Solar Magnetic Indices, SSN, and $F_{10.7}$

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Outline

- Solar Indices: SSN & $F_{10.7}$
- Solar Magnetic Indices
- Modeling $F_{10.7}$ w/ Global Magnetic Maps
- Forecasting w/ Helioseismic Farside Data

Introduction

- Solar EUV radiation drives the Total Electron Content (TEC) within the ionosphere. The TEC is used to estimate the time delays in trans-ionospheric radio propagation that can result in GPS application errors.

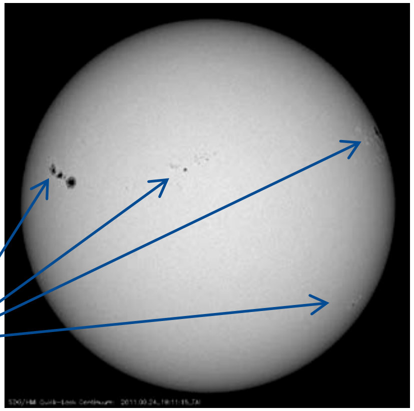
- Since most of the solar EUV radiation is absorbed in the upper terrestrial atmosphere, several solar indices have been found useful to model variations in EUV for periods without satellite measurements. Some of these indices include: *sunspot number, Mg II core-to-wing ratio,* Ca II K*, and F10.7.*

Introduction: solar activity indices

Solar Indices are typically full-disk integrated quantities and act as a form of data compression. For example, the Sunspot Number (SSN):

Full-disk HMI (pseudo-continuum) Intensitygram

Sunspots



$k(10g + s)$

88*

* SWPC estimated value for 9/24/2011

The SSN is a useful proxy for past "strong field" magnetic activity:

Galileo Galilei Drawings (1612)

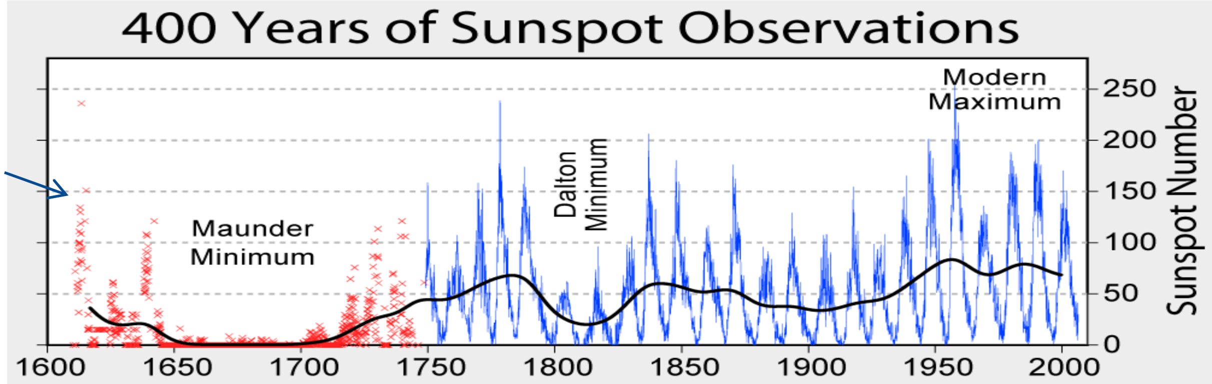


Image created by Robert A. Rohde

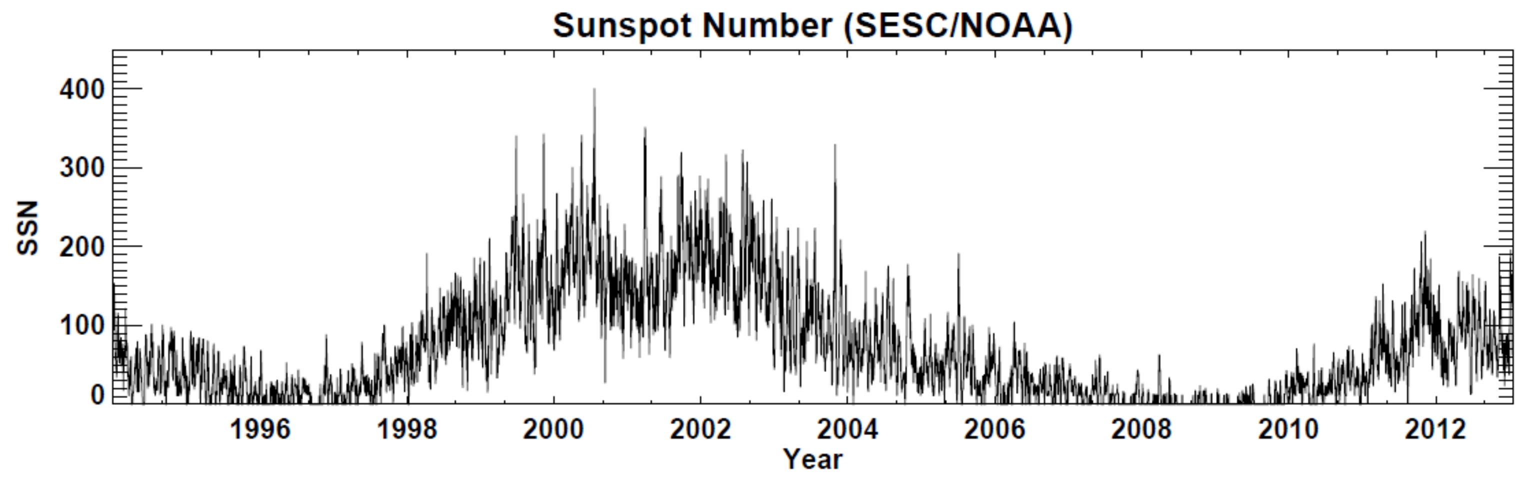
Introduction: $F_{10.7}$

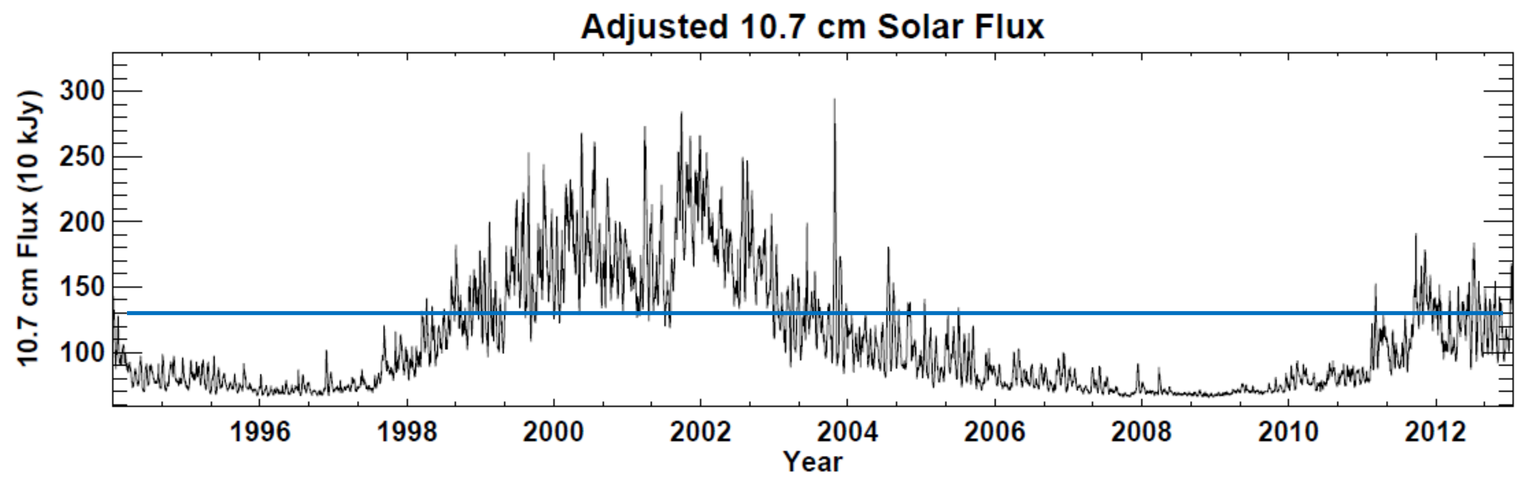
- The solar 10.7 cm (2.8 GHz) radio flux, abbreviated as $F_{10.7}$, is of interest since the signal is modulated mostly from the same energetic plasma trapped in the corona above active regions as observed in EUV images.

- The radio flux observations led by Ken Tapping are extremely well calibrated measurements and reliable (beginning in 1947).

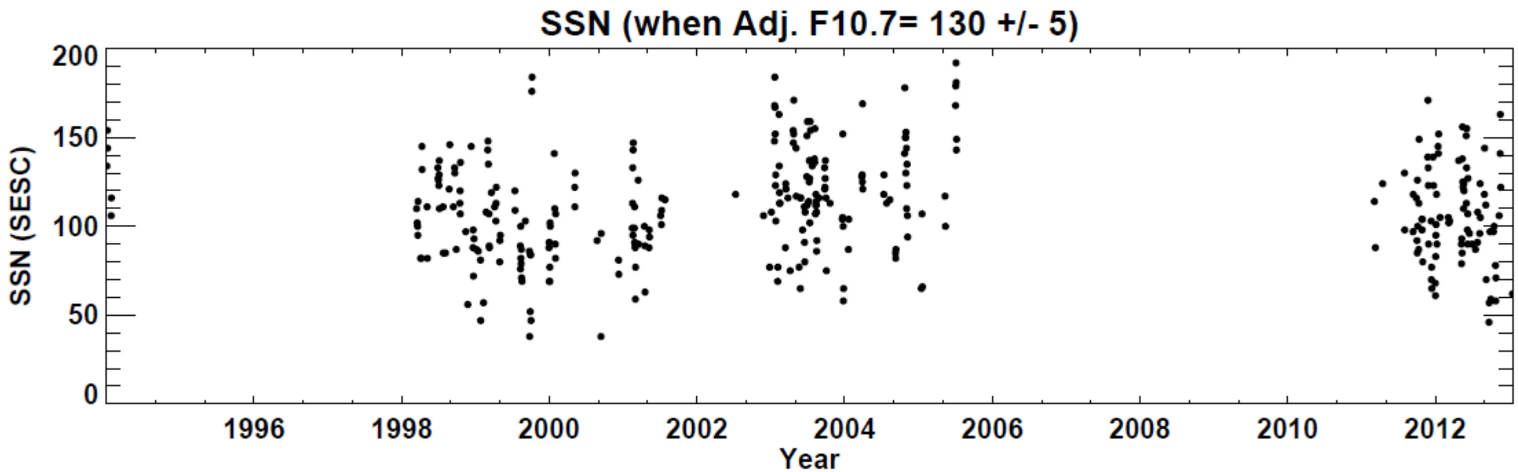
- The source of the $F_{10.7}$ signal is a combination of gyro-resonance and thermal bremsstrahlung emission, where the relative contribution is still in question.

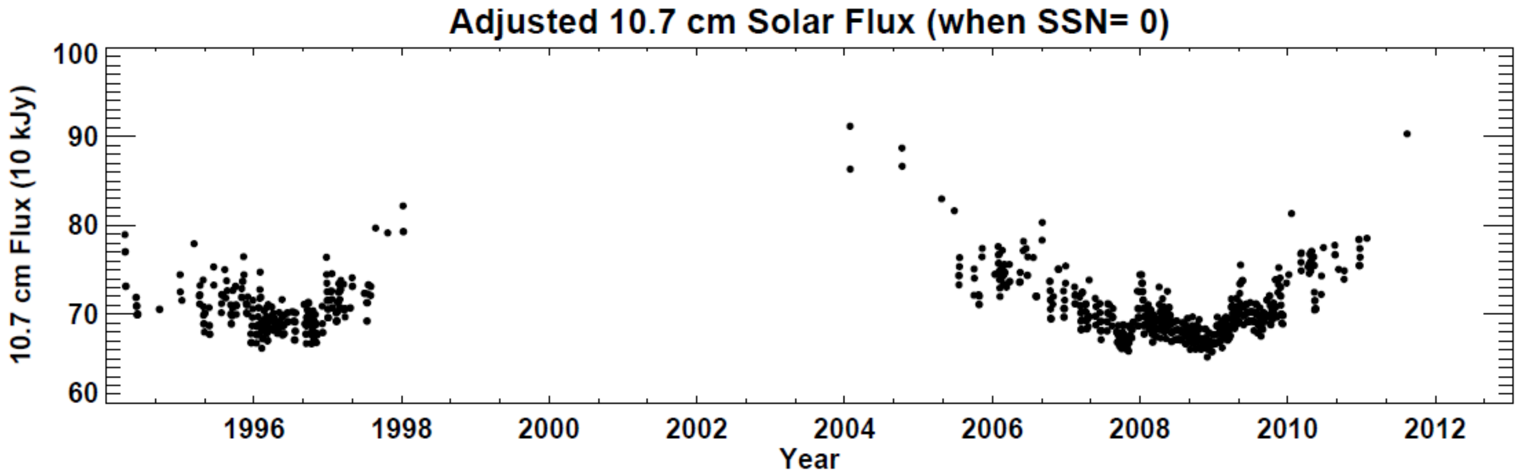
Intro: sunspot number & $F_{10.7}$



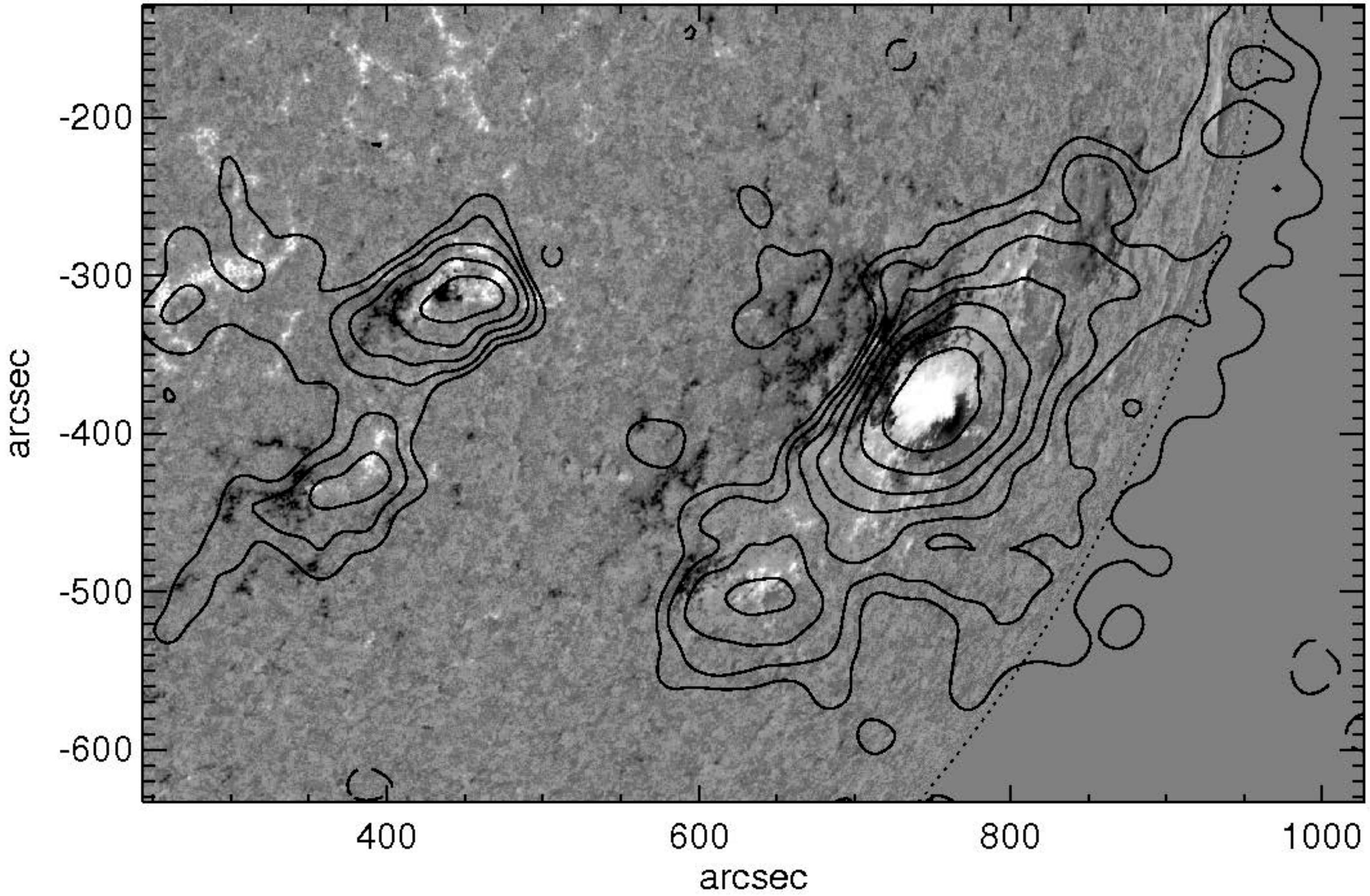


Sunspot Number & $F_{10.7}$ (cont'd)





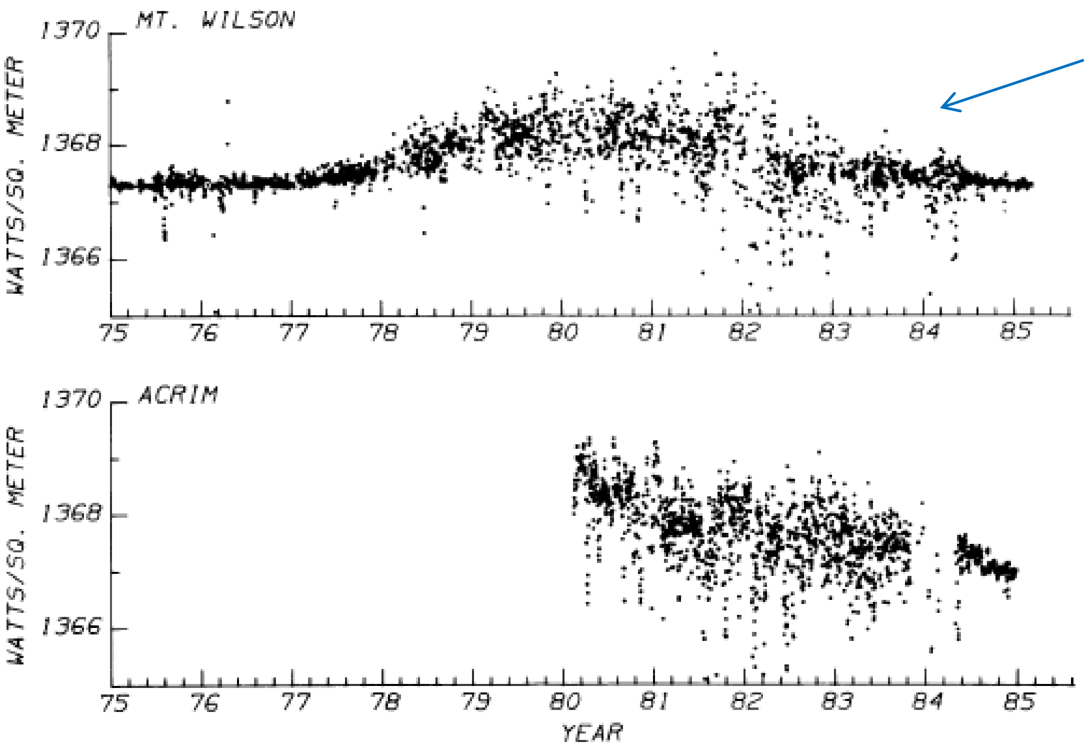
2.8 GHz VLA & LOS-Mag HMI



Preliminary reduction of 1 of the 7 fields that comprise the solar full-disk at 2.8 GHz (aka 10.7 cm) from an observation from the VLA on Dec 9, 2011 (Courtesy of Stephen White).

Intro: solar magnetic indices

Chapman & Boyden (*ApJ, 302, L71, 1986*) modeled solar irradiance variations using "Plage" and "Sunspot" fields from magnetograms:



$$A + B\phi + C\psi$$

where

$$\phi = \Sigma|B|_{10}(1 - 3\mu + 2\mu^{-1})$$ [Plage]

$$\psi = \Sigma|B|_{100}(3\mu + 2).$$ [Sunspot]

Intro: $F_{10.7}$ and Magnetic Indices

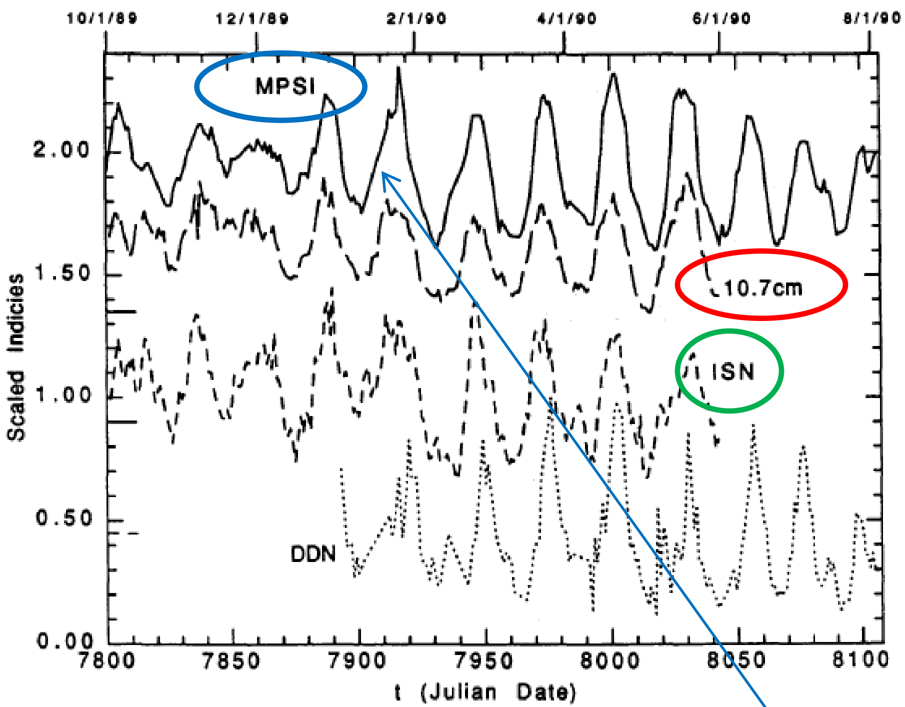


Figure from Ulrich (1991), where the **F10.7** is shown for the period October 1, 1989 to June 15, 1990. The international sunspot number is shown as **ISN**.

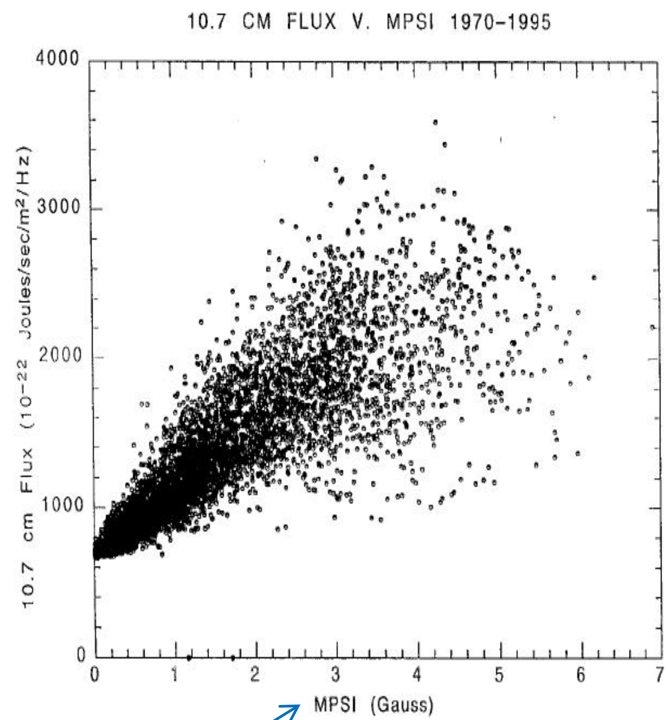


Figure 2. The scatter plot of the MPSI versus the $F_{10.7}$ for the period 1970–1995. The scatter increases with increased activity.

Figure from Parker, Ulrich, and Pap (1998).

$$MPSI = \frac{1}{N} \sum_{10\ \text{gauss} < |B|}^{|B| < 100\ \text{gauss}} |B|$$

ADAPT Flux Transport Modeling

The solar magnetic flux transport model being developed at AFRL is called **ADAPT, Air Force Data Assimilative Photospheric Flux Transport** (Arge et al. 2010, 2011, 2013; also see Henney et al. 2012 & Lee et al. 2012) **.**

The ADAPT Model Team members include:

- C. Nick Arge, Carl J. Henney, Stephen White *(**AFRL, Kirtland AFB**)*
- Irene Gonzalez-Hernandez, Alex Toussaint, Jack Harvey *(**NSO, Tucson**)*
- Josef Koller, Humberto C. Godinez *(**LANL, Los Alamos**)*

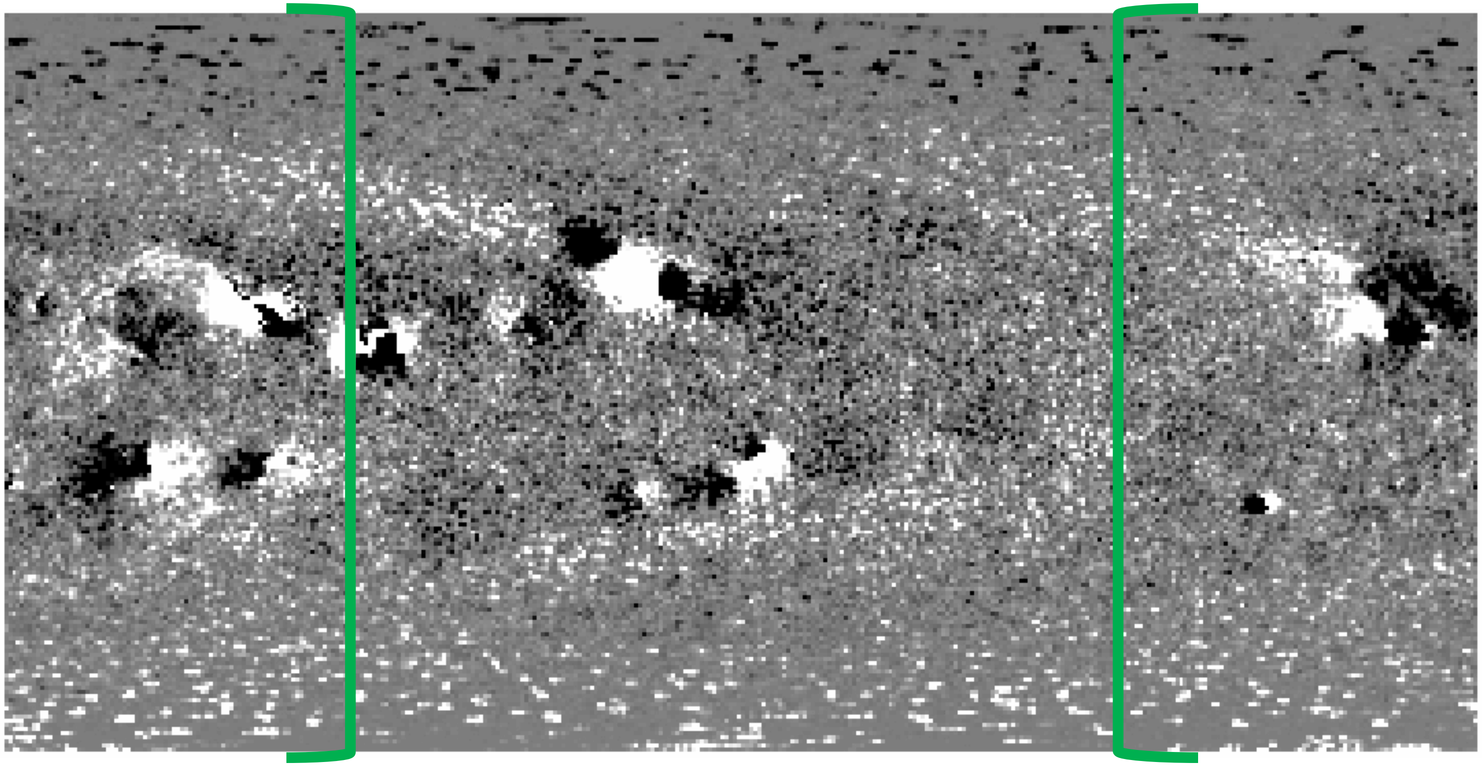
ADAPT is based on Worden & Harvey (2000, Solar Physics, 195, 247), which **accounts for known flows in the solar photosphere (differential rotation, meridional circulation, supergranular diffusion) along with random flux emergence to produce "forecast" maps**.

The modified Worden & Harvey model used with **ADAPT includes an ensemble of solutions representing the model parameter uncertainties**

ADAPT currently utilizes NSO KPVT, VSM and GONG data.

ADAPT Global Maps

An example ADAPT map from 3/17/2011 (w/ VSM magnetograms):



Earth-side

Earth-side

$F_{10.7}$ Empirical Model

The F10.7 empirical Model used for the ADAPT study:

$$\mathrm{F}_{\mathrm{model}} = m_0 + m_1 S_{\mathrm{P}} + m_2 S_{\mathrm{A}} \qquad (1)$$

where

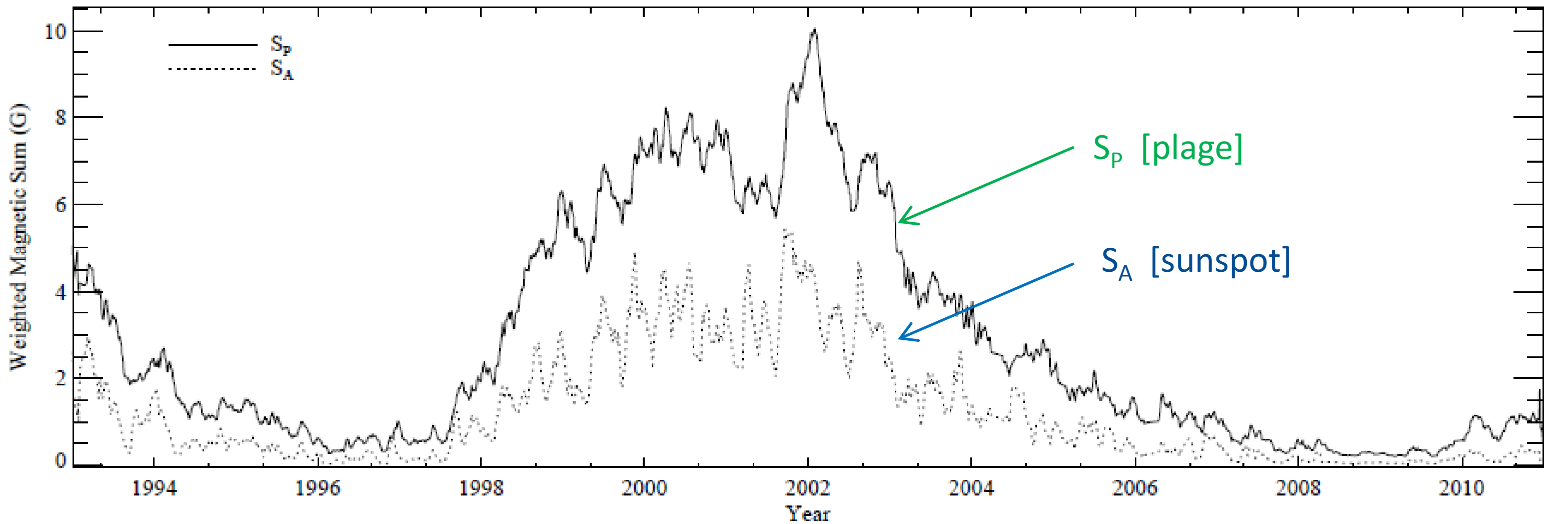
$$S_{\mathrm{P}} = \frac{1}{\sum \omega_\theta} \sum_{25\mathrm{G} < |\mathrm{B_r}|}^{|\mathrm{B_r}| < 150\mathrm{G}} |\mathrm{B_r}|\, \omega_\theta$$ ["Plage"]

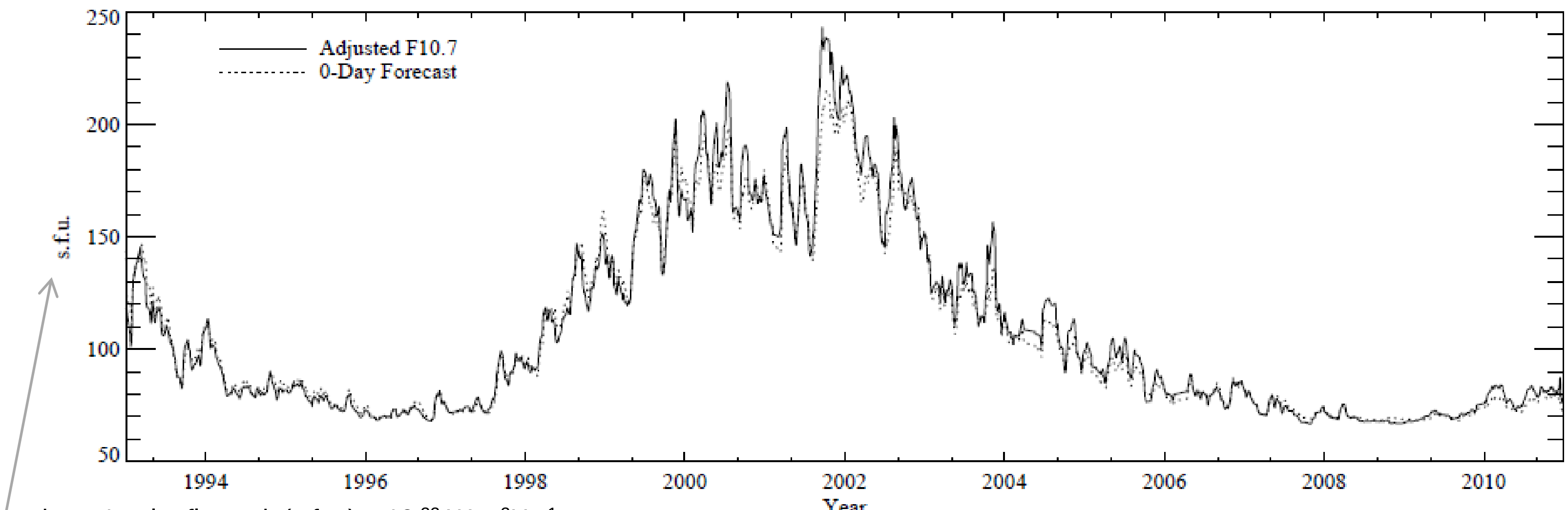
and

$$S_{\mathrm{A}} = \frac{1}{\sum \omega_\theta} \sum_{150\mathrm{G} \leq |\mathrm{B_r}|} |\mathrm{B_r}|\, \omega_\theta .$$ ["Sunspot"]

From Henney et al., Space Weather, 10, S02011, 2012

ADAPT "0-day" $F_{10.7}$ Forecast

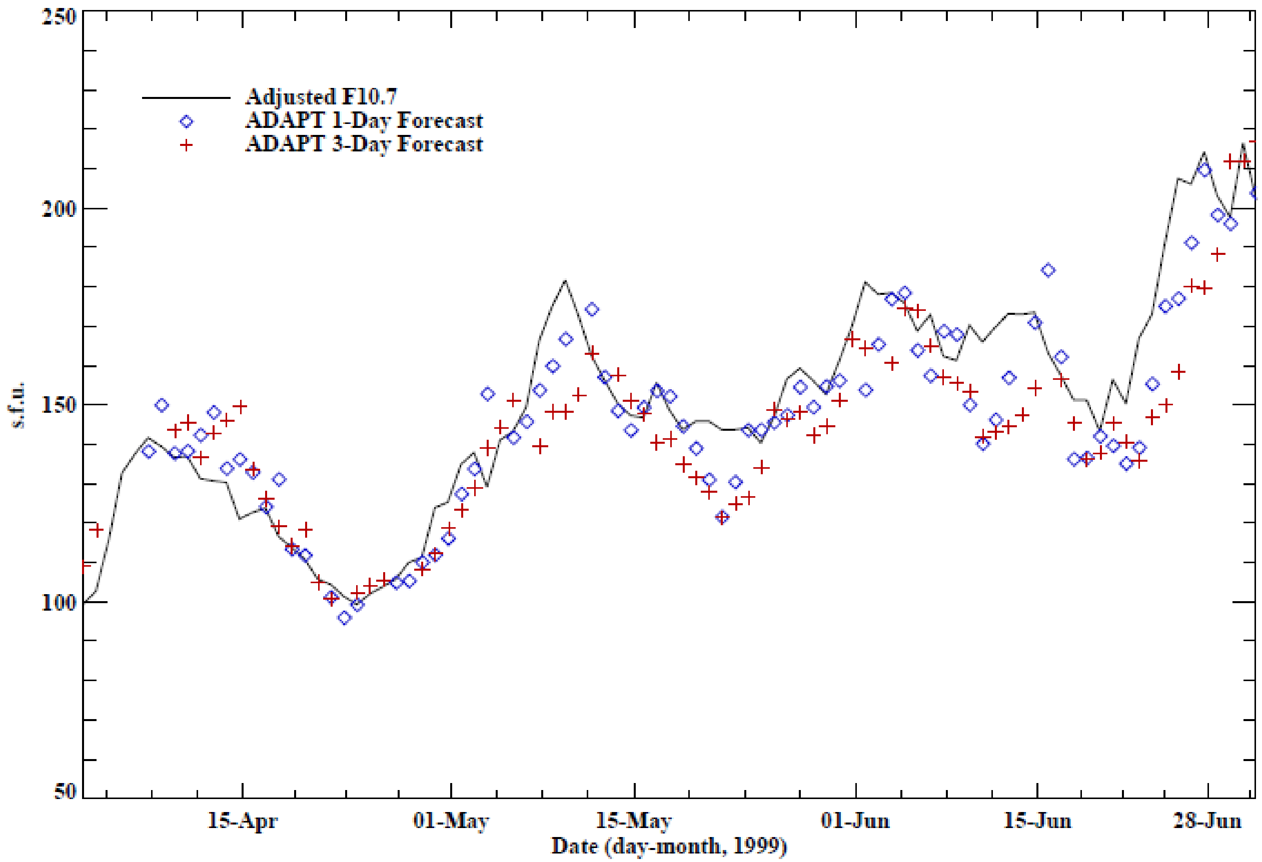




where 1 solar flux unit (s.f.u.) = 10^{-22} $Wm^{-2}Hz^{-1}$

From Henney et al., Space Weather, 10, S02011, 2012)

Forecasting $F_{10.7}$



ADAPT 1-day (diamond) & 3-day (+) F10.7 forecast values, from ADAPT global magnetic maps, compared with the adjusted F10.7 **(solid line)*****. Data shown for April through June 1999.***

Model & Obs. Correlation Table

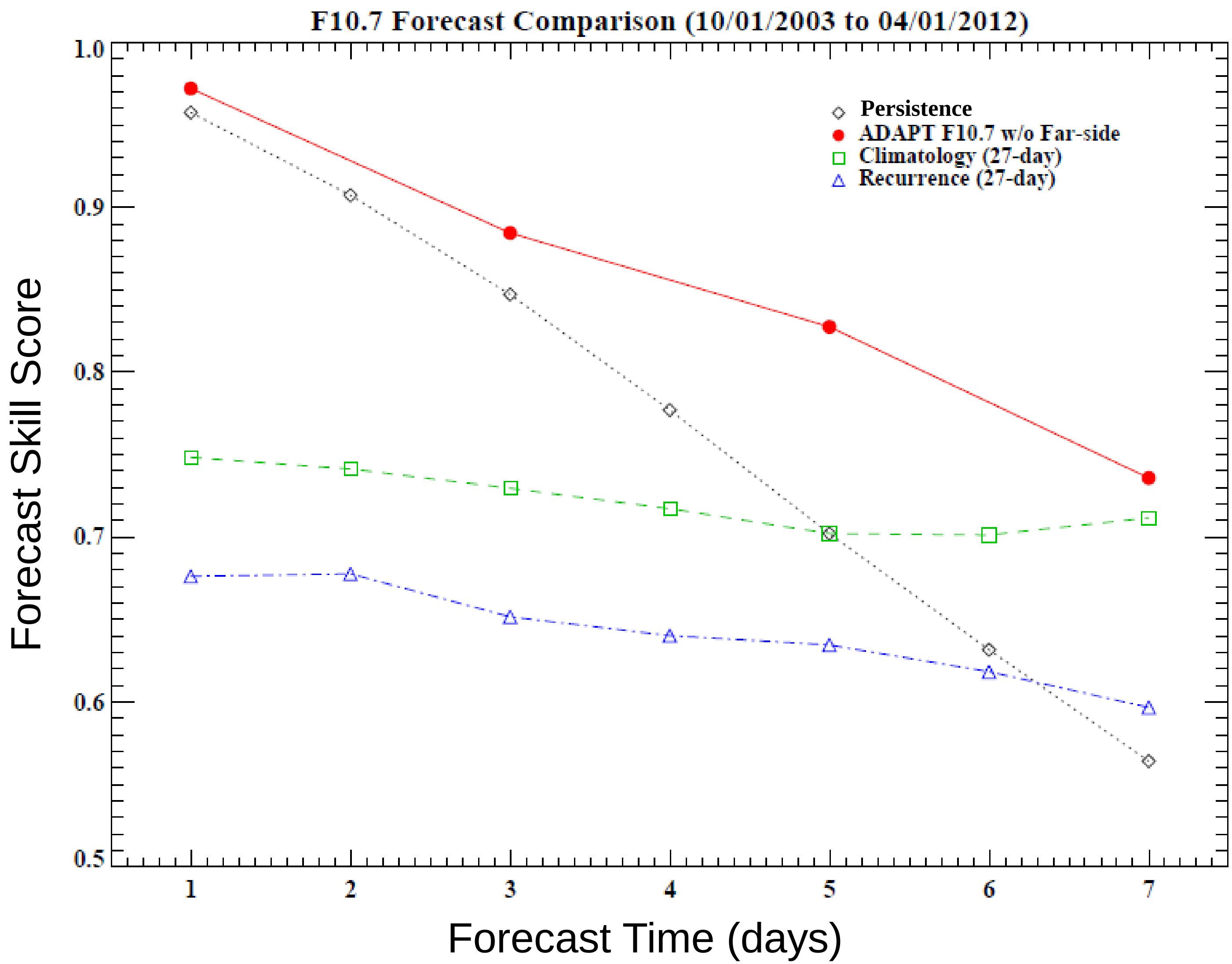
Mean ADAPT Forecast Time

Spearman correlation coefficient

Period	Year Range	Coverage	<Forecast Time> (days)	m_0 (s.f.u.)	m_1 (s.f.u./G)	m_2 (s.f.u./G)	r_s	r
Total	1993-2010	67.0%	0.13 ±0.05	66.08 ±0.09	8.508 ±0.11	16.56 ±0.18	0.98	0.97
			1.13 ±0.05	65.26 ±0.10	8.522 ±0.11	17.20 ±0.19	0.97	0.96
			3.13 ±0.05	65.00 ±0.10	10.76 ±0.10	15.90 ±0.22	0.96	0.95
			7.13 ±0.05	64.75 ±0.09	14.83 ±0.09	8.861 ±0.27	0.94	0.91
A	1993-2001	70.9%	0.15 ±0.05	65.41 ±0.14	8.153 ±0.14	16.81 ±0.22	0.98	0.97
			1.15 ±0.05	64.88 ±0.15	8.446 ±0.14	17.04 ±0.24	0.98	0.96
			3.15 ±0.05	64.80 ±0.15	10.90 ±0.13	15.46 ±0.27	0.96	0.94
			7.15 ±0.05	64.59 ±0.14	15.56 ±0.13	6.870 ±0.34	0.94	0.90
B	2002-2010	63.2%	0.12 ±0.05	66.31 ±0.12	9.058 ±0.18	16.92 ±0.31	0.97	0.98
			1.12 ±0.05	65.44 ±0.13	8.495 ±0.17	18.22 ±0.33	0.96	0.97
			3.12 ±0.05	65.14 ±0.13	10.50 ±0.16	17.02 ±0.37	0.94	0.96
			7.12 ±0.05	64.92 ±0.12	13.87 ±0.14	11.95 ±0.46	0.92	0.93

From Henney et al., Space Weather, 10, S02011, 2012

Forecasting w/o farside data



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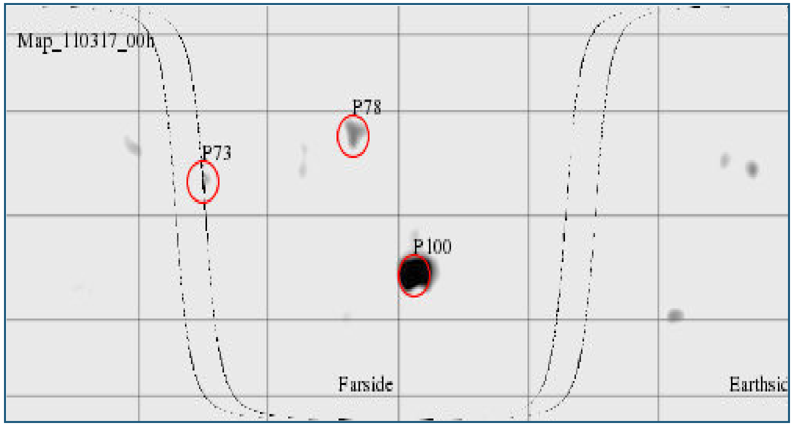
Incorporating Farside Maps

- **Without farside data, space weather forecasting models are reliant on the persistence & recurrence of past observations.**

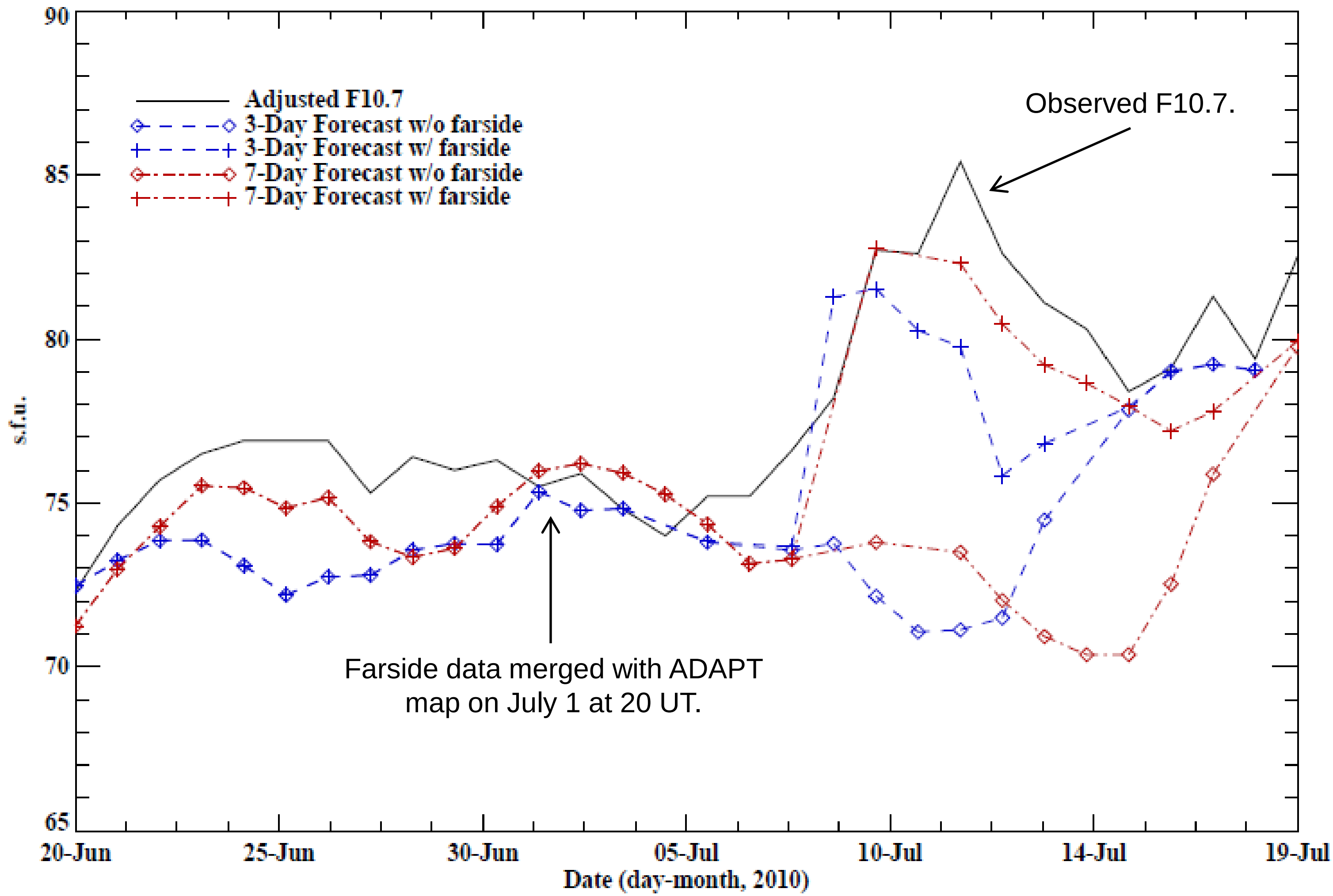
- **Farside data assimilation requires a realistic estimation of the:**
  - **magnetic field strength and uncertainty.**
  - **position and uncertainty (i.e., how reliable is the current result for this latitude and longitude)**



GONG farside map for March 17, 2011.

- **Utilizing the strength & spatial error estimates, a "farside ensemble" can be generated based on a simple polarity estimation (i.e., Hale's law), along with a "climatological" estimation of the general active region flux distribution at 1-deg resolution. *With the errors represented within the ensemble, the far-side ensemble can be directly added to the normal ADAPT ensemble.***

$F_{10.7}$ Forecasting with Farside



Summary

- A two component magnetic field model agrees well with F10.7 obs.
- Developed a method to forecast the solar 10.7 cm radio flux using solar magnetic flux transport with ADAPT. Correlations of 0.98, .97 & .95 are found for 0-day, 1-day & 3-day empirical model forecast.
- Method can be expanded to predict other space weather parameters, e.g. EUV, SSN, TEC, and total solar irradiance.
- Incorporating helioseismic farside data is key to improving space weather forecasting.

Acknowledgements

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