Forecasting Daily VUV Solar Irradiance for Atmospheric Models

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“A survey of customers of space weather information”

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

Propagation of radio signals • Satellite orbit determination

Credit: R. Viereck/SWPC/NOAA
• 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

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

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

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ADAPT generates global solar photospheric magnetic maps:

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.
The $F_{10.7}$ empirical model, from Henney et al. 2012, uses the Earth-side magnetic fields from the ADAPT maps:

$$F_{model} = m_0 + m_1 S_P + m_2 S_A$$

where

$$S_P = \frac{1}{\sum \omega_\theta} \sum_{25G < |B_r|} |B_r| \omega_\theta$$

Solar radial magnetic field from ADAPT

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

Contribution from solar Active region

Contribution from solar Plage

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

F10.7 Forecast Comparison (10/01/2003 to 04/01/2012)

- **Persistance**
- **ADAPT F10.7 w/o Far-side**
- **Climatology (27-day)**
- **Recurrence (27-day)**

Forecast Skill Score vs. Forecast Time (days)

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Binning the VUV Spectrum for Atmospheric Models

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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 $\alpha$
Effect of Different Components

0-day Forecast Using TIMED/SEE

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Effect of Different Components
Correlations for Forecasting

Forecast Using TIMED/SEE

0-day Forecast • 1-day Forecast • 3-day Forecast • 7-day Forecast 

Band 1 (0.3-0.4 mm) • Band 2 (0.6-0.8 mm) • Band 3 (0.8-1.8 mm) • Band 4 (1.8-3.2 mm) • Band 5 (3.2-7.0 mm) • Band 6 (7.3-15.5 mm) • Band 7 (15.5-22.4 mm) • Band 8 (22.4-29.0 mm) • Band 9 (29.0-65.0 mm) • Band 10 (65.0-79.8 mm) • Band 11 (79.8-91.3 mm) • Band 12 (91.3-97.5 mm) • Band 13 (97.5-102.7 mm) • Band 14 (102.7-110.0 mm) • Band 15 (110.0-120.0 mm) • Band 16 (120.0-130.0 mm) • Band 17 (130.0-140.0 mm) • Band 18 (140.0-150.0 mm) • Band 19 (150.0-165.0 mm) • Band 20 (165.0-170.0 mm) • Band 21 (170.0-175.0 mm)

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Example: Forecasting Lyman $\alpha$

Lyman $\alpha$ Composite (Band 26)

- Measurement ±5%
- 0-day Forecast
- 1-day Forecast
- 3-day Forecast
- 7-day Forecast

Irradiance (10$^{-10}$ ph/s/cm$^2$)

01 Jun 2003 to 01 Dec 2003

01 Jun 2008 to 01 Dec 2008

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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
Forecasting with Farside

F$_{10.7}$ data merged with ADAPT map on July 1 at 20 UT.

Observed F$_{10.7}$. 
Questions?
Correlations for Different Data

0-day Forecast S_p+S_A Model

Correlation coefficient (r)

Band 1 (0.17-0.4 mm)
Band 2 (0.4-0.8 mm)
Band 3 (0.8-1.8 mm)
Band 4 (1.8-3.2 mm)
Band 5 (3.2-5.5 mm)
Band 6 (5.5-7.0 mm)
Band 7 (7.0-15.5 mm)
Band 8 (15.5-29.4 mm)
Band 9 (29.4-50.0 mm)
Band 10 (50.0-85.0 mm)
Band 11 (85.0-193.0 mm)
Band 12 (193.0-320.0 mm)
Band 13 (320.0-540.0 mm)
Band 14 (540.0-910.0 mm)
Band 15 (910.0-1450.0 mm)
Band 16 (1450.0-2150.0 mm)
Band 17 (2150.0-3500.0 mm)
Band 18 (3500.0-5500.0 mm)
Band 19 (5500.0-8500.0 mm)
Band 20 (8500.0-11000.0 mm)
Band 21 (11000.0-14500.0 mm)
Band 22 (14500.0-19500.0 mm)
Band 23 (19500.0-27500.0 mm)
Band 24 (27500.0-37500.0 mm)
Band 25 (37500.0-47500.0 mm)
Band 26 (47500.0-57500.0 mm)
Band 27 (57500.0-67500.0 mm)
Band 28 (67500.0-77500.0 mm)
Band 29 (77500.0-87500.0 mm)
Band 30 (87500.0-97500.0 mm)
Band 31 (97500.0-107500.0 mm)
Band 32 (107500.0-117500.0 mm)
Band 33 (117500.0-127500.0 mm)
Band 34 (127500.0-137500.0 mm)
Band 35 (137500.0-147500.0 mm)
Band 36 (147500.0-157500.0 mm)
Band 37 (157500.0-167500.0 mm)

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