Developing a Proxy Model for Solar EUV Irradiance

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Abstract

Several instruments are able to measure the full EUV spectrum at sufficient wavelength resolution for those interested in upper-atmosphere modeling, the effects of space weather, and modeling satellite drag. No missions are planned at present to succeed TIMED and SDO, which currently provide this data source. In order to develop a suitable replacement for these measurements, we use the magnesium core-to-wing ratio from SORCE SOLSTICE as well as broad-band EUV measurements made by the NOAA GOES satellite to model the EUV spectrum from 0.1-105 nm at 5 nm resolution. Using a Levenberg-Marquardt least squares fitting algorithm, we determined a matrix of coefficients that could be multiplied by our input data time series to produce our output data time series. As inputs, we used the SORCE Mg II index, the GOES EUVS-B, EUVS-E, XRS-A, and XRS-B channels as well as 40-day backwards smoothed versions of these time series to provide operationally useful data with the Carrington rotation dependence removed. We fit to the observed spectrum from TIMED SEE and SDO EVE for the full 2012 year. Applying this model to 2011 and the first six months of 2013, we found that the correlation between the model predictions and the observed spectrum was above 90% for the 0.1-50 nm range, and between 60% and 90% for the 50-105 nm range. These results provide a very promising potential source for an empirical EUV spectral model after direct measurements are no longer available.

Objectives

- For 20 5-nm bins between 5 and 105nm, determine a set of weights that will convert a linear combination of input data into the desired output data
- Use these weights as a proxy model for EUV that, because it includes EUV data, will be more accurate and dynamic then an F10.7 proxy alone
- Test this model's effectiveness when compared to other common EUV models and proxies: sunspot number, F10.7 index, EUVAC model [1], SOLAR2000 model [2], FISM model [3]

Artist's conception of GOES satellite, where much of our input data comes from. Photo courtesy NASA and Lockheed Martin.

[1] Richards, P. G., J. A. Fennelly, and D. G. Torr (1994), EUVAC: A solar EUV flux model for aeronomic calculations, J. Geophys. Res., 99, 8981.

[2] Tobiska, W. K., T. N. Woods, F. G. Eparvier, R. Viereck, L. Floyd, D. Bower, G. J. Rottman, and O. R. White (2000), The SOLAR2000 empirical solar irradiance model and forcast tool, J. Atmos. Sol.Terr. Phys., 62, 1233.

[3] Chamberlin, P. C., T. N. Woods, and F. G. Eparvier (2007), Flare Irradiance Spectral Model (FISM): Daily component algorithms and results, Space Weather, 5, S07005

Model

- Recreate the EUV irradiance in each bin by using least-squares analysis to fit observed irradiance from to broadband GOES-15 EUVS & XRS data and current proxies
- Use 2012 measurements to find weights for: observed irradiance in a 5nm band = weight 1 (offset) + weight 2*XRS-A + weight 3*XRS-B + weight 4*EUVS-B + weight 5 * EUVS-B 40-day smooth + weight 6*EUVS-E + weight 7*EUVS-E 40-day smooth + weight 8* SORCE Mg II index + weight 9* SORCE Mg II 40-day smooth
- Fitting algorithm returns an array of fitting weights; 9 columns of weights by 21 rows of bins
- Use these weights multiplied by today's proxy data to obtain a prediction for the EUV flux

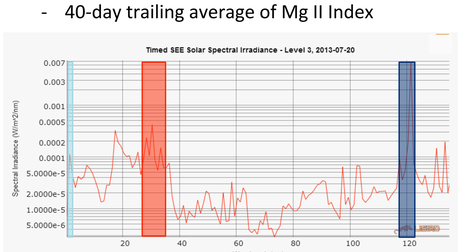
Data Sets

Reference Spectra

Wavelength Range	Reference Data
0.1 – 6 nm	TIMED SEE Integrated Spectrum*
6 – 40 nm	SDO EVE Time Series
40 – 105 nm	TIMED SEE Time Series

Input Data Sets

- NOAA GOES XRS-A Channel
- NOAA GOES XRS-B Channel
- NOAA GOES EUVS-B Channel (includes He II line)
- NOAA GOES EUVS-E Channel (includes Ly-α line)
- Mg II Index from SORCE SOLSTICE
- 40-day trailing average of EUVS-B
- 40-day trailing average of EUVS-E
- 40-day trailing average of Mg II Index



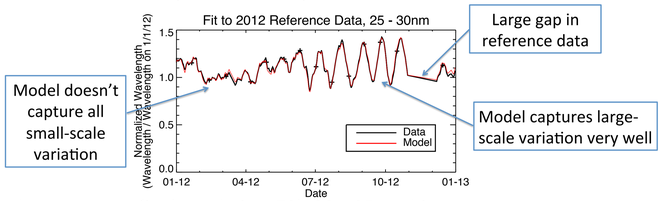
- Fitting algorithm: mpfit for IDL
  - Developed by Craig Markwardt [4], based on the Levenberg-Marquardt algorithm (damped least-squares method)

- [4] Markwardt, C. B. 2009, 'Non-Linear Least Squares Fitting in IDL with MPFIT,' in proc. *Astronomical Data Analysis Software and Systems XVIII*, Quebec, Canada, ASP Conference Series, Vol. 411, p. 251-254.

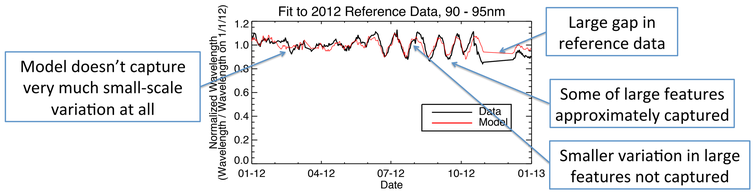
Results

Fit to 2012 Reference Spectra

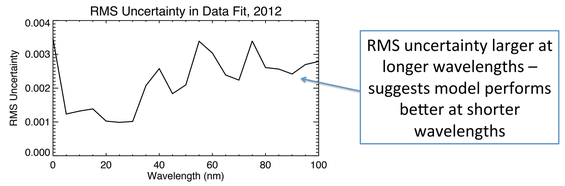
- Essential for initial fit to be accurate, as this is what determines the fitting coefficients
- Inaccuracies in initial fit will likely produce inaccuracies in the model predictions for that band
- One of the more accurate fits (correlation .98): 25 - 30 nm bin



- One of the least accurate fits (correlation .73): 90 – 95 nm bin

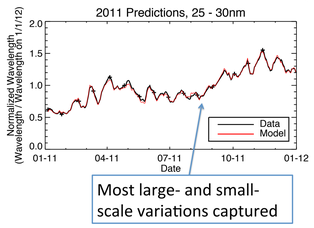


- Instead of showing graphs of all other bands, we provide a plot of the RMS error between the model and data for each wavelength bin

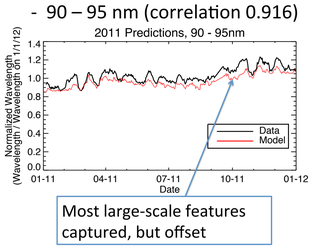


2011 Model Predictions

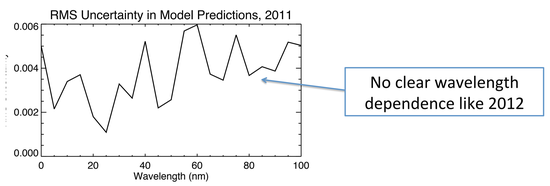
- Next, used weights from fitting to 2012 to predict 2011 data
  - 25 – 30 nm (correlation 0.997)



  - 90 – 95 nm (correlation 0.916)

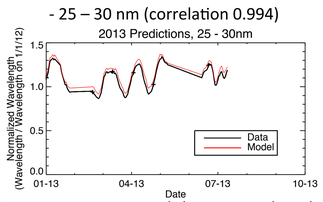


- Again, we examine the RMS difference between the model and the data

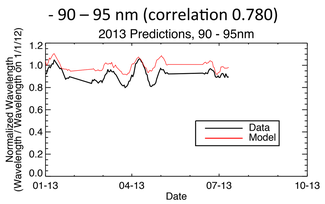


2013 Model Predictions

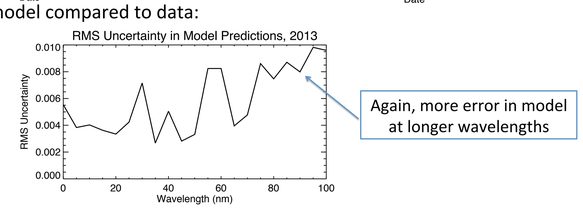
- Used weights from 2012 to predict data from the first half of 2013
  - 25 – 30 nm (correlation 0.994)



  - 90 – 95 nm (correlation 0.780)



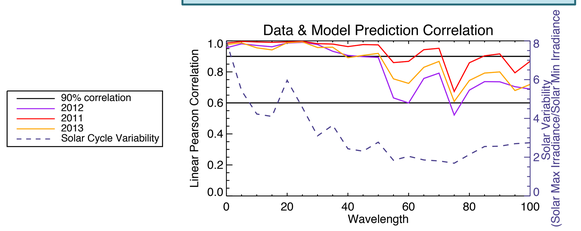
- RMS uncertainty in model compared to data:



- All three years suggest that the model is more accurate below ~50 nm

Discussion

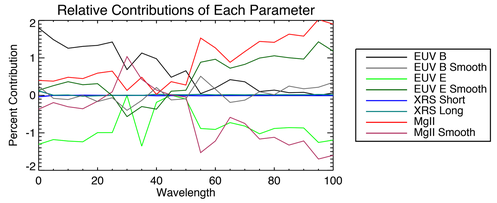
Linear Correlation Coefficient



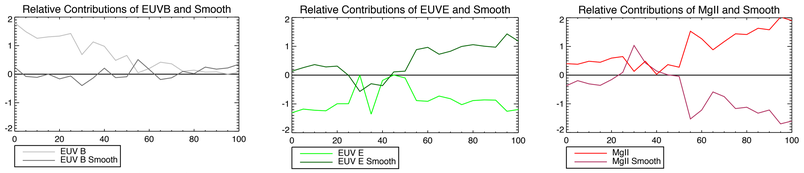
- Correlation for all three years is above 90% for wavelengths below 50 nm
- Correlation then drops, remaining between about 60% and 90% for 50 – 105 nm
- However, solar variability has opposite trend – most variable (therefore most important to model) wavelengths have the best correlation
- Even at longer wavelengths, model can be used as a guide for EUV irradiance; at shorter wavelengths, it can very accurately predict irradiance

Relative Contributions of Each Input

Some inputs add, some subtract to make the total contribution



- As expected, XRS bands important only at very short wavelengths
- Trends in input and the smoothed input tend to counteract each other:

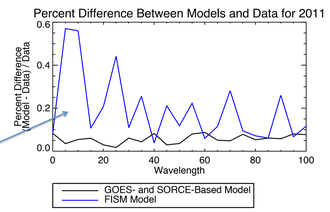


- This has the effect of making inputs that originally showed limb darkening show limb brightening, which is characteristic of EUV irradiance

Comparison to FISM Model

- FISM (Flare Irradiance Spectral Model) developed as model for solar irradiance 0.1 – 190 nm
  - Uses one proxy per 1-nm bin to predict irradiance in that bin
- The use of real-time EUV measurements from GOES as well as the dependence of each bin on multiple proxies may allow our model a higher degree of flexibility and accuracy than FISM
- When comparing the two models, we found that our model had up to 8% higher correlation at shorter wavelengths, and the FISM model had ~3-4 % better correlation at longer wavelengths

FISM model differs more from data at shorter wavelengths, where our model performs better



- Unclear whether some of the short-wavelength differences between FISM and our model originate from inconsistencies between the reference data sets (SDO-EVE for our model, TIMED-SEE for the FISM model)
- Both models have drops in accuracy past ~50 nm – possible that there is not very good data at this range, or that proxies and inputs are not available in this region

Conclusions

- Assuming that EUV irradiance can be modeled as a linear combination of input data sets and proxies is both effective and computationally efficient
- Predictions for 0.1 – 50 nm could be made with a high degree of accuracy (< 4% difference between data and model predictions)
- Predictions for 50 – 105 nm could be made, but with less accuracy (6-10% difference between data and model predictions)
- Our model compares favorably with the FISM model
- There may be inconsistencies or errors in the reference spectrum for the 60-80 nm range, leading to difficulties in model predictions
  - EUV is difficult to measure and degredations in instruments may have not been fully accounted for