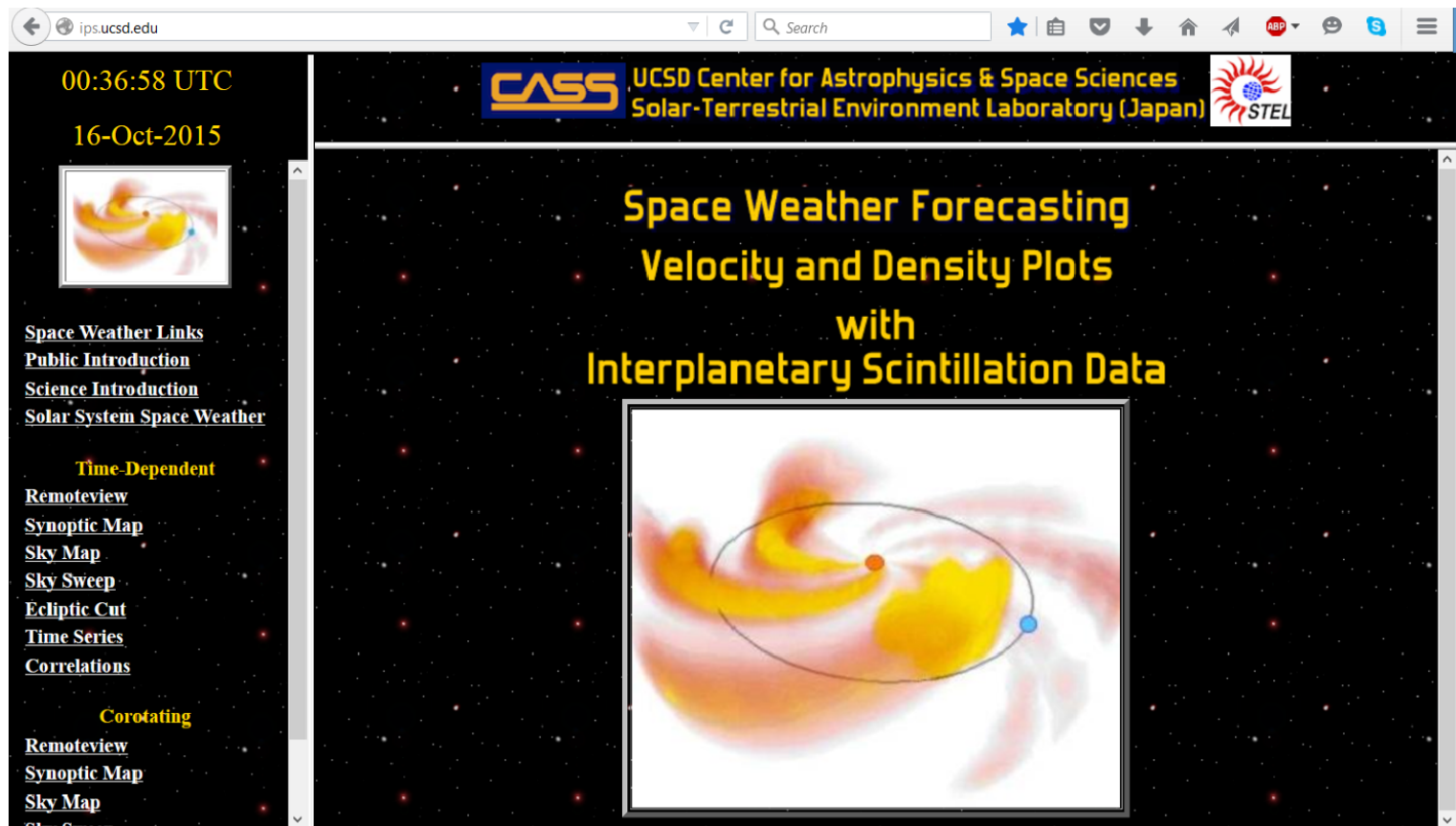
Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

<http://ips.ucsd.edu/>

Current Prediction Analyses

UCSD IPS analysis

UCSD
Web
pages



The screenshot shows a web browser window displaying the UCSD IPS website. The browser's address bar shows 'ips.ucsd.edu'. The website header includes the CASS logo (UCSD Center for Astrophysics & Space Sciences) and the STEL logo (Solar-Terrestrial Environment Laboratory (Japan)). The main content area features the text 'Space Weather Forecasting Velocity and Density Plots with Interplanetary Scintillation Data' and a large image of a solar wind velocity and density plot. The left sidebar contains a navigation menu with the following items: '00:36:58 UTC', '16-Oct-2015', 'Space Weather Links', 'Public Introduction', 'Science Introduction', 'Solar System Space Weather', 'Time-Dependent', 'Remoteview', 'Synoptic Map', 'Sky Map', 'Sky Sweep', 'Ecliptic Cut', 'Time Series', 'Correlations', 'Corotating', 'Remoteview', 'Synoptic Map', 'Sky Map', and 'Sky Sweep'.

Web Analysis Runs Automatically Using Linux on a P.C.

Space Weather Predictions using IPS

<http://ips.ucsd.edu/> **Skysweep View**

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

UCSD IPS prediction analysis

00:36:58 UTC
16-Oct-2015

[Space Weather Links](#)
[Public Introduction](#)
[Science Introduction](#)
[Solar System Space Weather](#)

Time-Dependent
[Remoterview](#)
[Synoptic Map](#)
[Sky Map](#)
[Sky Sweep](#)
[Ecliptic Cut](#)
[Time Series](#)
[Correlations](#)

CASS UCSD Center for Astrophysics & Space Sciences
Solar-Terrestrial Environment Laboratory (Japan) **STEL**

2015/10/15 03 UT
IPS speed (km s^{-1})
Go to movie

2015/10/15 03 UT
q-level
Go to movie

Time-Dependent Model: Last observed IPS sources
The display presents a [Hammer-Aitoff](#) (an equal area projection of the entire sky) or "[Fisheye](#)" (equal distances for equal solar elongation angles) projection of the sky as observed from Earth. The map represents a 'sweep of the sky' view of the meridian over Japan in a 24-hour period centered on local noon at 2015/10/15 03 UT, about 20.9 hours ago, as indicated at the top. The horizontal axis is the ecliptic plane. In the Hammer-Aitoff projection, the celestial equator is marked by a curved line. The position of the Sun is centered in the image. The circles indicate the location of the last IPS observations obtained. The color of each circle indicates its observed value. The size reflects the difference of the observations with the time-dependent, solar wind model last run at 2015/10/15 18 UT. Areas where coverage is poor are left blank. The animations run in 6.0-hour steps from 6.0 days before, to 1.0 days after the last time data were received.

Web analysis runs automatically using Linux on a P.C.

Space Weather Predictions using IPS

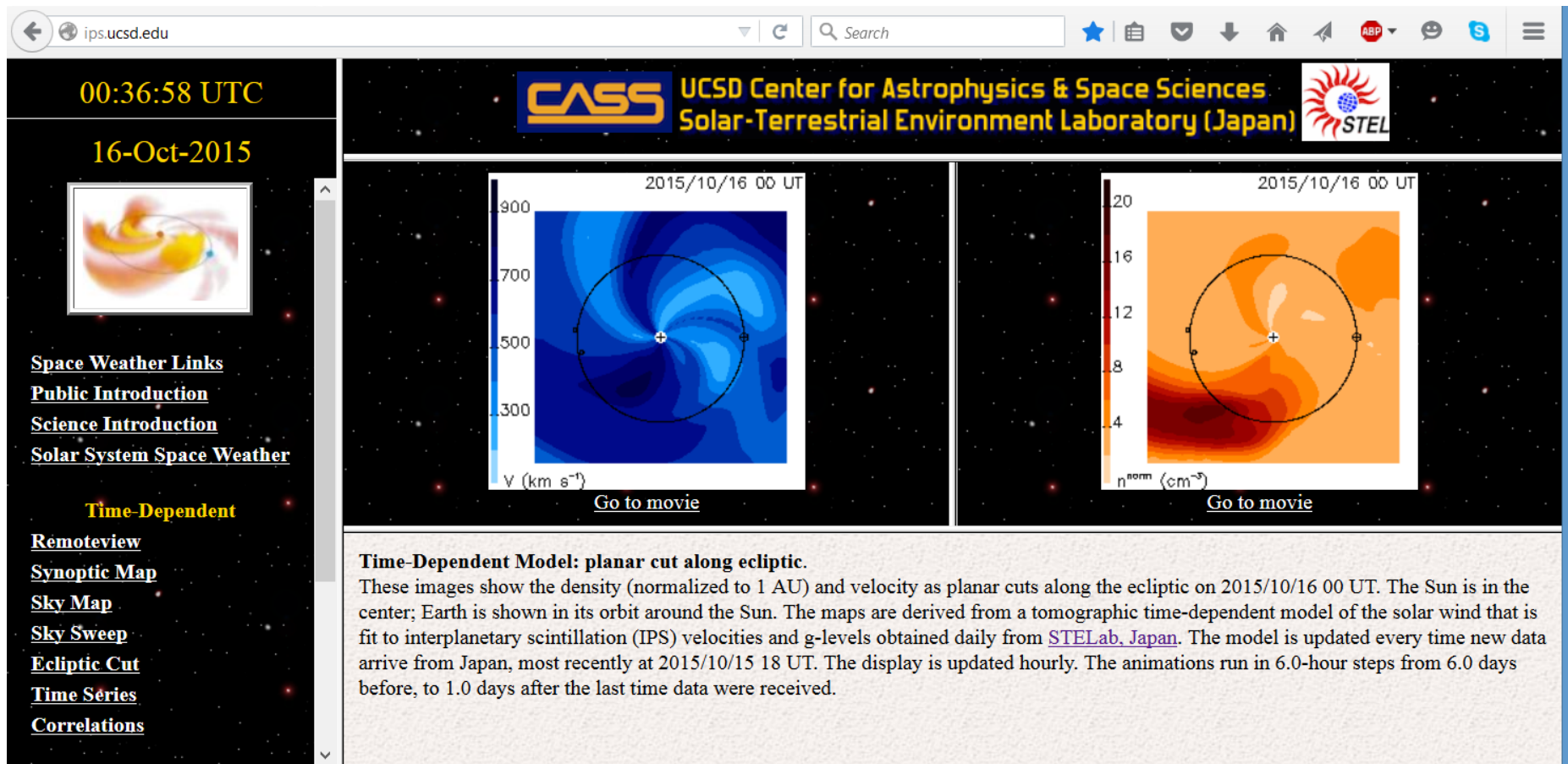
<http://ips.ucsd.edu/>

Ecliptic Cut

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

UCSD IPS prediction analysis

Fit to ACE and
CELIAS data



Web analysis runs automatically using Linux on a P.C.

Space Weather Predictions using IPS

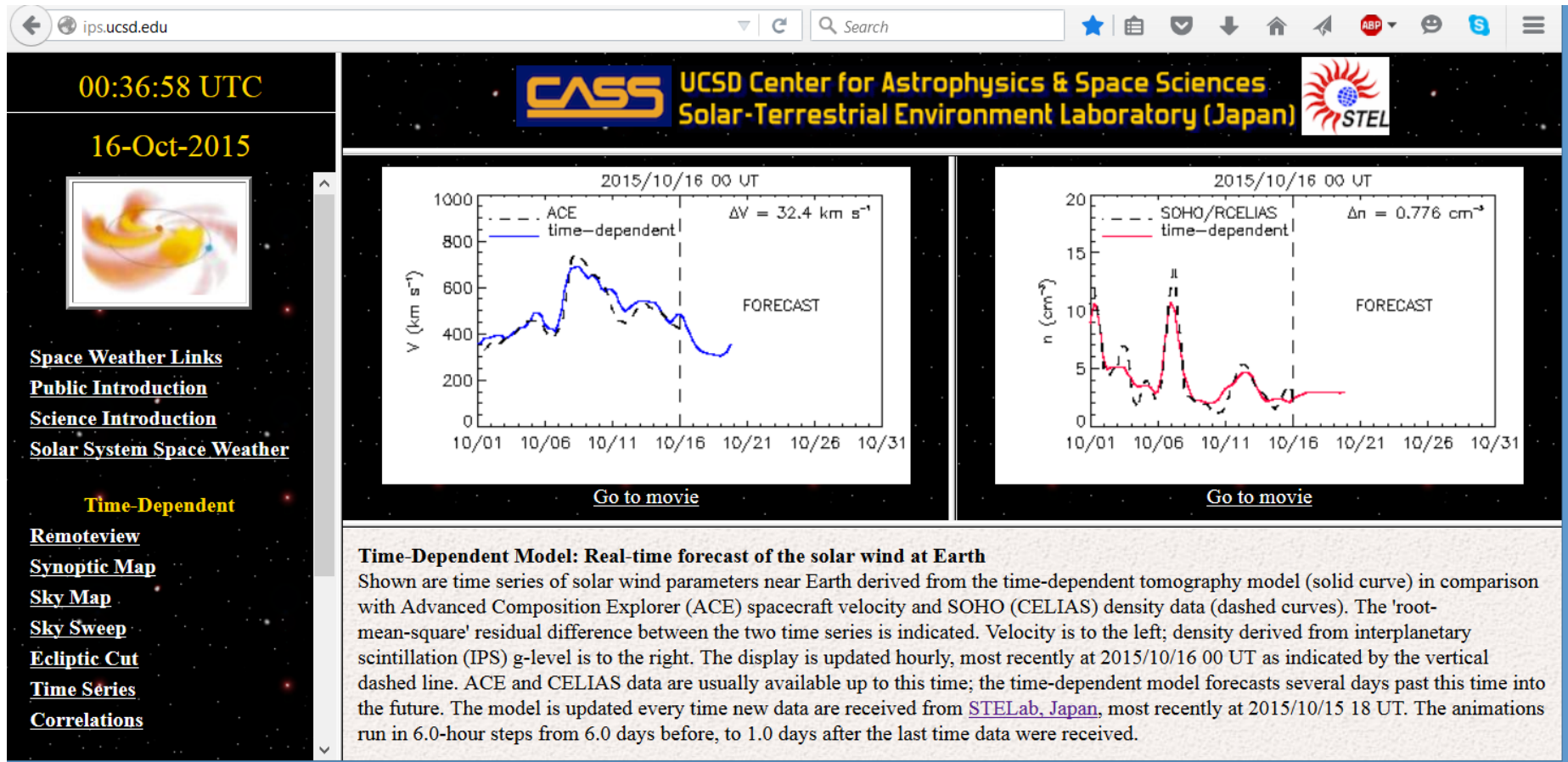
<http://ips.ucsd.edu/>

**In-situ Analysis and
Real-Time Prediction**

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

UCSD IPS prediction analysis

**Fit to ACE and
CELIAS data**



Web analysis runs automatically using Linux on a P.C.

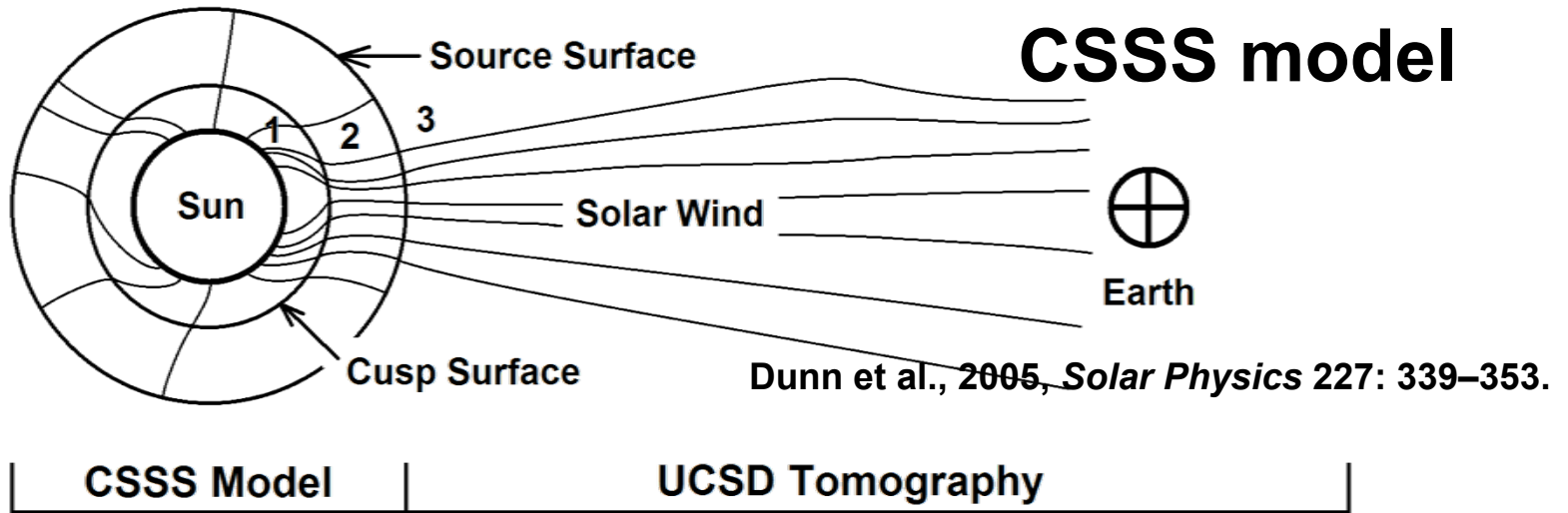
Space Weather Predictions using IPS

More Details

Magnetic Field

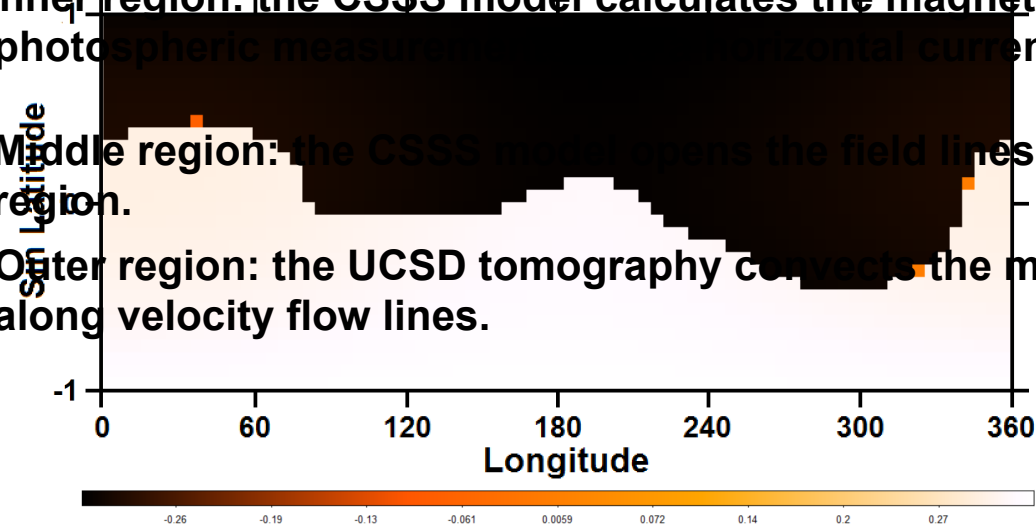
Space Weather Predictions using IPS

(Zhao, X. P. and Hoeksema, J. T., 1995, *J. Geophys. Res.*, 100 (A1), 19.)



Source surface B_r field component sample

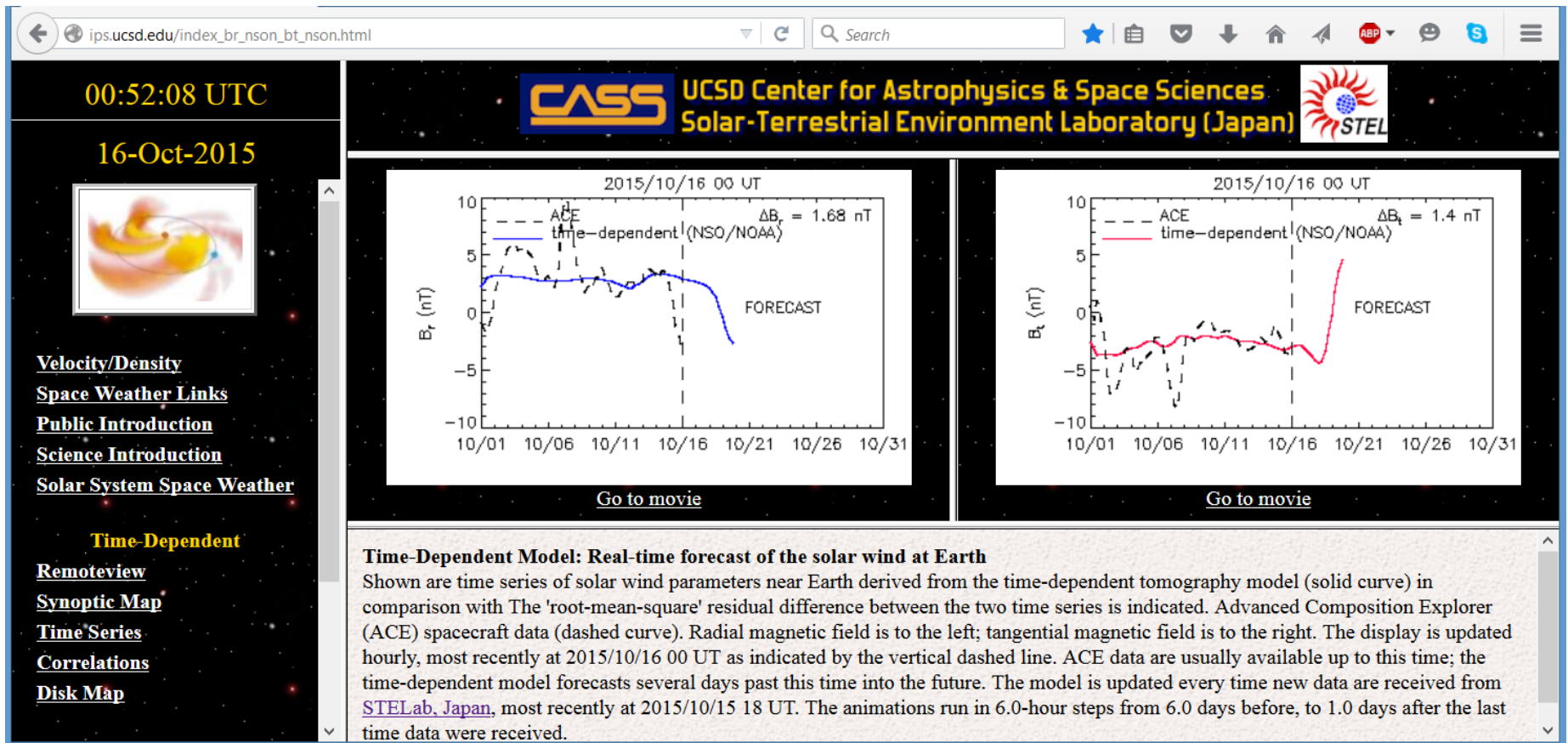
1. Inner region: the CSSS model calculates the magnetic field using photospheric measurements and a potential current model.
2. Middle region: the CSSS model follows the field lines. In the outer region.
3. Outer region: the UCSD tomography converts the magnetic field along velocity flow lines.



Space Weather Predictions using IPS

(Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115)

<http://ips.ucsd.edu/> Earth Radial and Tangential Magnetic Field Magnetic Field Extrapolation



Web Analysis Runs Automatically Using Linux on a P.C.

Space Weather Predictions using IPS

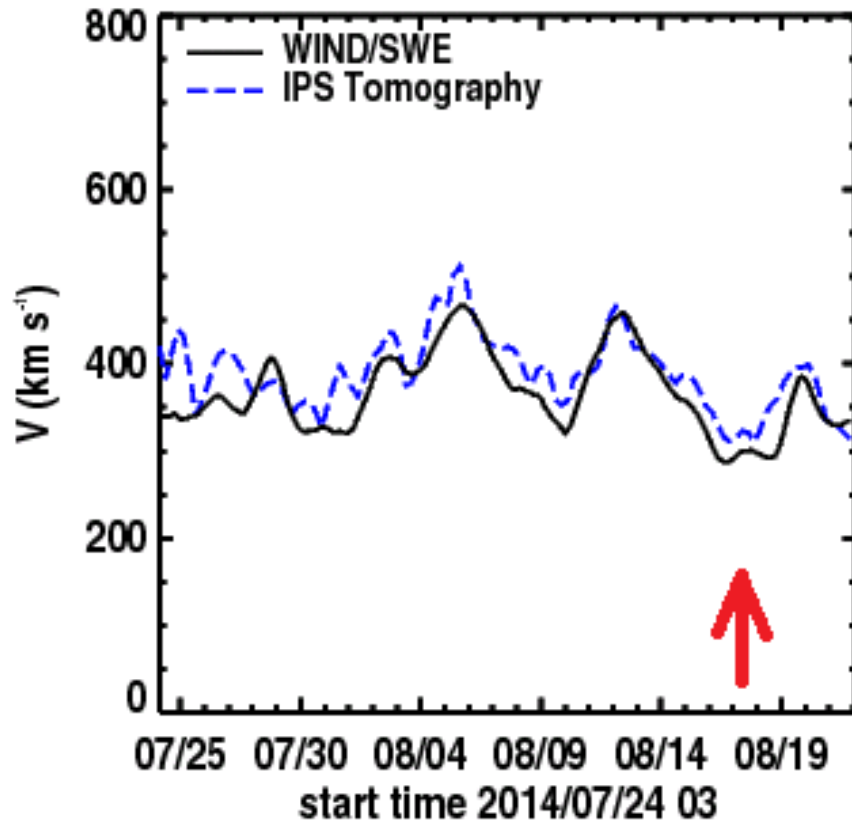
<http://ips.ucsd.edu/>

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

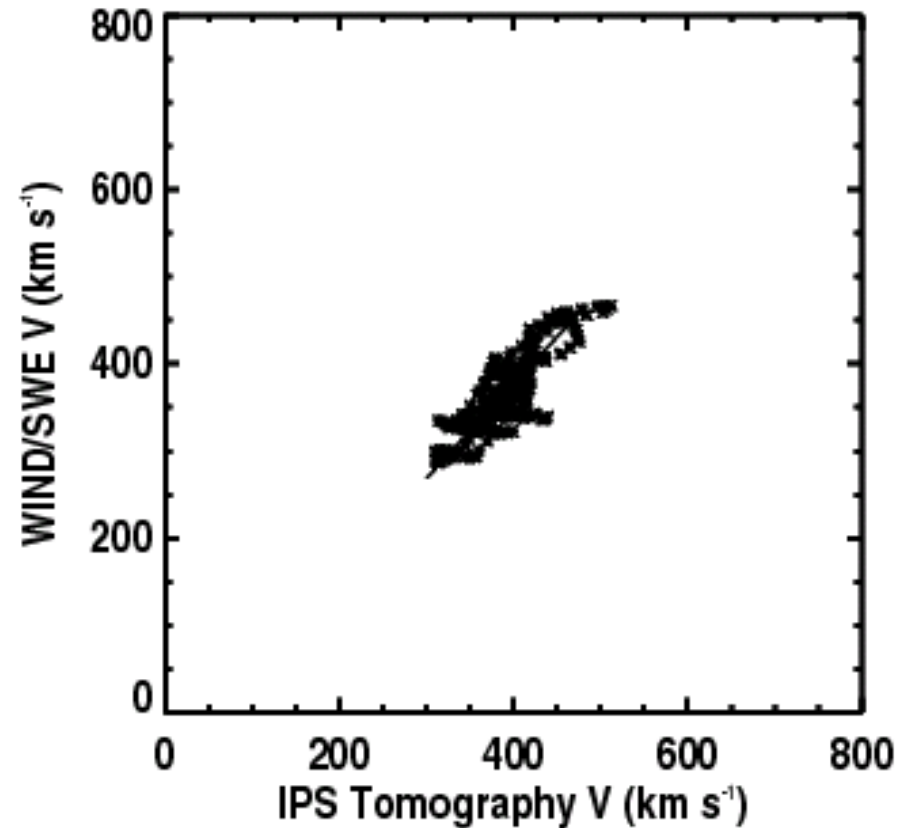
UCSD Sample Analysis (CME 08/13/2014)

ISEE Time Series 07/25 – 08/22 2014

2014/08/07 15 UT



correlation 0.851



Space Weather Predictions using IPS

IPS Prediction (KSWC)

<http://www.spaceweather.go.kr/models/ips>

UCSD
Kinematic
IPS Model

www.spaceweather.go.kr/models/ips

Solar Radiation Storms

Geomagnetic Storms

- ENLIL
- GIC Prediction
- IPS**
- SEM
- IPS-driven ENLIL
- SWSM
- Kp prediction

Ionosphere Activity

IPS

- Prediction of the arrival time and impact scale of the solar wind based on ground-based STEL, Japan IPS observations
 - Based on ground-observations of IPS, the solar wind data fit and modeling predicts the arrival time and impact scale of velocity and density variations.
 - Developed by the Center for Astrophysics and Space Sciences, UCSD, U.S.A.
 - In-situ comparisons are updated 11:00 AM.

Fig1. Solar Wind Density

Fig2. Solar wind Density compared with ACE

Fig3. Solar wind velocity

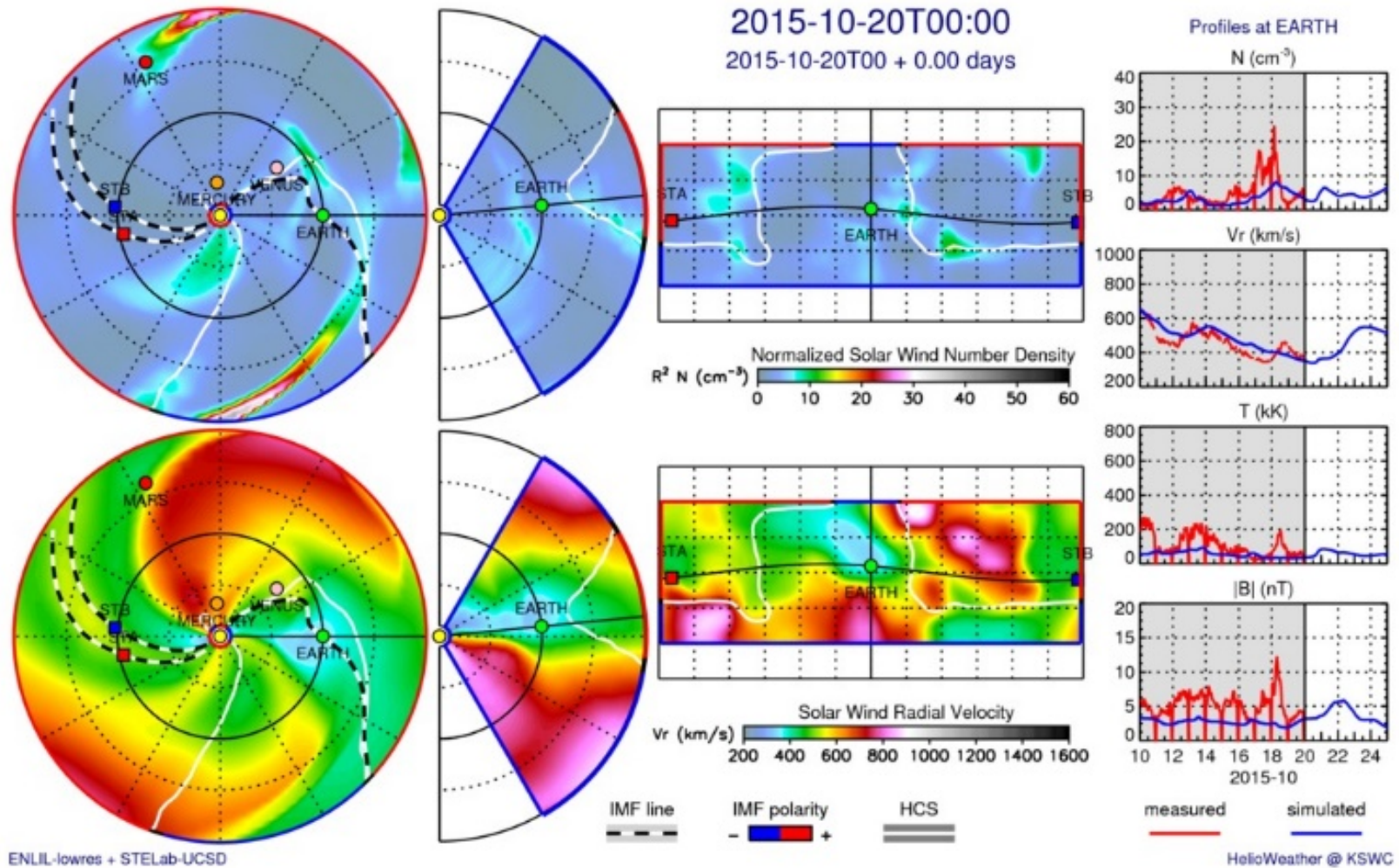
Fig4. Solar wind Velocity compared with ACE

URL : www.spaceweather.go.kr/models/ips
 Contact : KSWC, Observation Division, Jaehun Kim (snowqee@msp.go.kr)
 Developer : Dr. Bernard V. Jackson (bvjackson@ucsd.edu)

Space Weather Predictions using IPS

IPS Prediction (KSWC)

<http://www.spaceweather.go.kr/models/ips>



IPS-Driven ENLIL

Space Weather Predictions using IPS

World-Wide IPS observation network

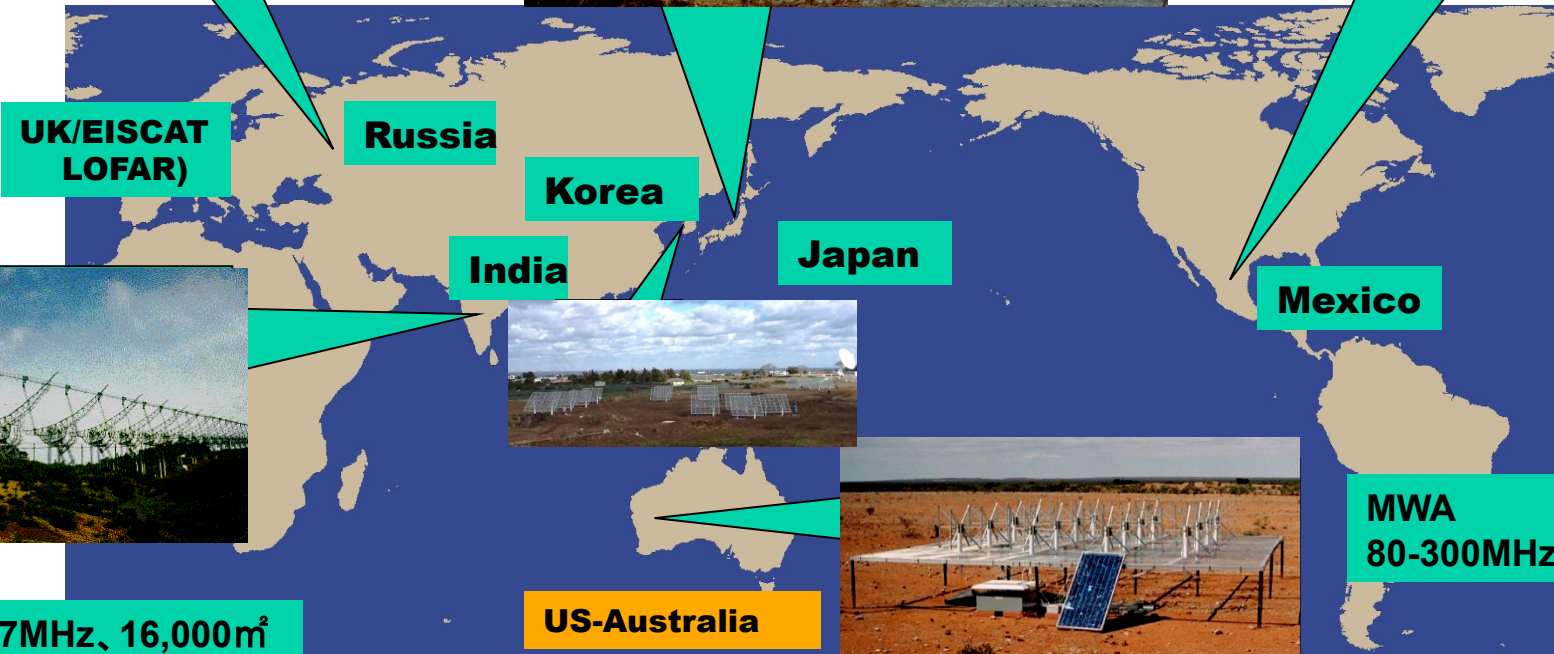
Pushchino 103MHz
70,000m²



STEL Multi-Station 327MHz
2000 m²×3, 3500 m²



MEXART
140MHz, 10,000m²



IPS

UK/EISCAT
LOFAR)

Russia

Korea

India

Japan

Mexico

Ooty 327MHz, 16,000m²

US-Australia

MWA
80-300MHz

Space Weather Predictions using IPS

Current Dedicated IPS Radio Systems



**The Pushchino Radio Observatory 70,000 m² 110 MHz array, Russia (summer 2006)
Now named the “Big Scanning Array of the Lebedev Physical Institute” (BSA LPI).**



**The Ootacamund (Ooty), India
off-axis parabolic cylinder 530 m
long and 30 m wide (15,900 m²)
operating at a nominal frequency
of 326.5 MHz.**

Space Weather Predictions using IPS

Other and Potential Future Dedicated IPS Systems



MEXART (Mexico)

**Dedicated IPS 9,600 m²
140 MHz IPS radio array
near Michoacan, Mexico**

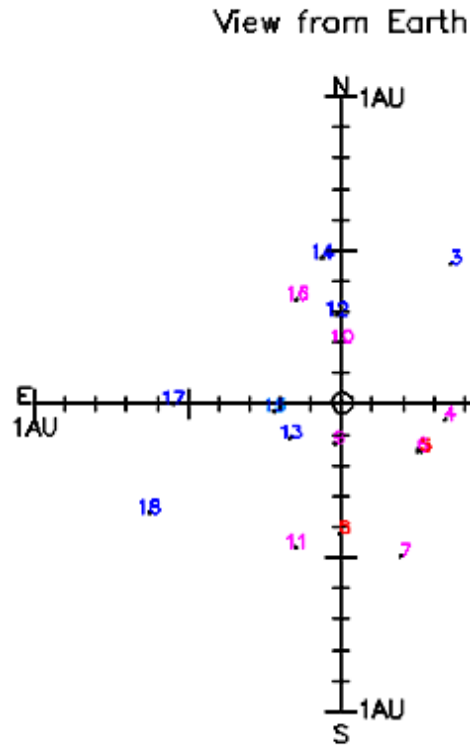


KSWC (South Korea)

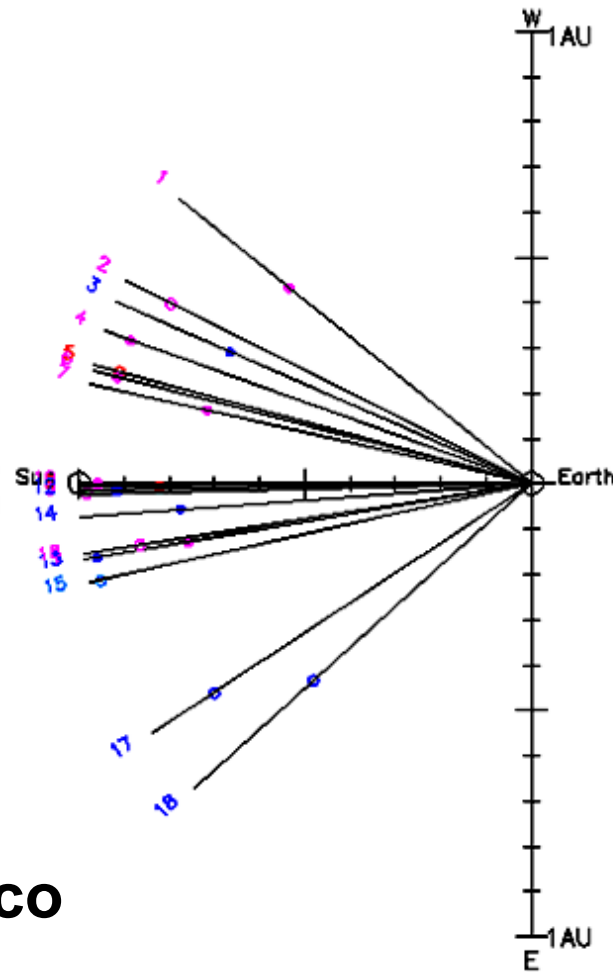
**Dedicated IPS 700 m² 327
MHz IPS radio 32 tile array,
Jeju Island**

Space Weather Predictions using IPS

“Image” of the Sky



Projection onto Ecliptic Plane



Date: 2007/07/13 (DOY:194)

No.	Source	UT	View(km/s)
1	3C119	23.9	630 +/- 17
2	0631+194	0.8	520 +/- ***
3	3C147	1.0	384 +/- 0
4	3C152	1.5	818 +/- 39
5	3C158	1.8	713 +/- ***
6	0622+147	2.0	511 +/- 17
7	3C161	2.2	636 +/- 13
8	0713-024	2.5	722 +/- 18
9	3C181	2.8	599 +/- ***
10	0732+33	3.0	475 +/- 7
11	0741-06	3.2	625 +/- 2
12	3C186	3.3	436 +/- 16
13	3C190	3.5	397 +/- 7
14	3C198	3.7	395 +/- 2
15	0817+183	3.9	214 +/- ***
16	0821+394	4.1	628 +/- ***
17	3C225	5.1	385 +/- ***
18	0941-08	5.3	370 +/- ***

View from MS&A, RT, Mexico

Ecliptic Plane Projection

Space Weather Predictions using IPS

Third Remote-Sensing Workshop

20-24 October 2015 Morelia, Mexico

<http://www.sciesmex.unam.mx/static/workshop2015/talks/>



Space Weather Predictions using IPS

Recent Morelia Remote Sensing Workshop (20-24 October 2015)

- 1) A standardized IPS format was settled upon.
- 2) All participants agreed to share their data and host websites to present their data in real time as soon as it becomes available.
- 3) At this time a new member joined the group of organizations that provide access to their IPS data set in real time from the world's largest (70,000 m²) radio array currently operating; the 110 Mhz system at Pushchino, Russia.

Space Weather Predictions using IPS

Standard Data Format

Space Weather Predictions using IPS

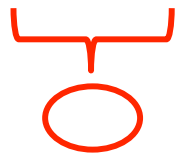
Standard IPS Format

Ascii – Fixed Format

AS: ftp://ftp.stelab.nagoya-u.ac.jp/pub/vlist/STEL2015.dat

Date	MidObsUT	Dur.	Site	Freq	BW	Source	Size	RA-J2000	Dec-J2000	Limb	Dist.
20150912	03:57:02	2.8	STEL	327	10	3C273	999	12 29 06	+02 03 12	E	68.70

Lat.	PA	Elong	Vel.	V-err	g-value	g-err	Method	Vel.	V-err	g-value	g-err	Method
16.9	74.5	17.6	560	3	1.002	0.515	3-St. CC	-999	-999	0.919	0.301	1-St. PS



New item



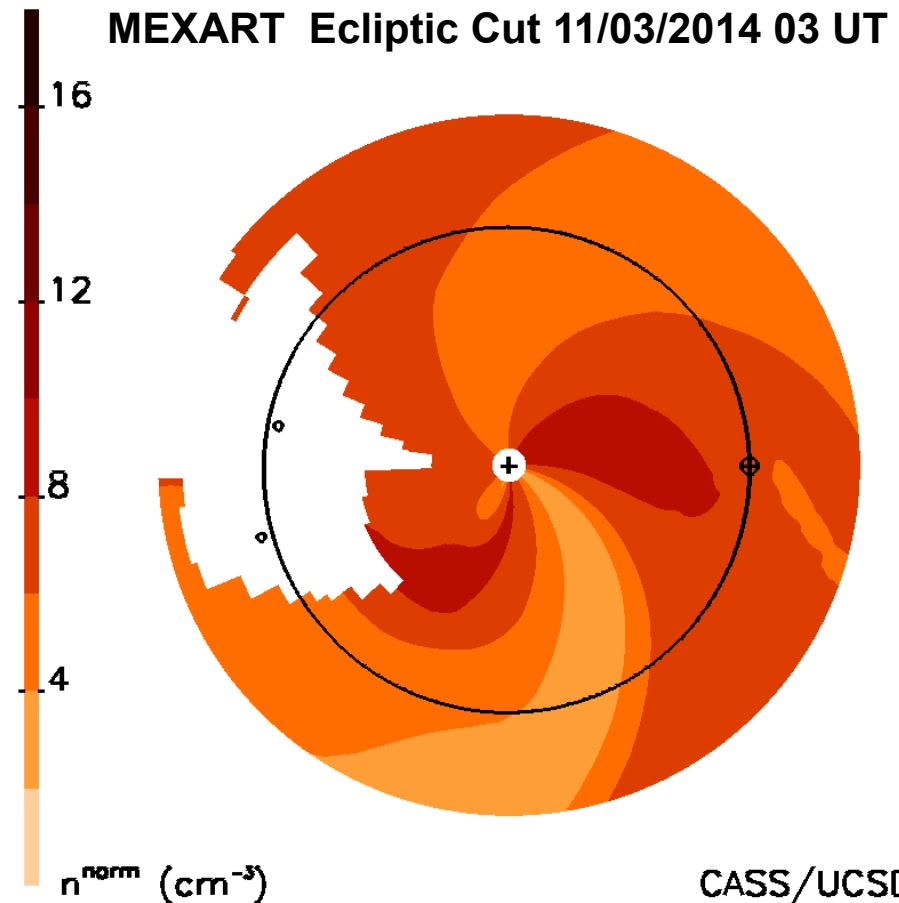
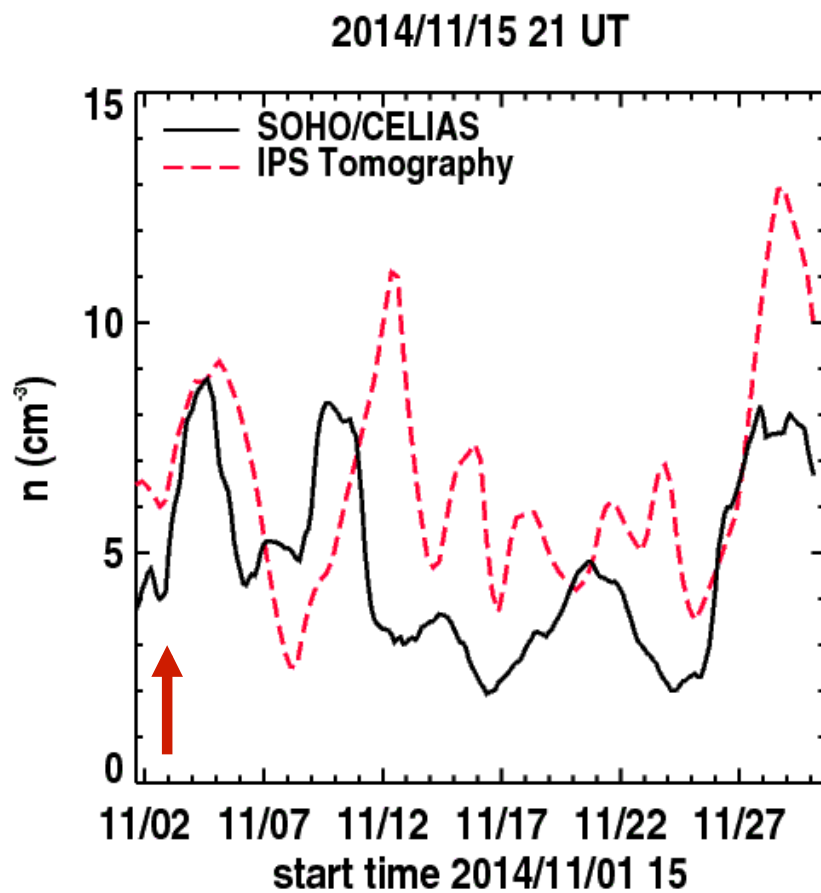
Used by UCSD tomo.

G-value, error

Space Weather Predictions using IPS

MEXART Analysis (Carrington Rotation 2156.7)

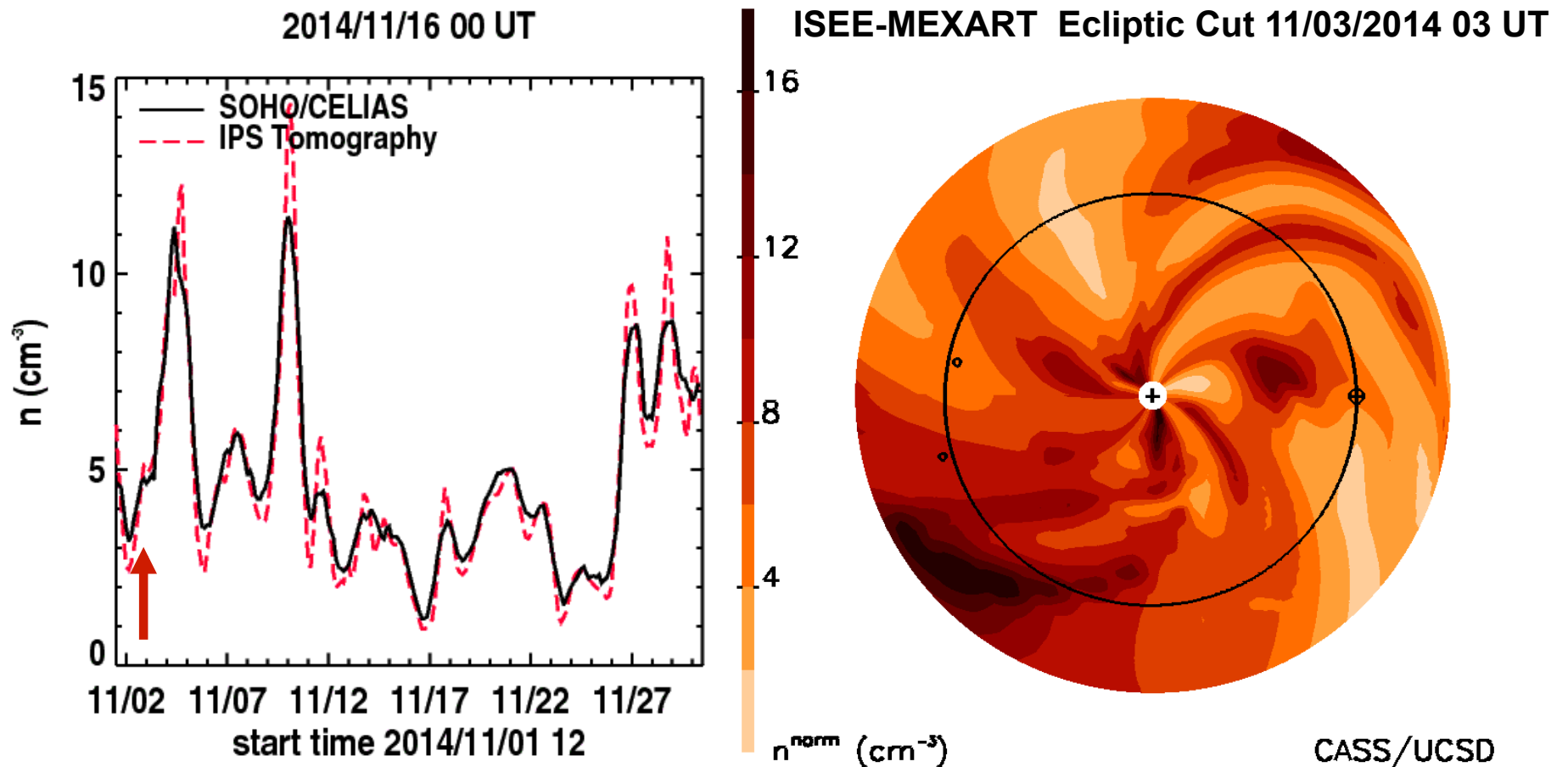
MEXART Time Series 11/02 – 11/29 2014



Space Weather Predictions using IPS

Combined ISEE and MEXART Analysis (Carrington Rotation 2156.7)

Combined Time Series 11/02 – 11/29 2014



CASS/UCSD

CASS/UCSD CCMC 2016

Space Weather Predictions using IPS

The IPS analyses provide a really-great 3D-MHD test-bed

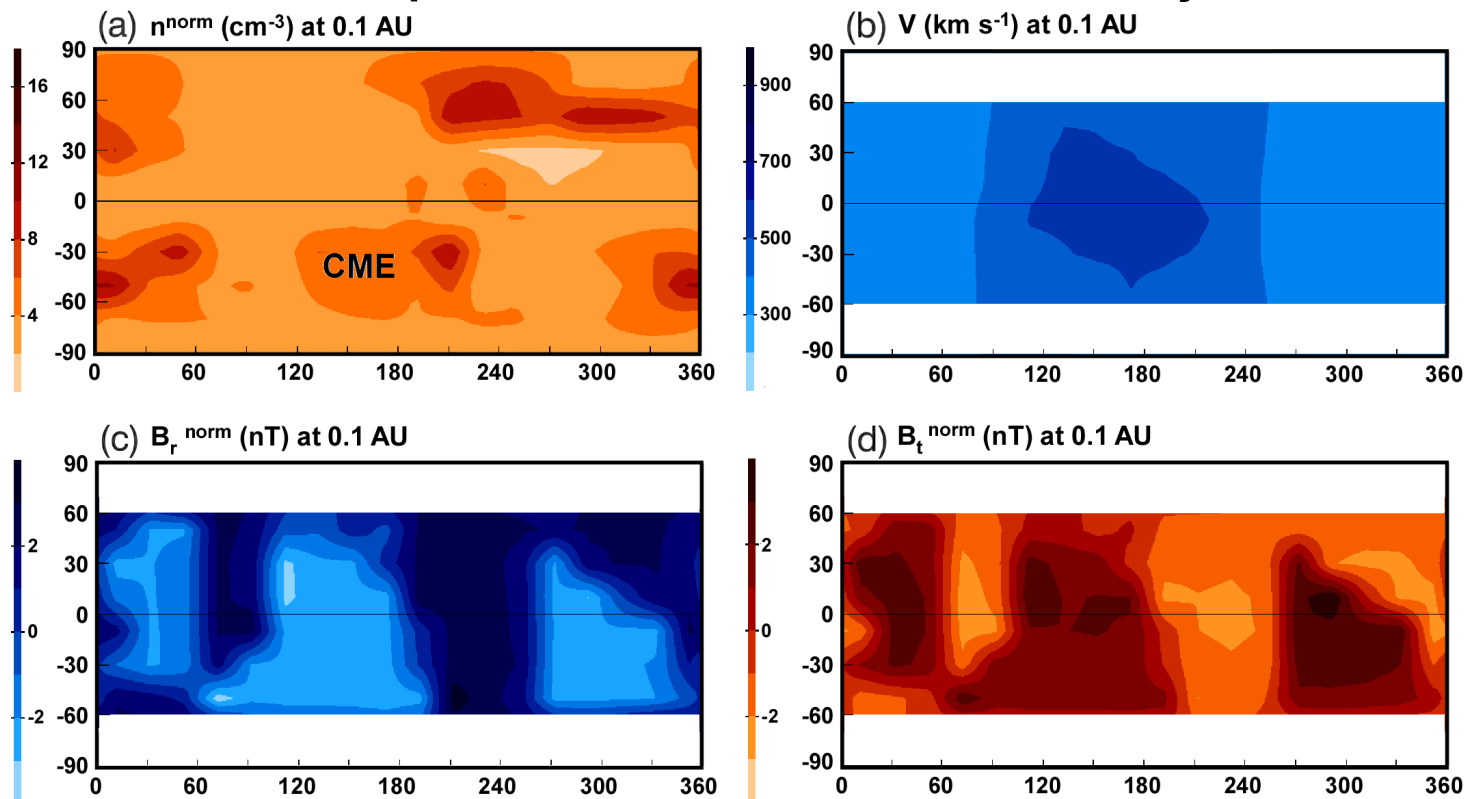
Space Weather Predictions using IPS

(Yu, H-S., *et al.*, *et al.*, 2015, *Solar Phys.*, doi: 10.1007/s11207-015-0685-0.)

(Jackson, B.V., *et al.*, *et al.*, 2015, *Space Weather*, 13, 104-115 doi: 10.1088/2041-8205/803/1/L1.)

IPS-Derived 3D-MHD Model Boundaries

2014 April 18 21:00UT at 0.1AU Boundary



Updated every 6 hours at: ftp://cass185.ucsd.edu/data/IPSD_Real_Time/ENLIL/ascii_data

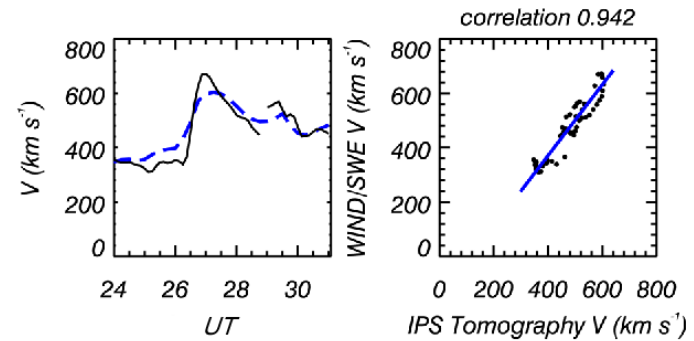
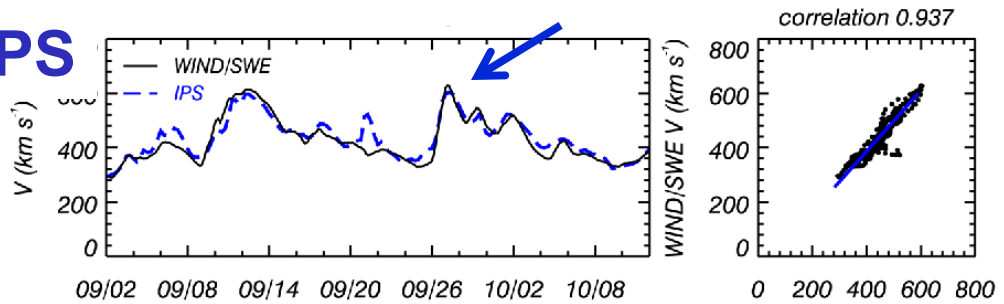
Space Weather Predictions using IPS

UCSD kinematic model and IPS-driven 3D-MHD models

Velocity 1-Day Averaged *In Situ*

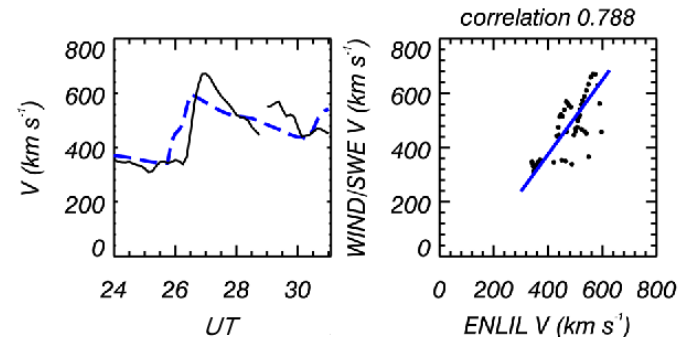
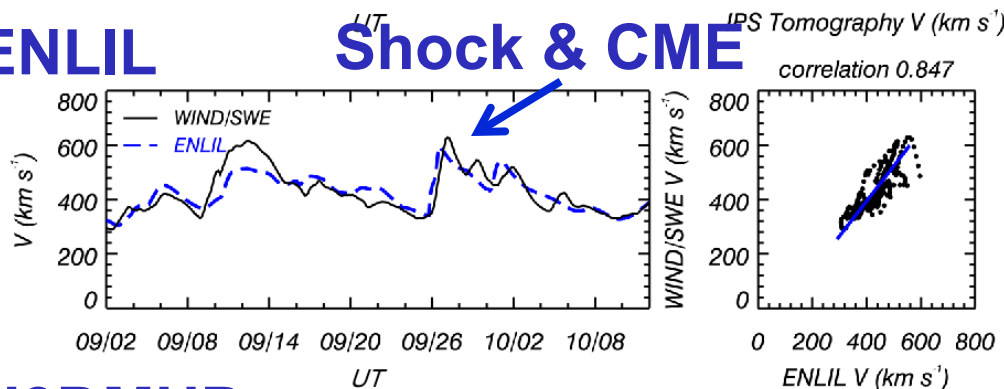
6-Hour Averaged *In Situ*

IPS

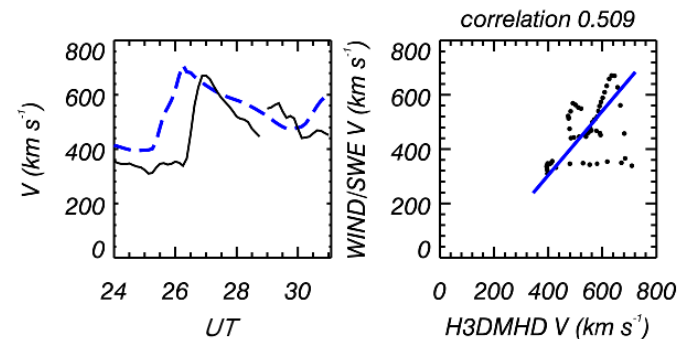
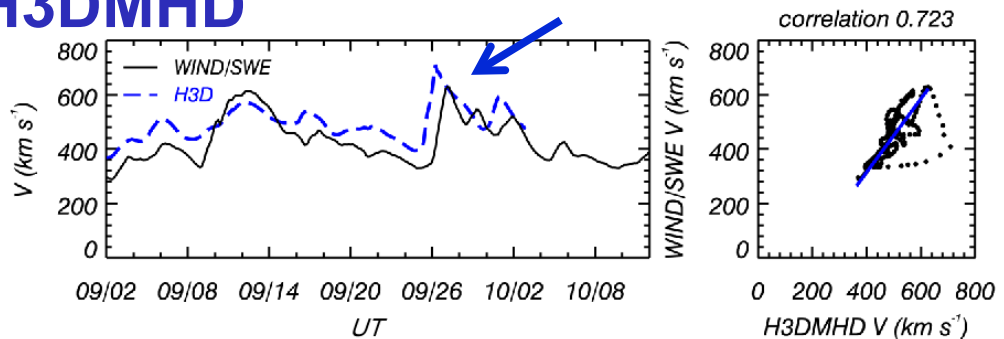


ENLIL

Shock & CME



H3DMHD



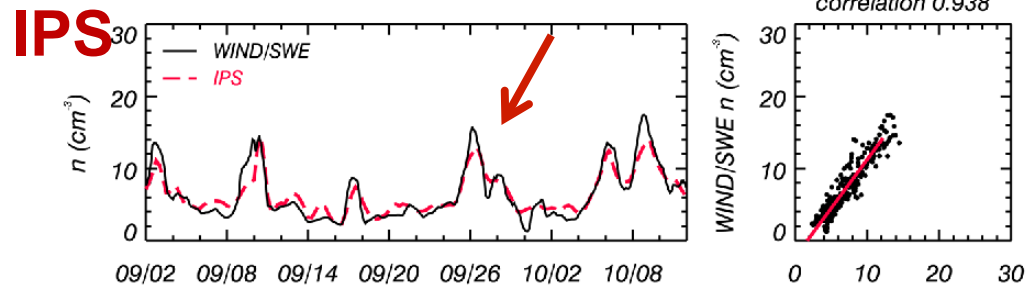
start time 2011/09/02

start time 2011/09/24

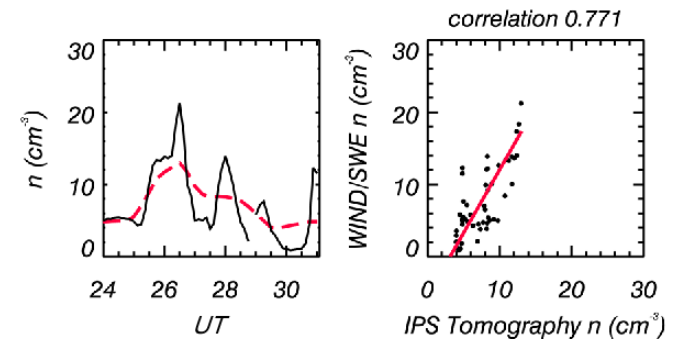
Space Weather Predictions using IPS

UCSD kinematic model and IPS-driven 3D-MHD models

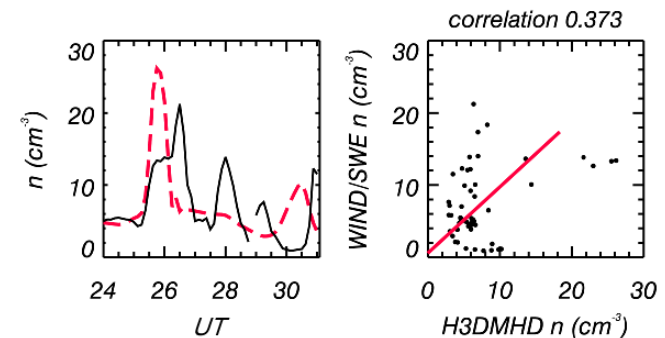
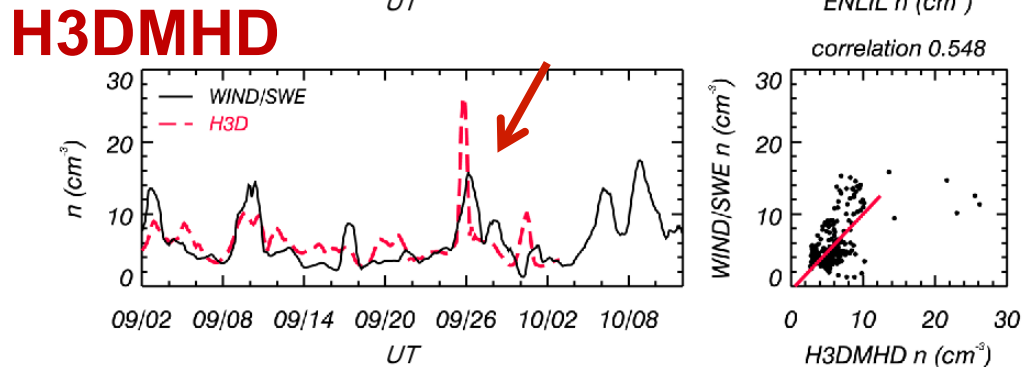
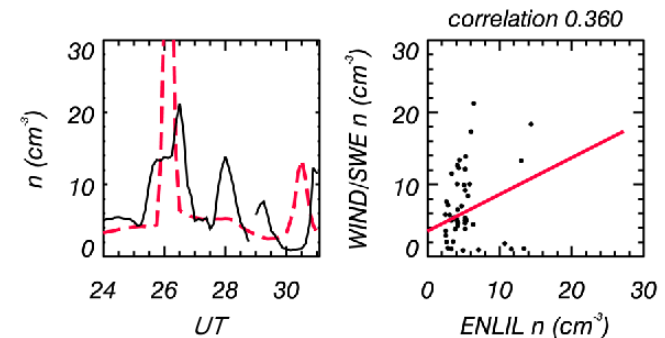
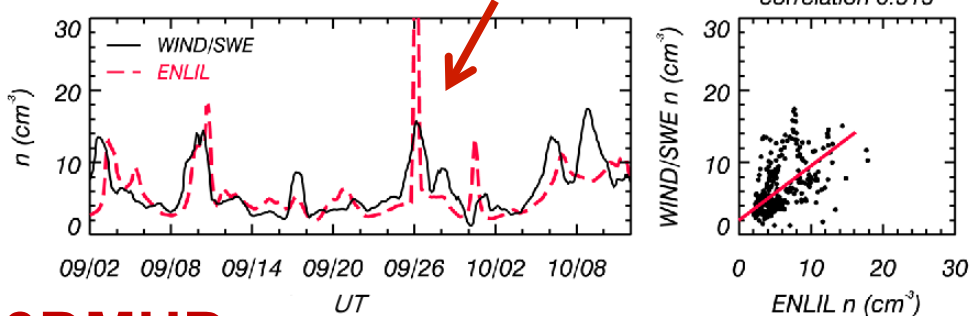
Density 1-Day Averaged *In Situ*



6-Hour Averaged *In Situ*



ENLIL Shock & CME



start time 2011/09/02

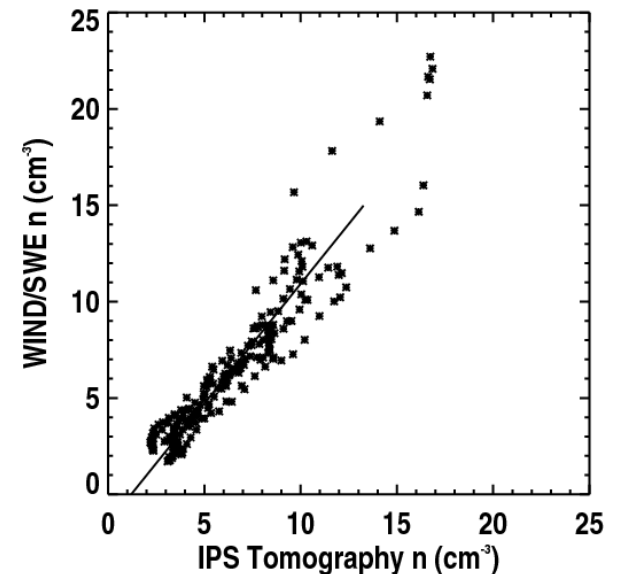
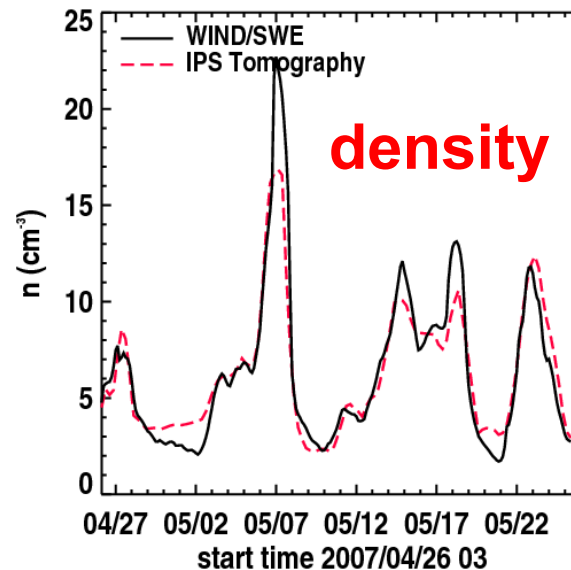
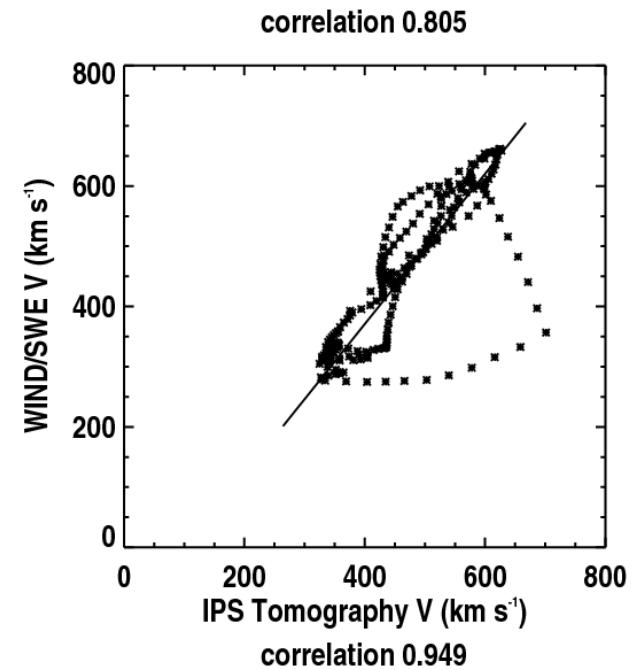
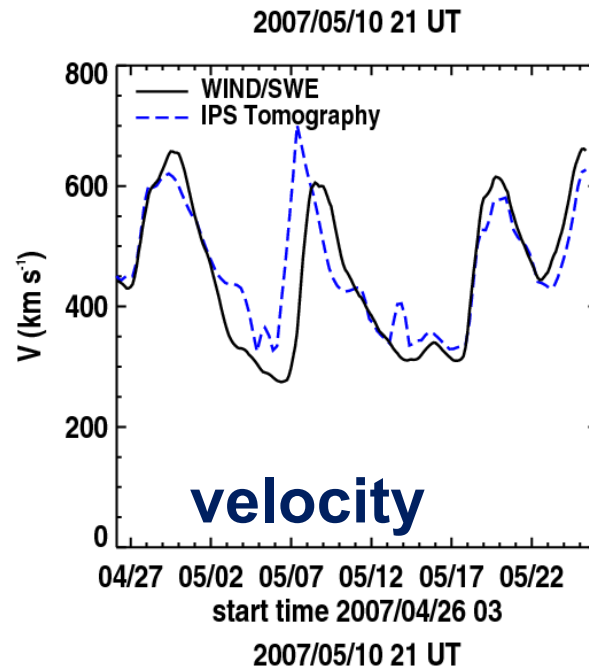
start time 2011/09/24

Space Weather Predictions using IPS

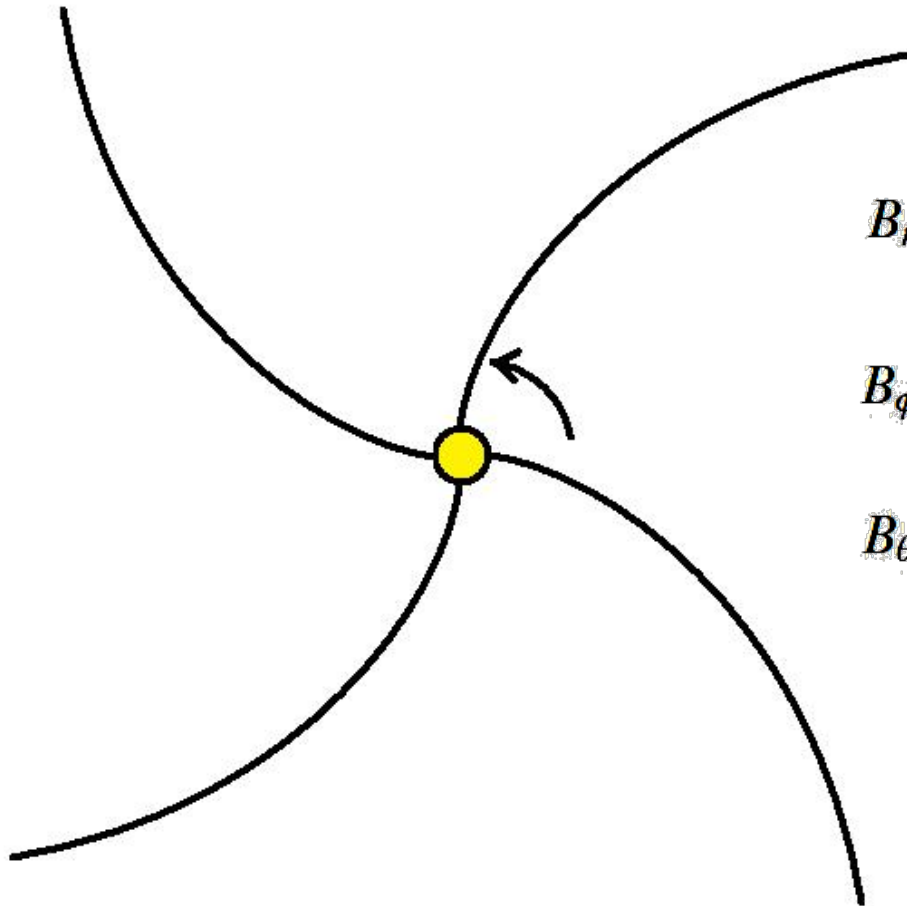
But what is really wanted is B_z

Space Weather Predictions using IPS

UCSD Archival
IPS Analysis
of V and D at
WIND over
Carrington
rotation 2056
(April 27 –
May 25, 2007)



Space Weather Predictions using IPS



$$B_r(r, \phi, \theta) = B(r_0, \phi_0, \theta_0) \left(\frac{r_0}{r} \right)^2$$

$$B_\phi(r, \phi, \theta) = -B(r) \left(\frac{\omega r_0 \sin(\theta)}{V} \right) \left(\frac{r_0}{r} \right)$$

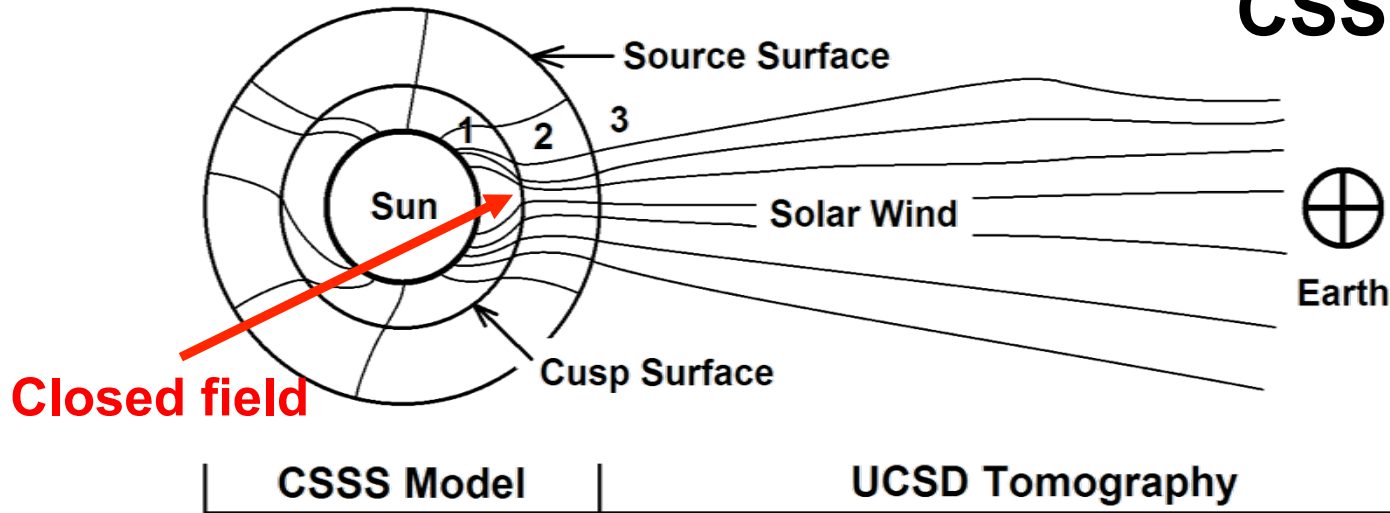
$$B_\theta(r, \phi, \theta) = 0$$

I have often wondered where the B_z in-situ field comes from. The Parker spiral analysis does not indicate how a normal field (north-south) can occur, and yet the field exists and is ever-present in the heliosphere.

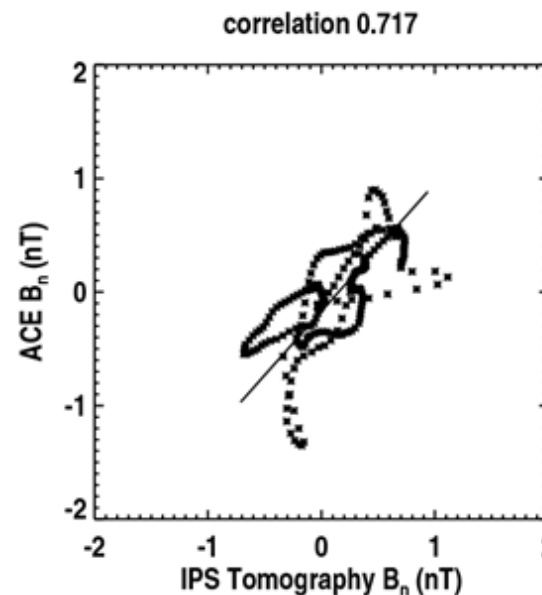
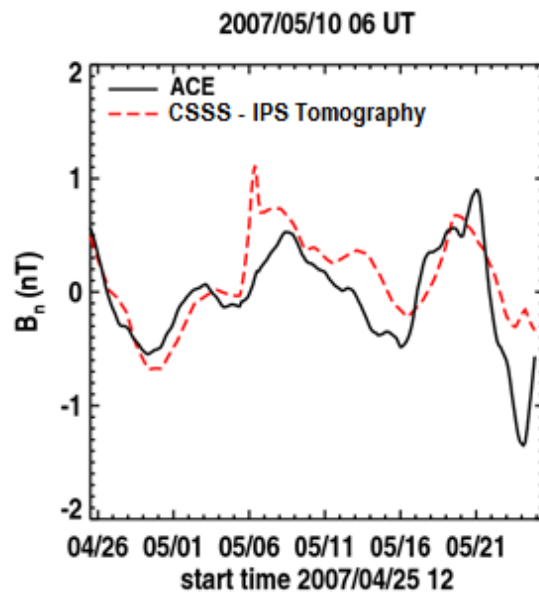
Space Weather Predictions using IPS

(Jackson, B.V., et al., 2015, *ApJL*, 803:L1. 1- 5, doi:10.1088/2041-8205/803/1/L1.)

CSSS model

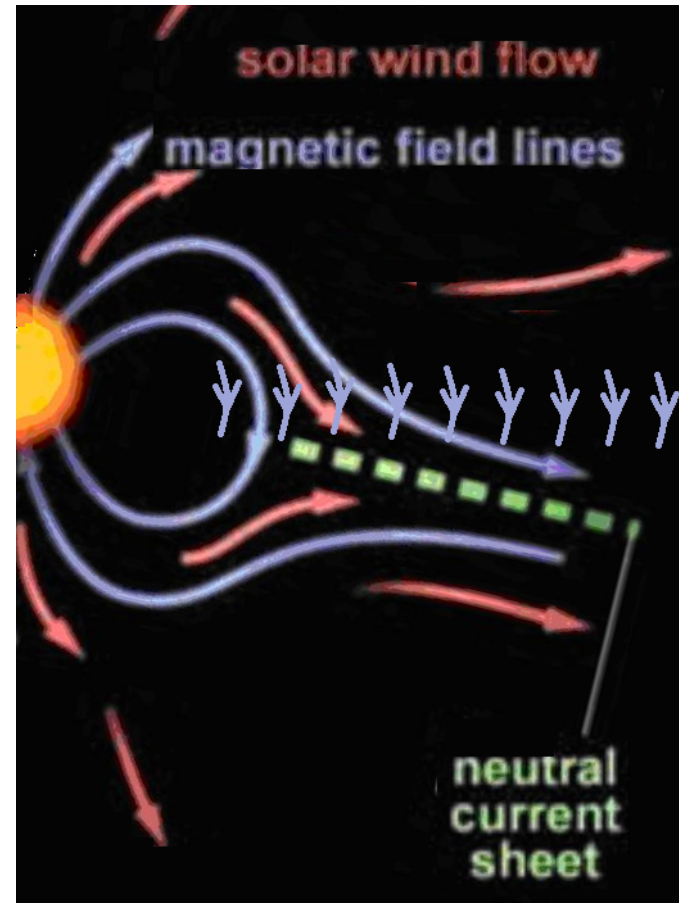
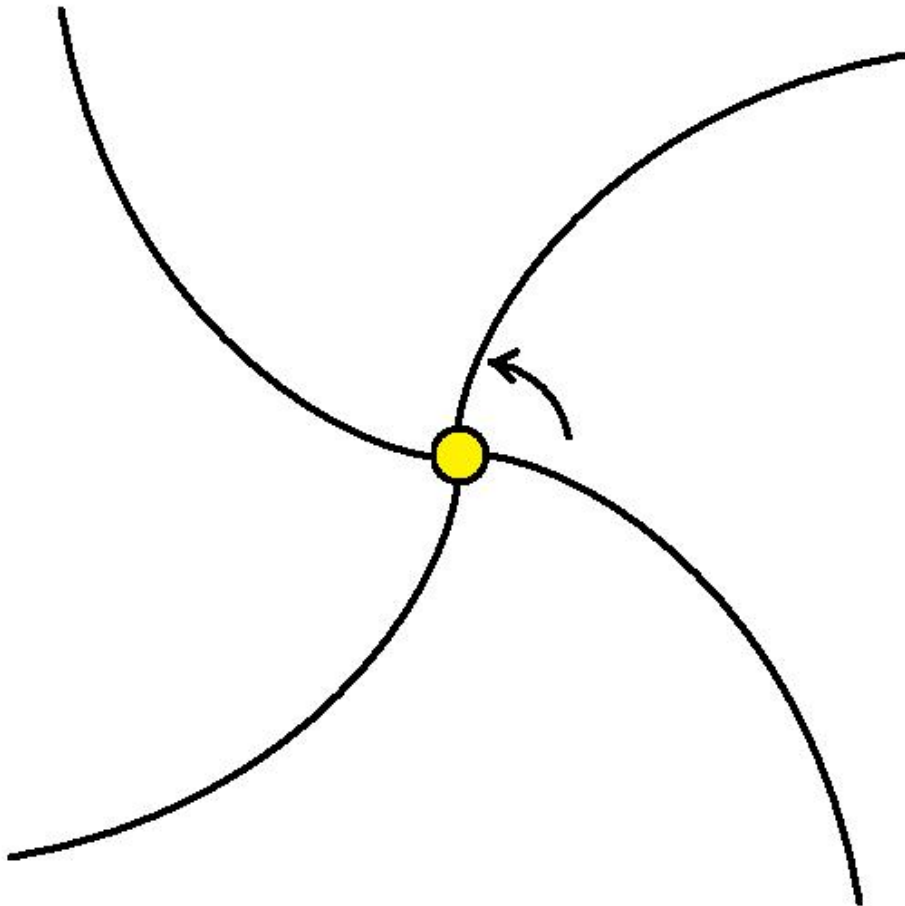


Extrapolated B_n closed field component for CR 2056



About
1/50th of
the static
flux $r^{-1.34}$
fall-off

Space Weather Predictions using IPS



I suggest that at least part of the B_n component comes from closed fields that escape from near the solar surface – perhaps through some non-static process.

Space Weather Predictions using IPS

Summary:

IPS Space Weather Predictions

IPS Tomography Analyses:

Making good predictions of in-situ measurements ahead of time keeps you “honest”.

New Systems:

Incorporation of other systems into the analysis is now available, and helps other IPS sites standardize and edit their own data sets.

Interesting Developments:

The IPS analysis is a really-great test-bed for many different types of heliospheric scientific endeavors.