Predicting solar spectra using broadband EUV irradiance measurements

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November 30, 2022

Abstract

Soft x-ray and EUV radiation from the Sun is absorbed by and ionizes the atmosphere, creating both the ionosphere and thermosphere. Temporal changes in irradiance energy and spectral distribution can have drastic impacts on the ionosphere, impacting technologies such as satellite drag and radio communication. Because of this, it is necessary to estimate and predict changes in Solar EUV spectral irradiance. Ideally, this would be done by direct measurement but the high cost of solar EUV spectrographs makes this prohibitively expensive. Instead, scientists must use data driven models to predict the solar spectrum for a given irradiance measurement. In this study, we further develop the Synthetic Reference Spectral Irradiance Model (SynRef). The SynRef model, which uses broadband EUV irradiance data from EUVM at Mars, was created to mirror the SORCE XPS model which uses data from the TIMED SEE instrument and the SORCE XPS instrument at Earth. Both models superpose theoretical Active Region and Quiet Sun spectra generated by CHIANTI to match daily measured irradiance data, and output a modeled solar EUV spectrum for that day. By adjusting the weighting of Active Region and Quiet Sun spectra, we update the SynRef model to better agree with the FISM model and with spectral data collected from sounding rocket flights. We also use the broadband EUVM measurements to estimate AR temperature. This will allow us to select from a library of AR reference spectra with different temperatures. We present this updated SynRef model to more accurately characterize the Solar EUV and soft x-ray spectra.

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Summary

What is SynRef?

The Synthetic Reference Spectra Model, SynRef, (Thiemann et al. 2017) was developed to mirror at Mars what the SORCE XPS model does at Earth (Woods et al. 2008). It takes a broadband measurement of multiple wavelengths lumped together (either Channel B 0-7 nm or Channel A 17-22 nm from the MAVEN EUVM instrument) and combines that measurement with active sun and quiet sun spectra generated by CHIANTI to output a modeled solar Extreme Ultra-Violet (EUV) spectrum for that day.

Goal:

- Generate a predicted solar irradiance spectrum (0-105 nm) based on fundamental physics and broadband EUV (0.1-7, 17-22 nm) measurements

Problems:

- Our model has trouble predicting spectra during and around solar minimum, likely due to calibration differences. Solar irradiance during this time is lower than the model can handle, resulting in negative contributions at some wavelengths.

Solution:

- Reduce the model's quiet sun contribution so that it can better predict irradiance values at solar minimum.

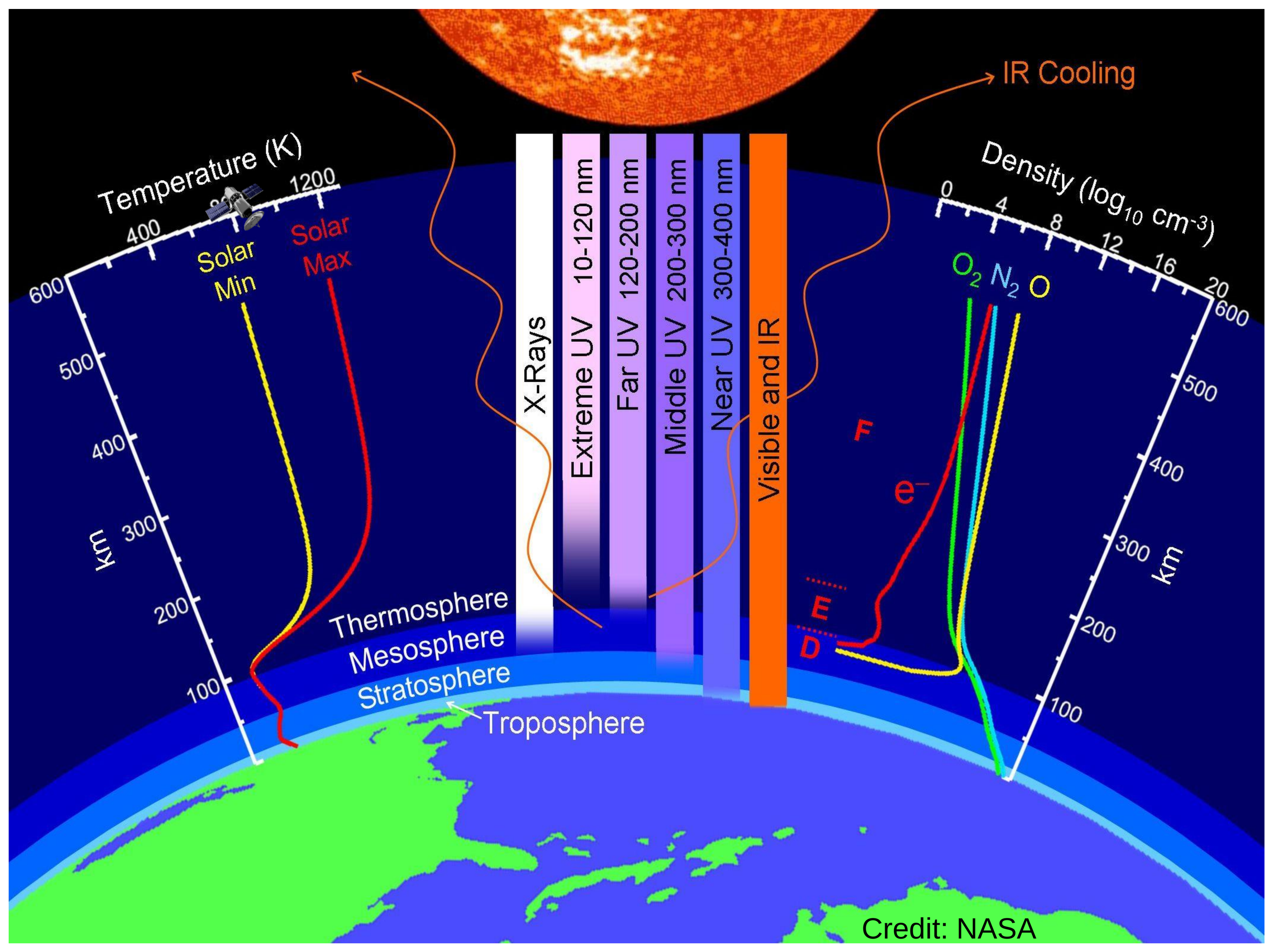
Next Steps:

- The model doesn't account for coronal holes, which appear frequently during solar minimum. Determine a way for the model to account for coronal holes.
- Compare spectra for a range of active region temperatures (currently assuming a two-temperature atmosphere)
- Combine data from both broadband channels to estimate quiet sun contribution, instead of using a single channel and assuming $f_{QS} = 1$.

Why is Solar EUV irradiance important?

EUV radiation (0.1-120 nm) from the sun ionizes and heats our atmosphere, creating the ionosphere and thermosphere.
Increased heating and ionization cause the atmosphere to 'puff up', causing layers of the atmosphere to increase in height. This results in

- Increased satellite drag
- Changes in long-distance radio communication usable frequencies
- Increased atmospheric loss (Mars)



From EUV Bands to an EUV Spectrum

The Math

Irradiance from the solar disk (in soft x-ray and EUV) is a combination of irradiance from the quiet sun plus that from its active regions, each scaled by their apparent fractional area of the solar disk. An instrument's photocurrent due to the sun's irradiance can be approximated as

$$I_{measured} = f_{QS} * I_{QS} + f_{AR} * I_{AR}$$

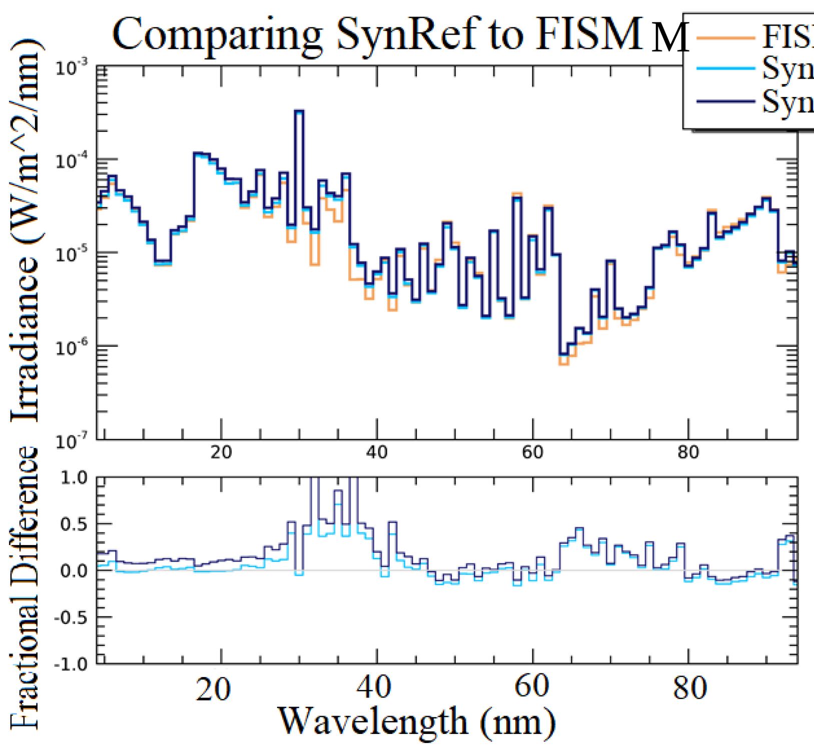
If $I_x = \int_0^\infty R(\lambda)E_x(\lambda)d\lambda$ where f represents the fraction of the solar disk covered by the feature, R is the response function of the instrument, and E is a modeled spectrum of the feature, then

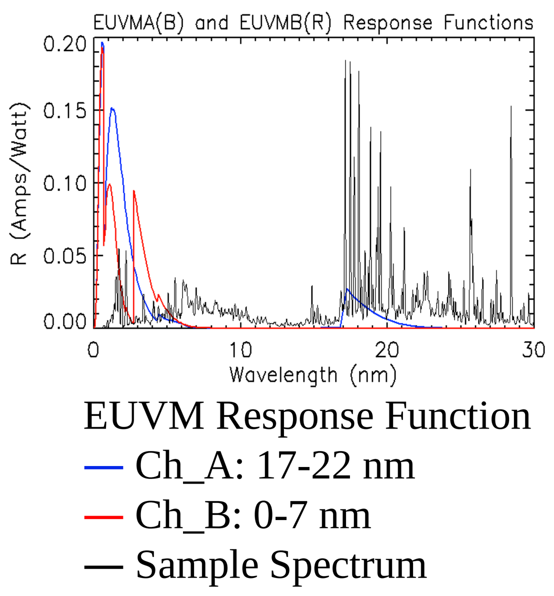
$$I_{measured}(t) = f_{QS}\int_0^\infty cR(\lambda)E_{QS}(\lambda)d\lambda + f_{AR}(t)\int_0^\infty R(\lambda)E_{AR}(\lambda)d\lambda$$

We add a correction factor, c, to scale down the quiet sun contribution. Assuming f_{AR} and f_{QS} are layered and not exclusionary and that f_{QS} covers the entire sun ($f_{QS} = 1$) then our only unknown is f_{AR}.

Once we calculate the active region fraction, we can generate a spectrum:

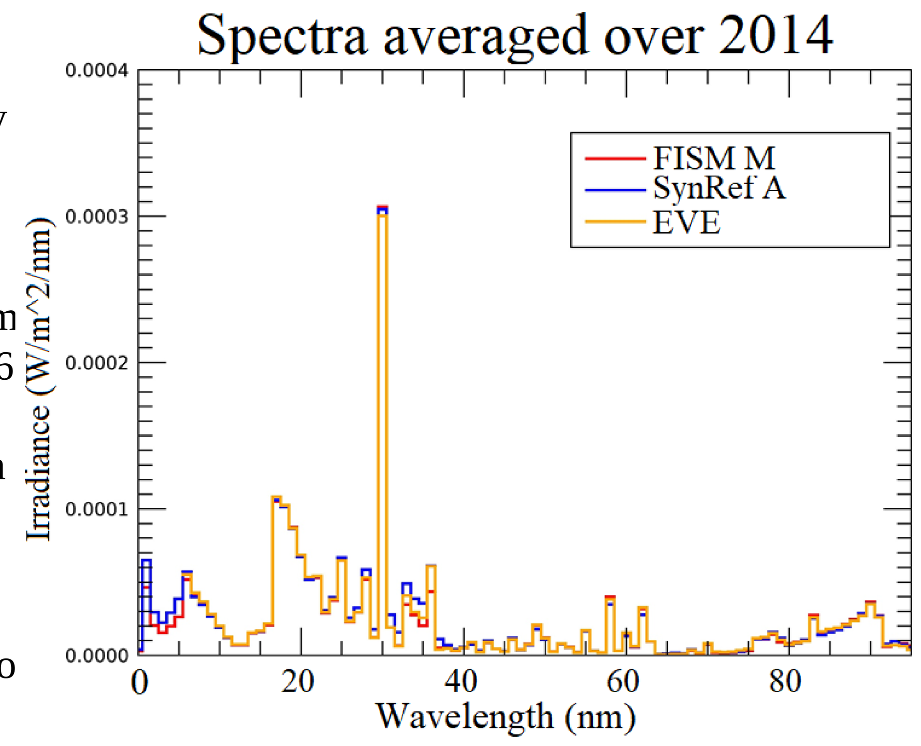
$$E_{solar} = E_{QS} + f_{AR}E_{AR}$$





Sample spectra generated by FISM M, SynRef (A Channel), and SynRef (B Channel)

Few instruments currently measure these wavelengths for comparison.
EVE measures 0.1-106 nm until 05/26/14, and 36-106 nm since 05/26/14
FISM M and SynRef both rely on data from MAVEN, which began taking data 11/15/14
Note these time periods do not overlap.

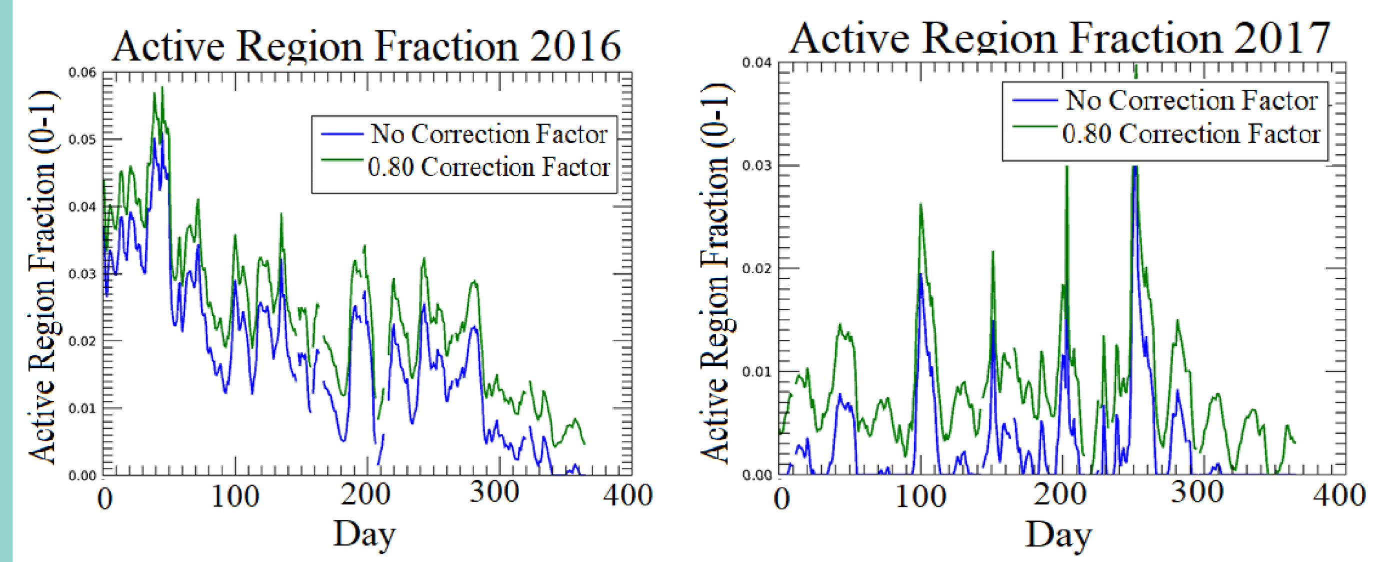


References and Acknowledgements

Eparvier, F.G., et al. (2015), *The Solar Extreme Ultraviolet Monitor for MAVEN*, Space Sci. Rev., doi:10.1007/s11214-015-0195-2 .
Thiemann, E. M. B., et al. "*The Mars topside ionosphere response to the X8. 2 solar flare of 10 September 2017.*" Geophysical Research Letters 45.16 (2018): 8005-8013.
Woods, Thomas N., et al. "*XUV Photometer System (XPS): Improved solar irradiance algorithm using CHIANTI spectral models.*" Solar Physics 250.2 (2008): 235-267.

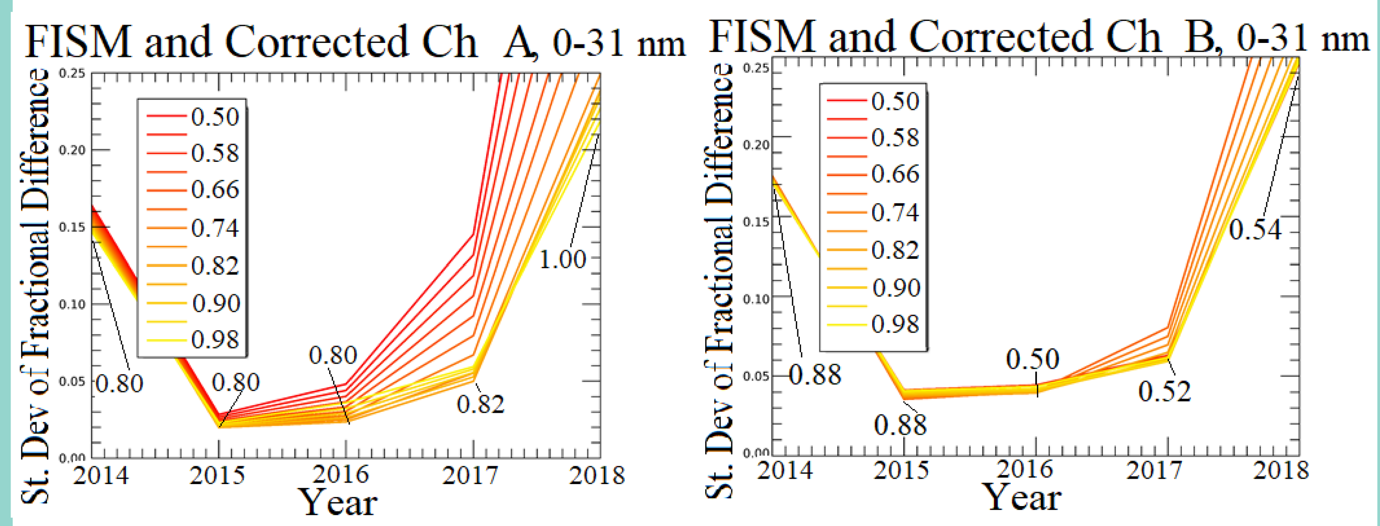
This work is sponsored by NASA grant NNX16AE86G

Scaling down the Quiet Sun contribution

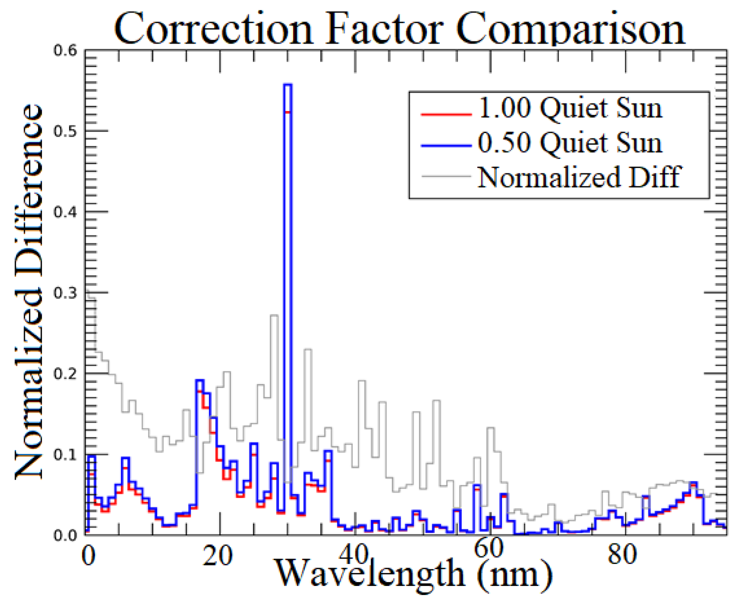


Our model was predicting solar minimum around a year too early.
To solve this, we scaled down the quiet sun contribution.

- Calibrating to the FISM-M model, we found the best correction factor for quiet sun was to reduce it to 0.80±0.02 its original value.



The high standard deviations for 2018 imply there are other factors we have not yet accounted for. We suspect coronal holes may need to be taken into account during solar minimum.



Adding the correction factor to reduce the quiet sun spectrum primarily affects wavelengths less than 60 nm by increasing irradiance at those wavelengths by 5-20% above an uncorrected spectrum

Conclusions

- In order for our model to more accurately generate a solar irradiance spectrum from broadband EUV measurements, the quiet sun reference spectrum input needs be reduced.
- Including this correction factor both:
  - keeps our prediction for active region fraction of the sun from becoming negative during solar minimum.
  - brings us more in line with what FISM M predicts, though we still need to address the issue of coronal holes in 2017 and 2018.
- **The correction factors which bring SynRef's generated spectra most in line with FISM M are as follows:**
  - **c_a: 0.80±0.02**
  - **c_b : 0.88±0.02**
- Calibration differences between MAVEN, EVE, and FISM M may be a source of the differences between the generated spectra.