Air Force Research Laboratory

Forecasting Daily VUV Solar Irradiance for Atmospheric Models

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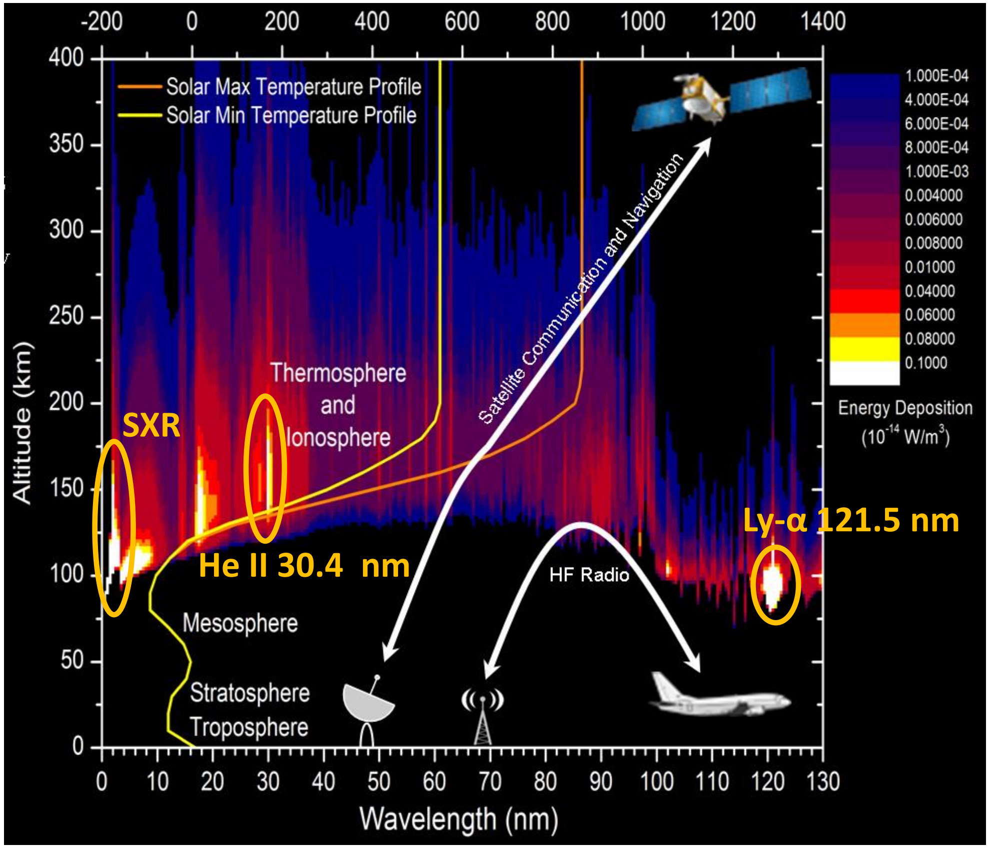
Integrity ★ Service ★ Excellence

"A survey of customers of space weather information"

- C. J. Schrijver and J. P. Rabanal, *Space Weather* (2013)
- Survey of SWPC email subscribers
- Key points:
  - Uncertainty about possible impacts of space weather and thus, how to act on the information
  - Most interested in current conditions and few-day forecasts though there is interest at all time scales
  - More likely to monitor than stop or modify operations in case of severe or extreme flares–situational awareness

Space Weather and the Vacuum Ultraviolet (VUV)

The VUV (1-200 nm) is highly variable across many timescales and is an important input for atmospheric models.



LEO

Credit: R. Viereck/SWPC/NOAA

Propagation of radio signals • Satellite orbit determination

Space Weather and the Vacuum Ultraviolet (VUV) - 2

- Solar flares (NOAA Radio Blackout Scale)
  - Specification
    - Location
    - Magnitude (GOES class, Hα importance)
  - Prediction: When and where is a flare of a certain magnitude going to occur?

- Input for atmospheric models
  - Direct input via “Stan” bands, Torr and Torr bands, etc.
  - Proxy models: $F_{10.7}$, Mg II core-to-wing, sunspot number, etc.

Using Magnetic Indices as Proxies for Solar Irradiance

Total Solar Irradiance

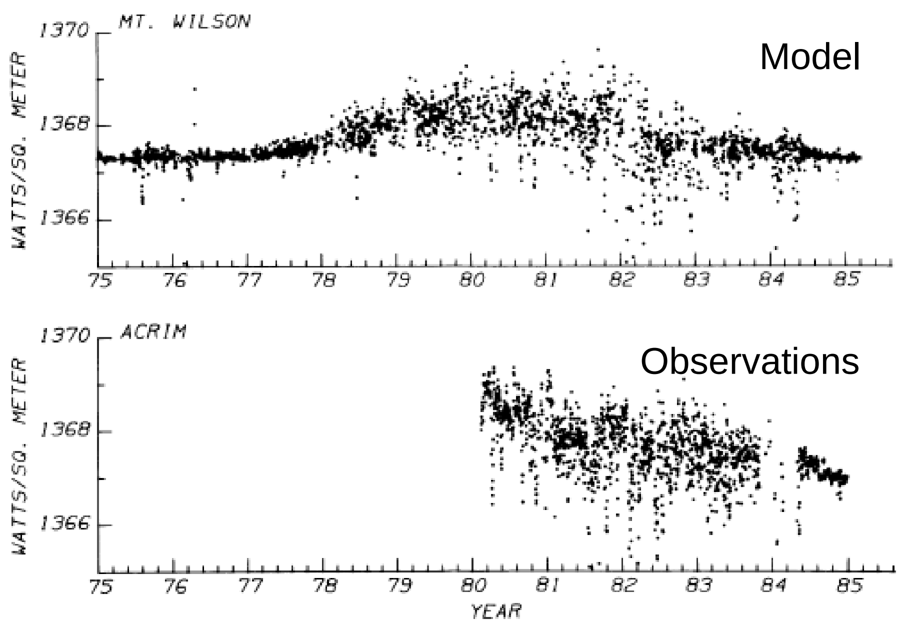


Figure from Chapman & Boyden (*ApJ, 302, L71, 1986*); they modeled solar irradiance variations using “Plage” and “Sunspot” fields from magnetograms:

Solar 10.7 cm Radio Flux

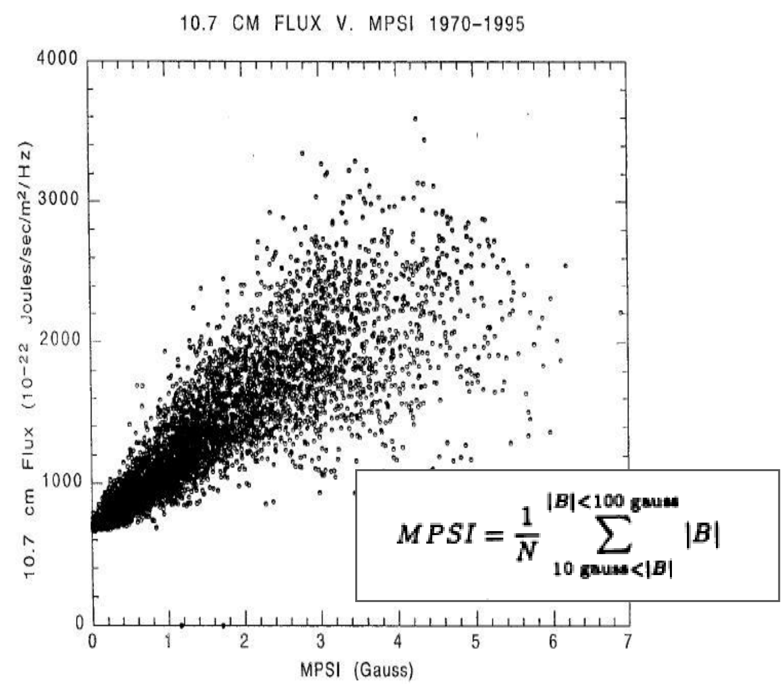


Figure 2. The scatter plot of the MPSI versus the $F_{10.7}$ for the period 1970–1995. The scatter increases with increased activity.

Figure from Parker, Ulrich, and Pap (1998), based on earlier work by Ulrich (1991), comparing plage fields with observed F10.7

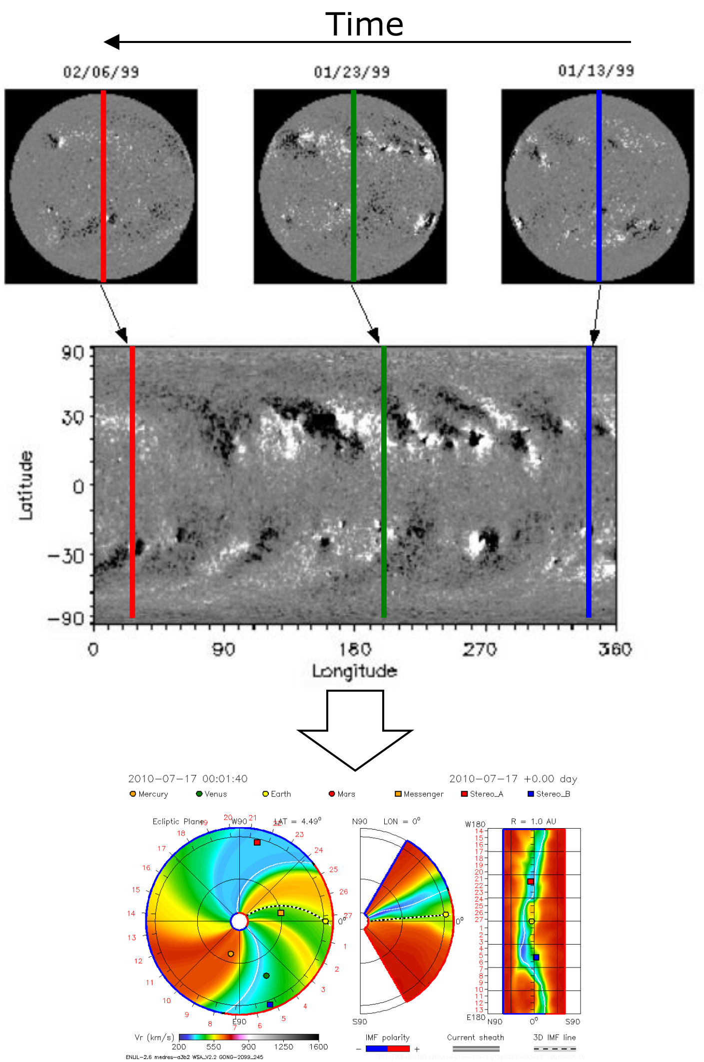
Global Solar Magnetic Maps

Until we have STEREO-like magnetograph observations, the global solar magnetic field can only be recorded for approximately half of the solar surface at any given time.

Typically, global solar magnetic maps:

- Are created by remapping line-of-sight full-disk magnetograms using the assumption that the magnetic field is radial.
- Employ a "solid body" rotation rate of 27.2753 days (commonly referred to as Carrington synoptic map).
- Include old data (i.e., 13 days to ~5 months) for equatorial to polar regions, respectively.

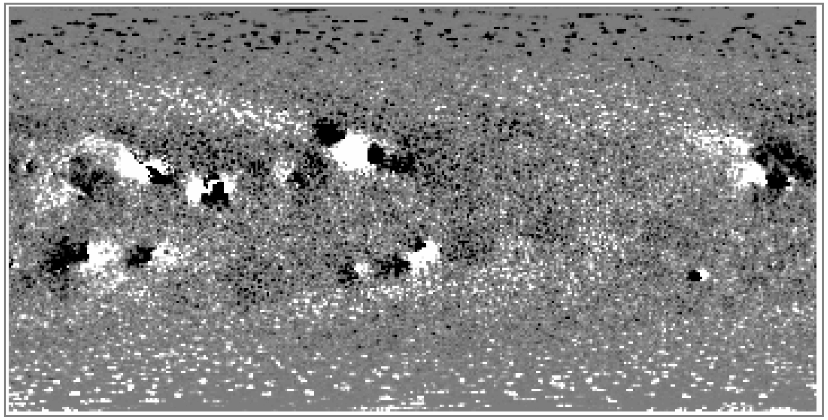
As the input boundary condition for coronal and solar wind models, synoptic map artifacts have tremendous influence on background wind estimates and with CME arrival time forecasts.



WSA-Enlil

Air Force Data Assimilative Photospheric Flux Transport

ADAPT generates global solar photospheric magnetic maps:



An example global solar magnetic map (360°×180°) created by ADAPT.

ADAPT is based on the solar magnetic flux transport model by Worden & Harvey (WH; 2000, Solar Physics, 195, 247). The WH model accounts for:

- Differential rotation
- Meridional circulation
- Super-granular diffusion
- Weak field random flux emergence

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

$F_{10.7}$ Empirical Model

The F10.7 empirical model, from Henney *et al.* 2012, uses the Earth-side magnetic fields from the ADAPT maps:

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

where

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

Contribution from solar <u>P</u>lage

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

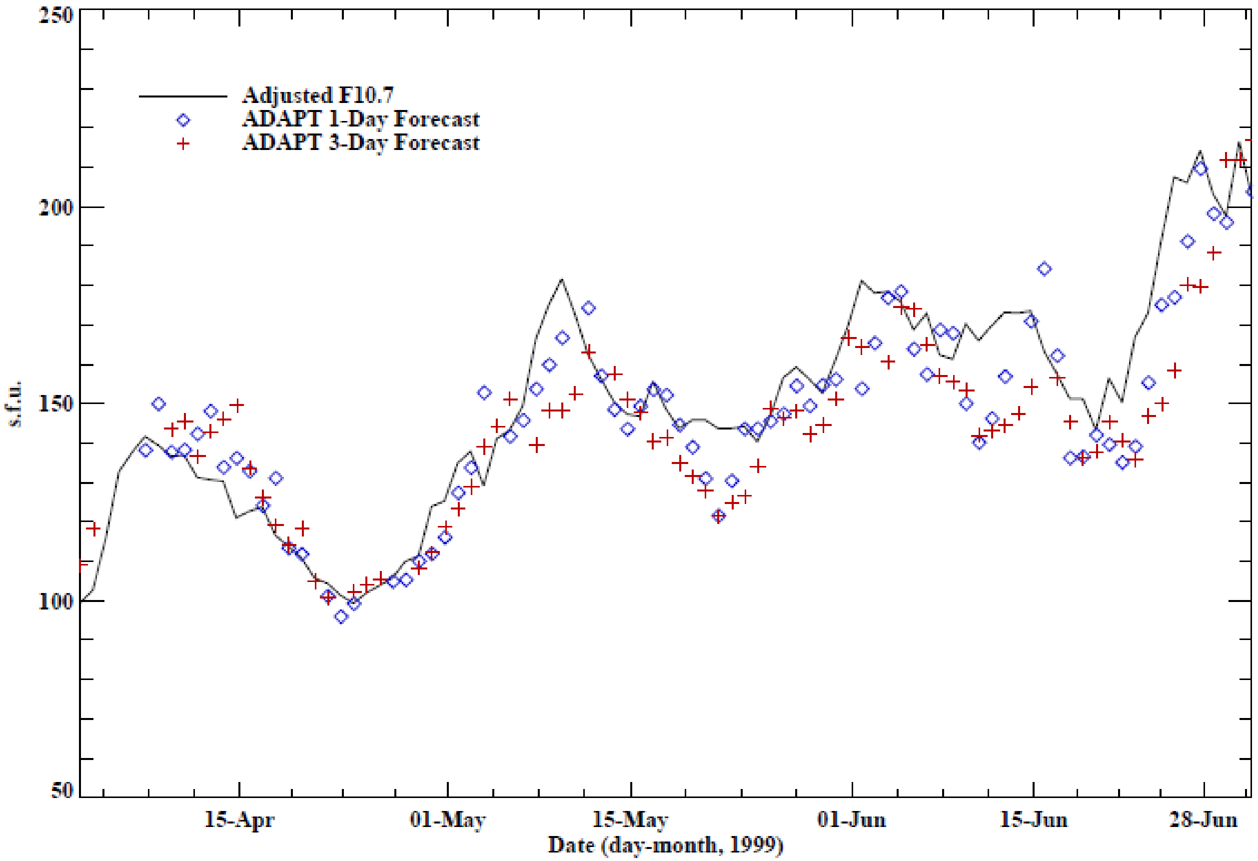
Contribution from solar <u>A</u>ctive region

Solar radial magnetic field from ADAPT

For more details, see Henney et al. 2012, Space Weather, 10, S02011

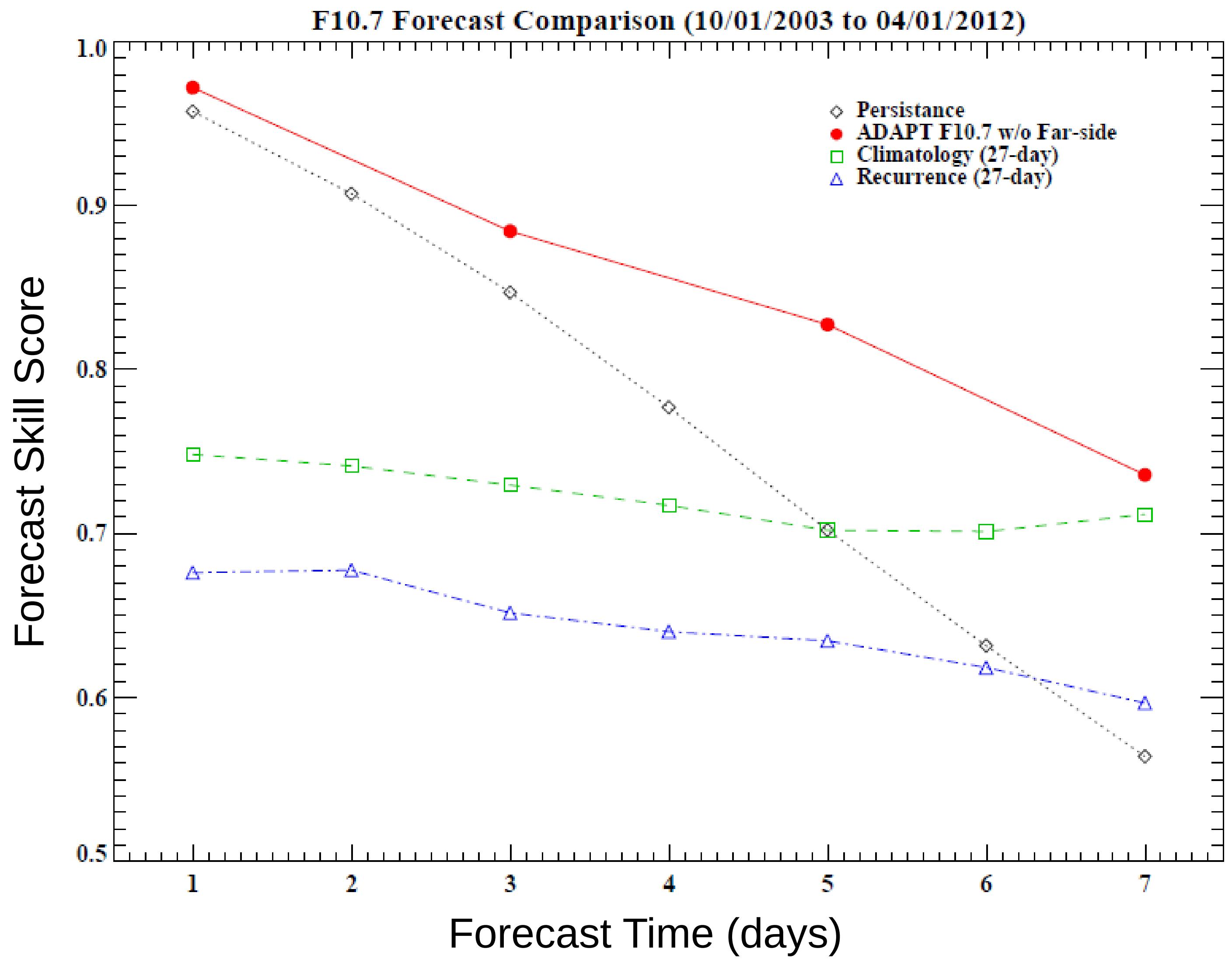
Forecasting $F_{10.7}$

3-Month Comparison

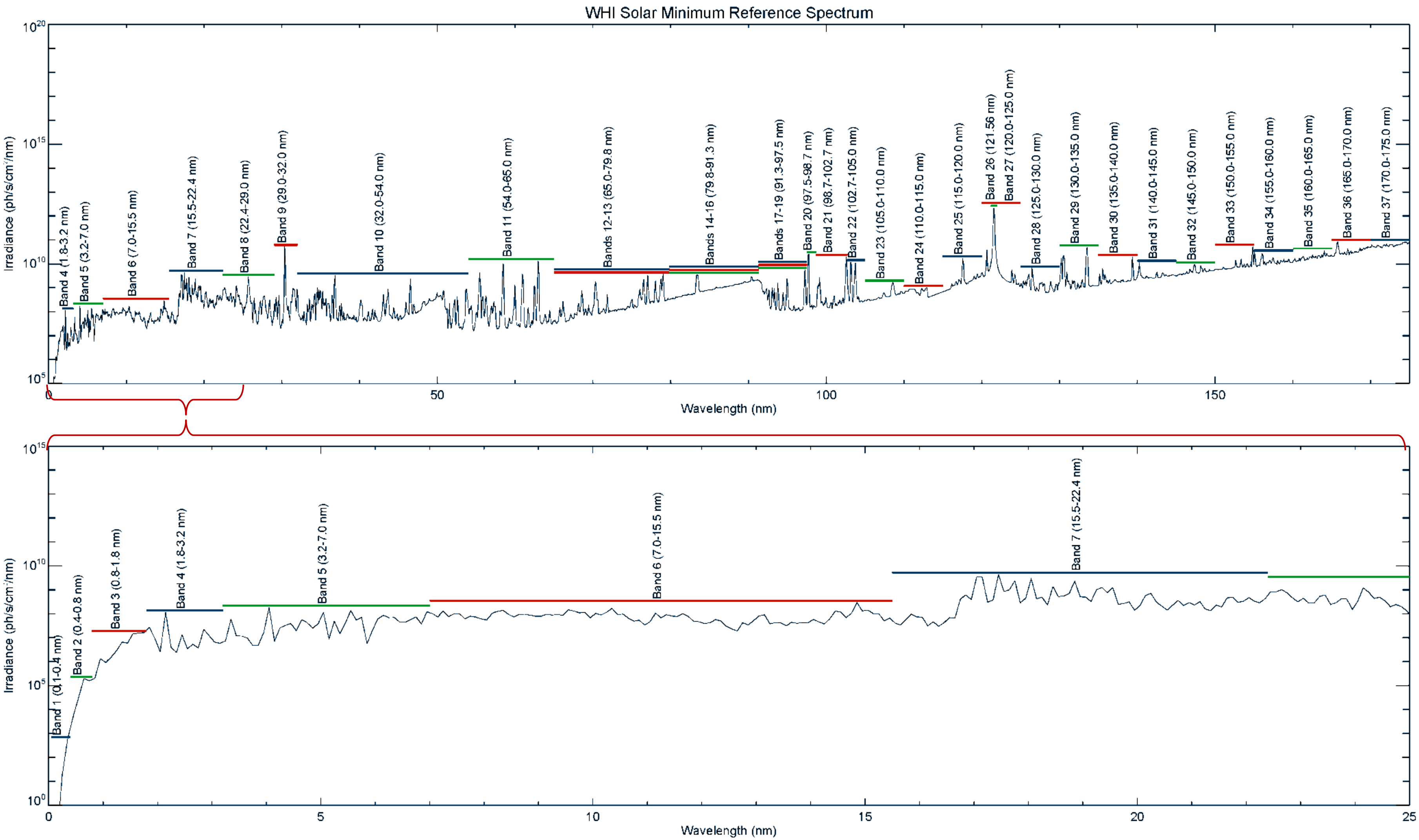


ADAPT 1-day (diamond) & 3-day (+) F10.7 forecast values, from ADAPT global magnetic maps, compared with the adjusted F10.7 (solid line). Data shown for April through June 1999.

Forecasting Skill Score for F10.7



Binning the VUV Spectrum for Atmospheric Models

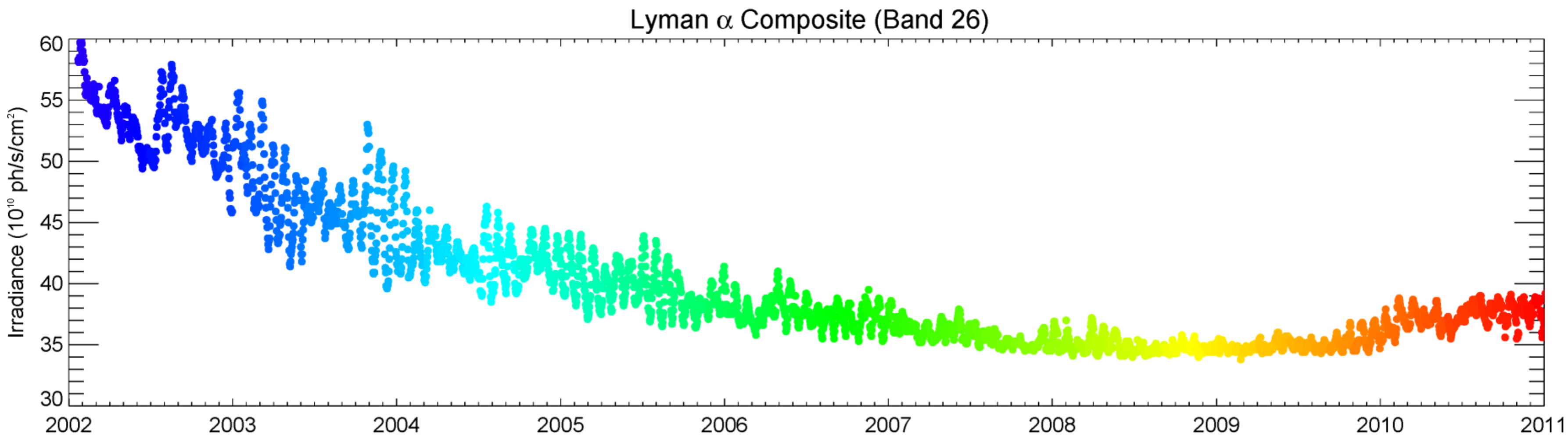


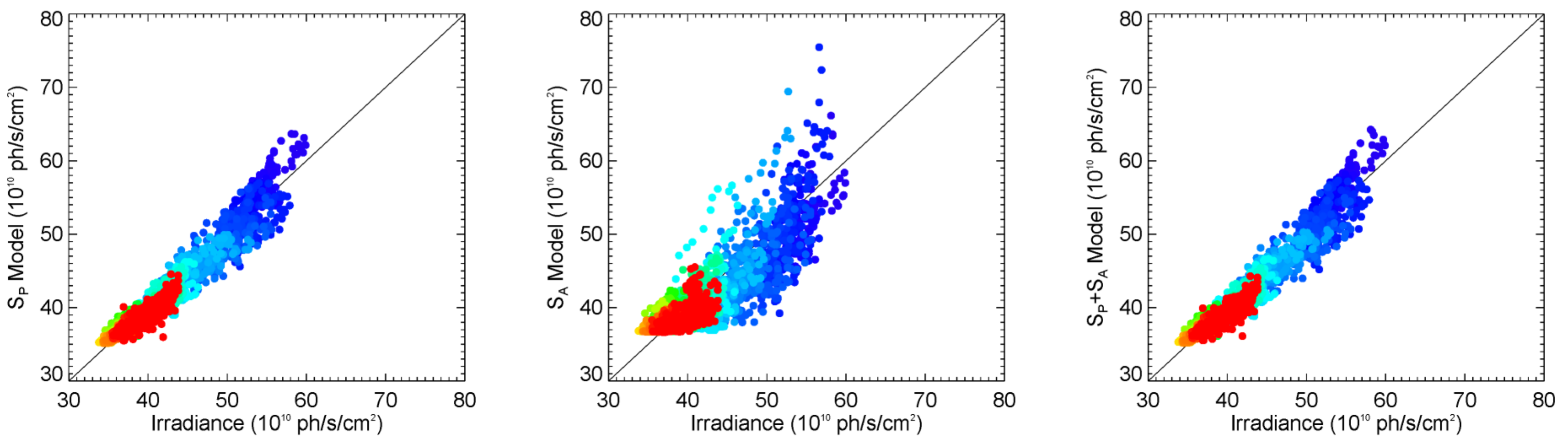
DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

TIMED SEE

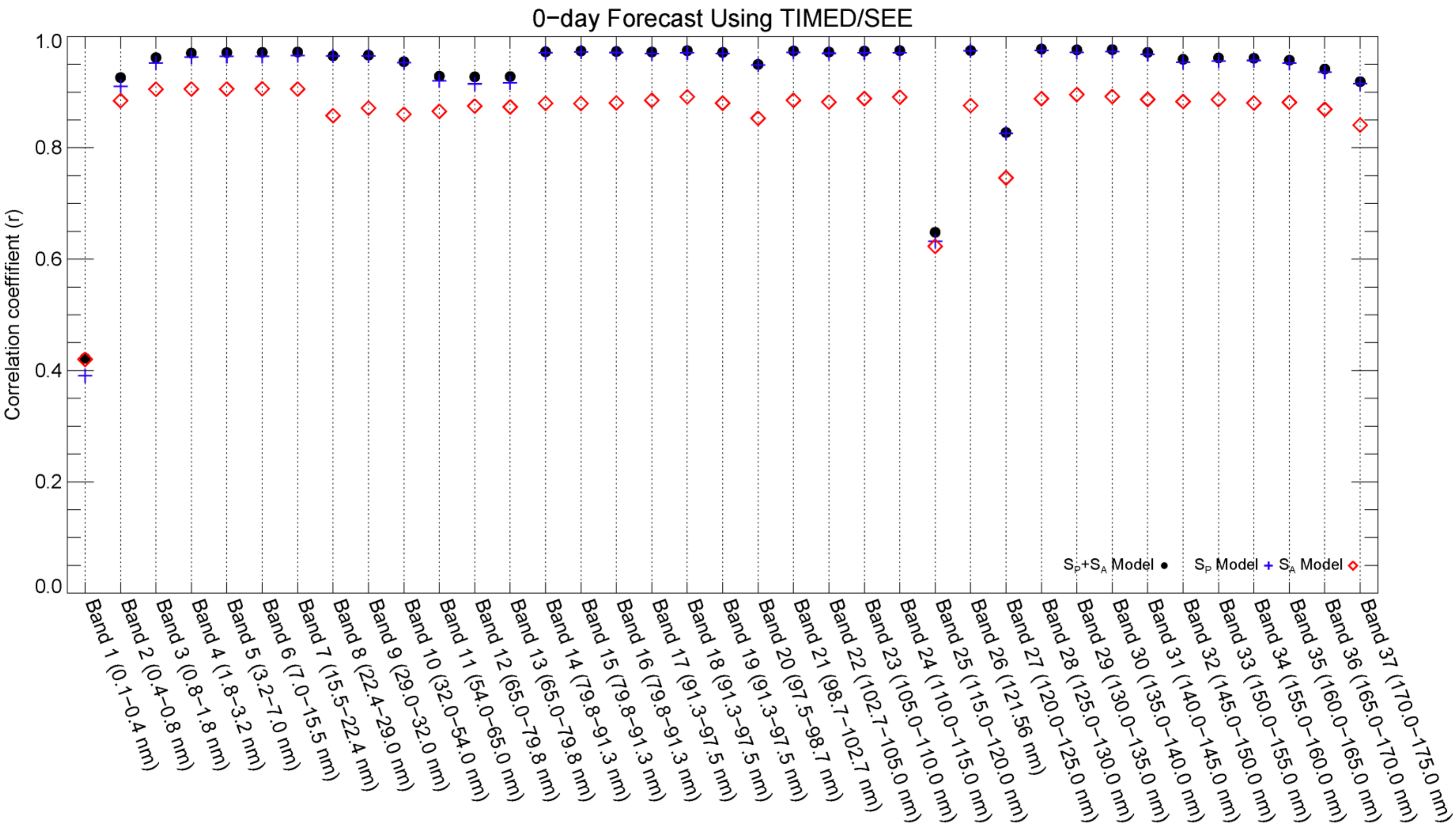
- VUV spectral irradiance from 2002-present (our analysis stops at 2011)
- Instruments:
  - EUV Grating Spectrograph (EGS)
    - 25 to 200 nm
    - 0.4 nm spectral resolution
  - XUV Photometer System (XPS)
    - Broadband photometers: 0.1-7 nm, 0.1-10 nm
- Data products:
  - 0-27 nm at 0.1 nm bins using XPS broadband data & CHIANTI model
  - 27-200 nm at 0.1 nm bins using EGS spectral *data*
  - Cadence:
    - Daily averages (flares removed)
    - Observational averages (3 minutes every ~90 minute orbit)

Example: Modeling Lyman α

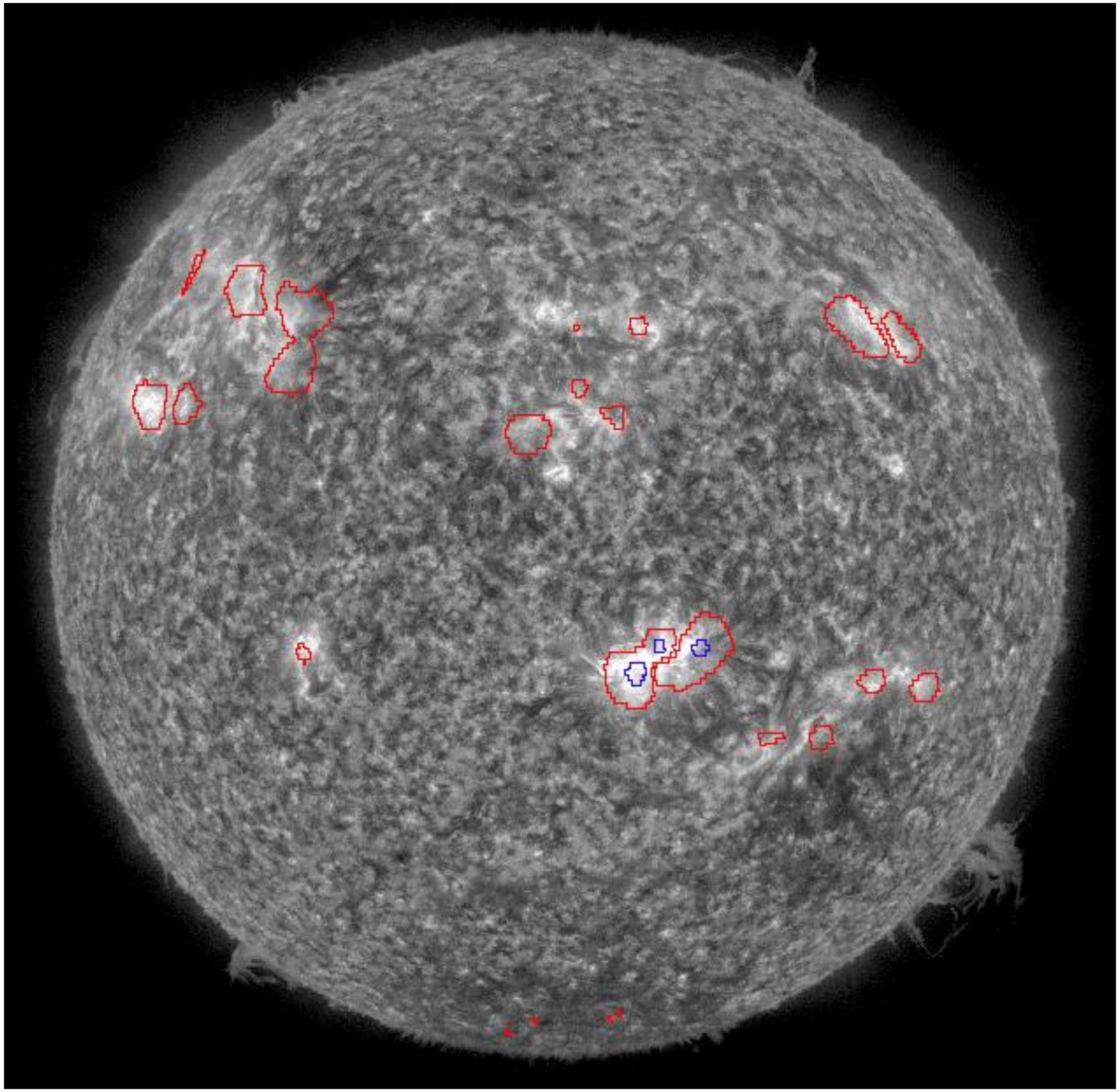




Effect of Different Components

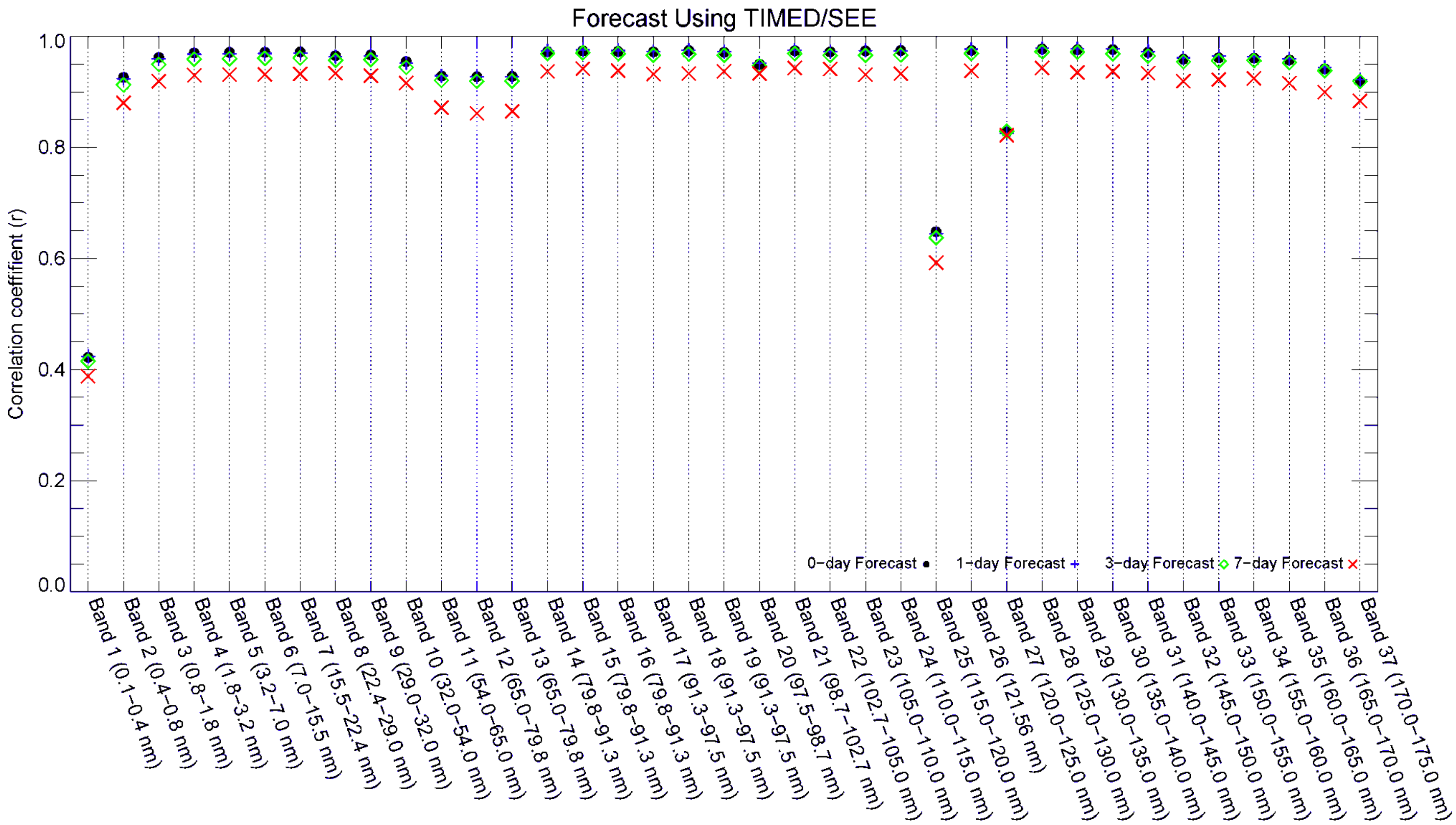


Effect of Different Components

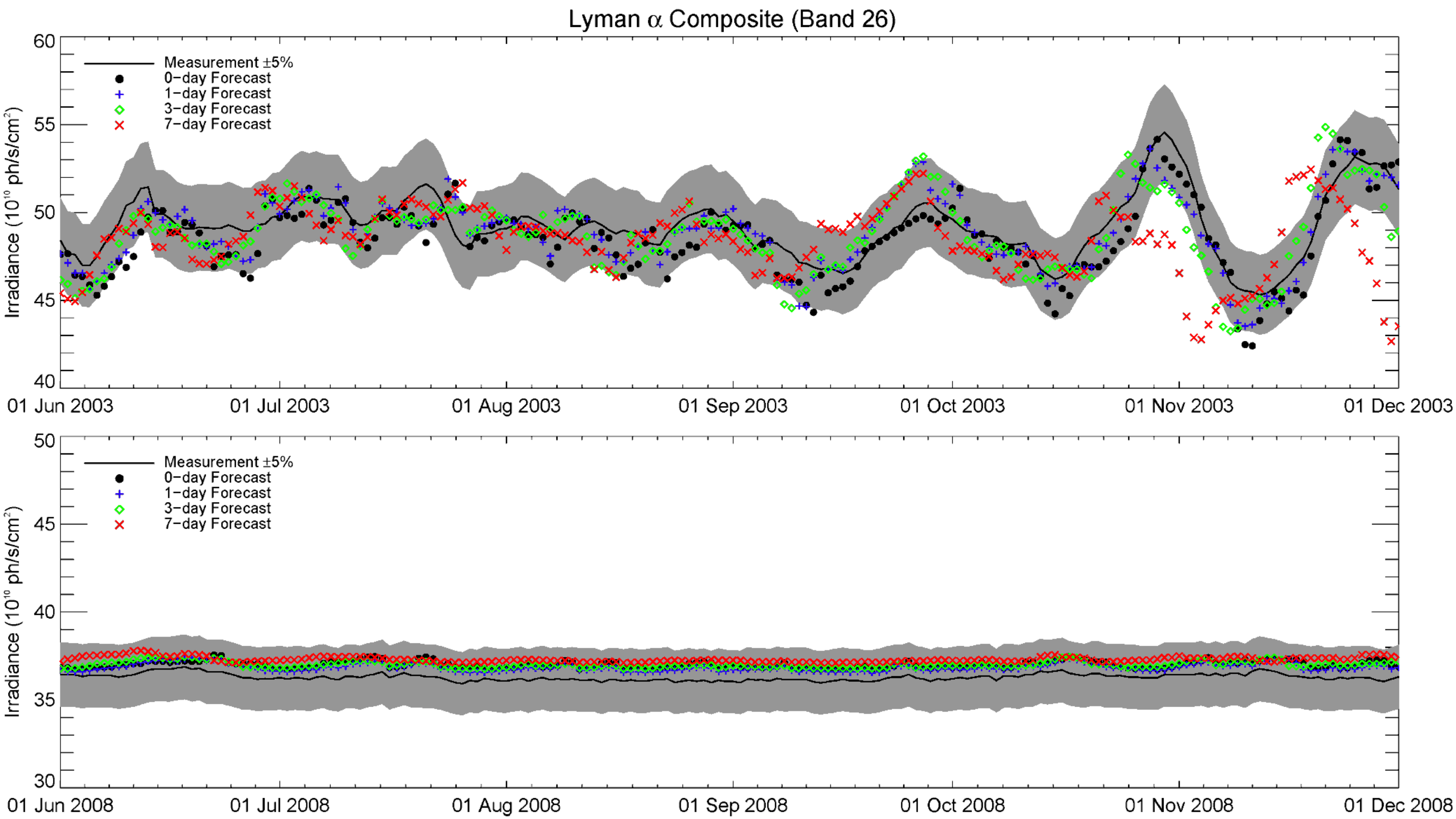


S_A
S_P

Correlations for Forecasting



Example: Forecasting Lyman α



Next Steps

- Explore the sensitivity of VUV irradiance in atmospheric models (i.e. TIEGCM)
- Explore changing magnetic thresholds and/or adding features (i.e. coronal holes, over-the-limb coronal loops)
- Examine center-to-limb variations

- Incorporate data assimilation into irradiance model (0-day correction)

- Incorporate far-side imaging into ADAPT

Incorporating Farside Maps

- Without far-side data, space weather forecasting models are driven by and reliant on the persistence & recurrence of past observations.
- Far-side data assimilation requires a realistic estimation of:
  - Magnetic field strength and uncertainty.
  - Position and uncertainty (i.e., how reliable is the current result for this latitude and longitude)
- The ADAPT global maps can be updated utilizing the farside magnetic field strength & spatial position

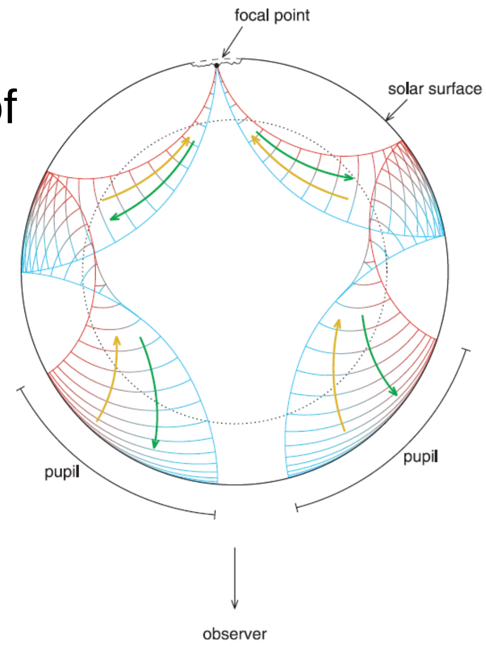
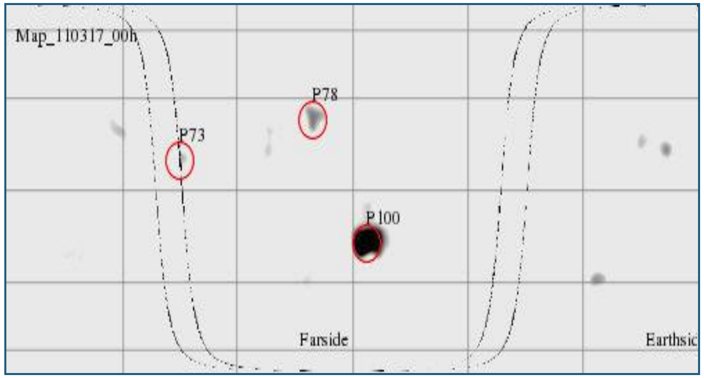
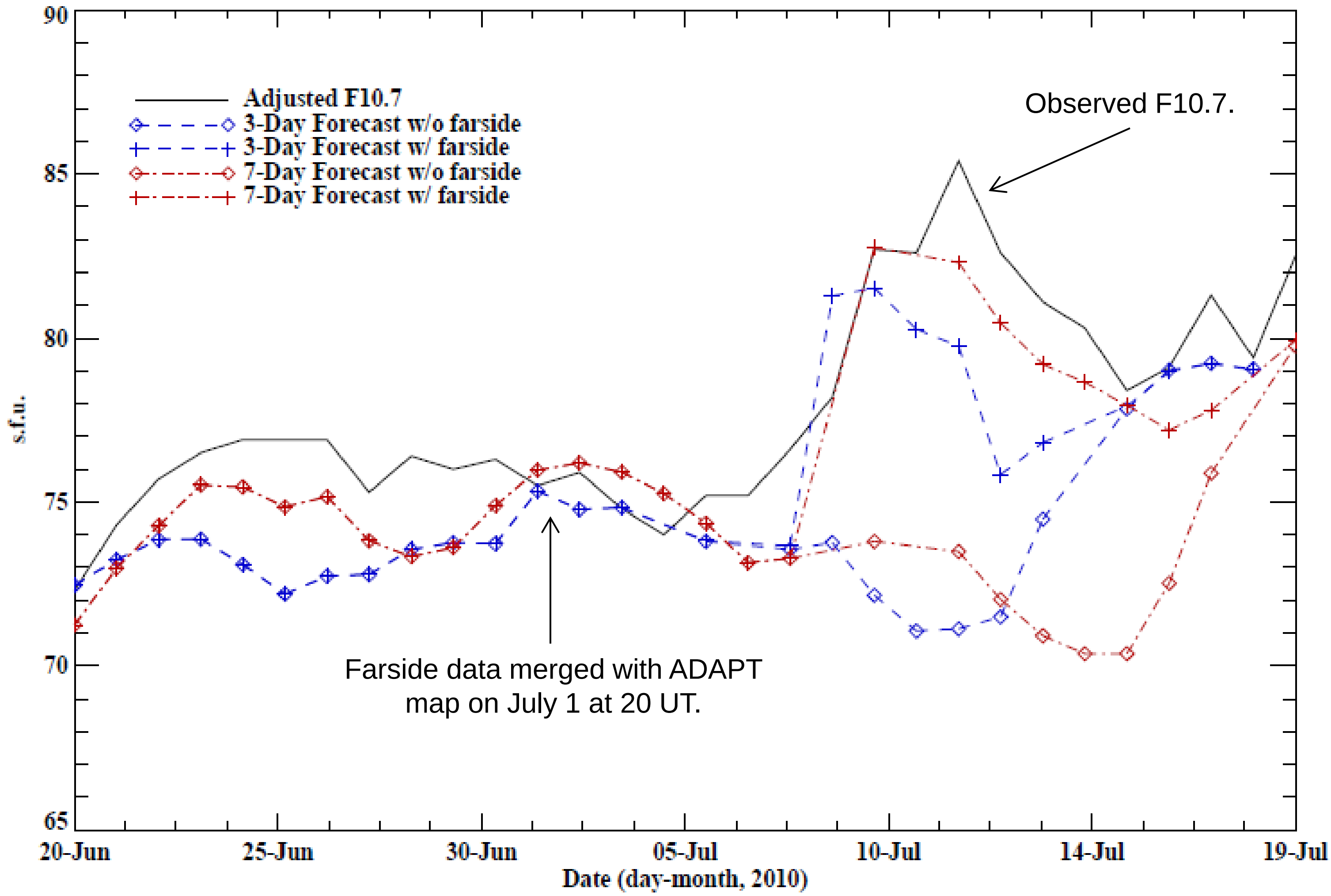


Figure from Lindsey & Braun 2000, Science, 287, 1799



$F_{10.7}$ Forecasting with Farside



Questions?

Correlations for Different Data