Developing a Proxy Model for Solar EUV Irradiance

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Outline

- Background & Motivation
- Objectives & Model
- Procedures & Considerations
- Methods & Materials
- Results
- Discussion
- Future Work
- Conclusions
- Acknowledgements & Questions

Background

- Extreme UltraViolet (EUV) is a major driver of the Ionosphere/Thermosphere (I/T) system, along with geomagnetic storms and forcing from the lower atmosphere
- Modeling the I/T system is important for developing forecast models for customers who operate technologies affected by space weather

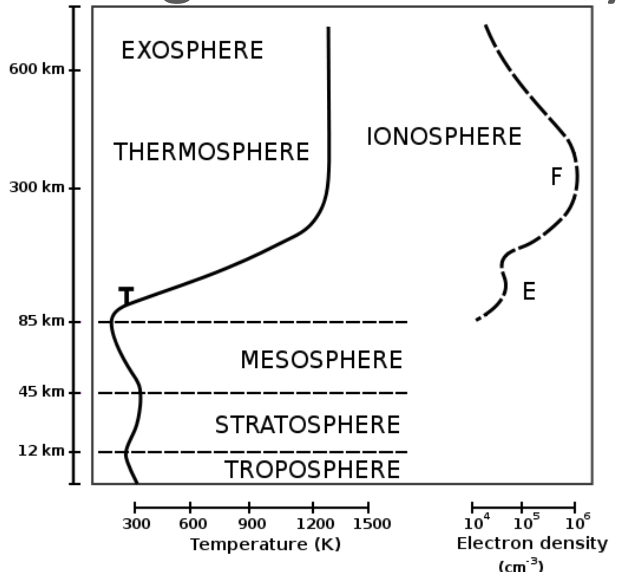


Image: Wikipedia

Background

- Space weather can have significant effects on Earth
  - GPS accuracy
  - HF communication
  - Power grids
  - Satellite drag
  - Aviation
  - Manned spacecraft
  - Aurora

Rosing, Norbert. *Northern Lights, Churchill, Canada*. N.d. Photograph. National GeographicWeb. 23 Jul 2013.

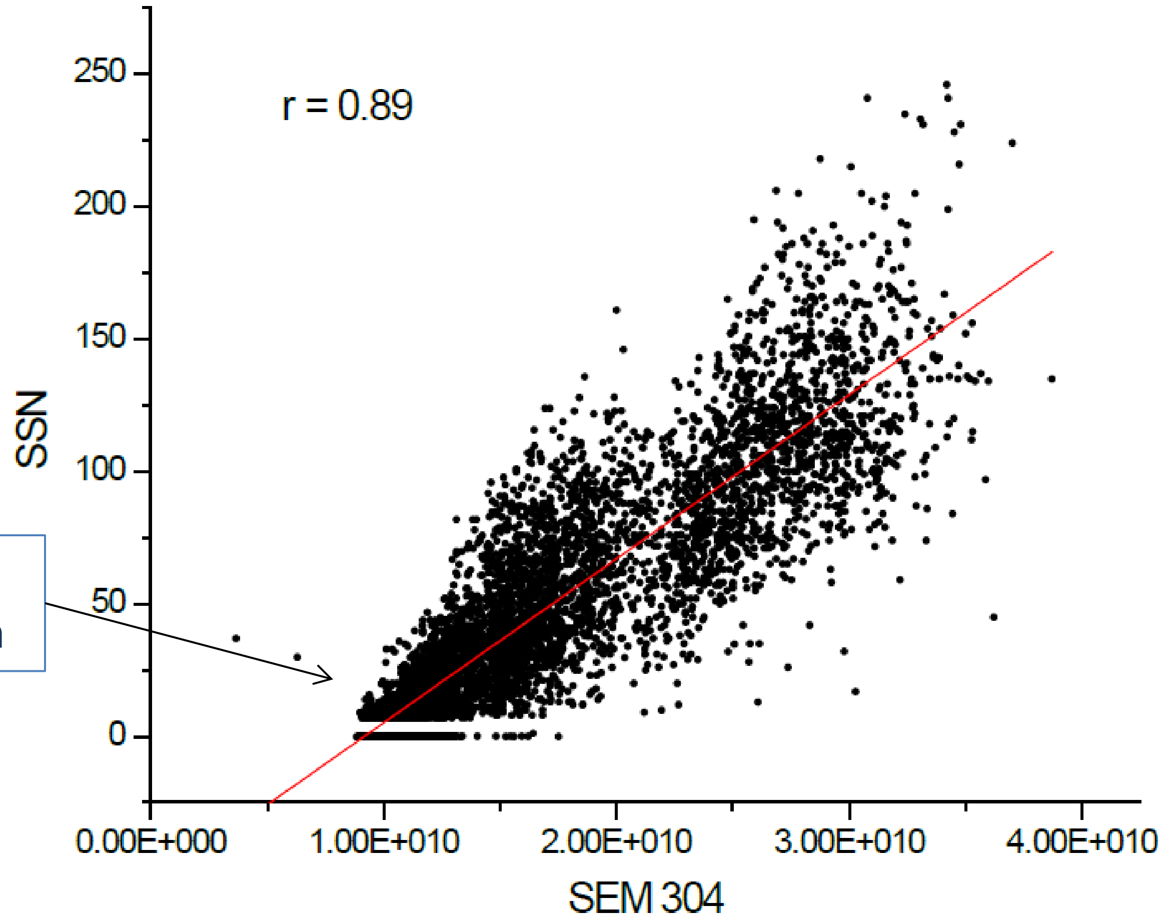
- It is desirable to be able to accurately predict space weather and how it will affect us

Background

- To have more accurate predictions of how space weather will affect us, we need to have an accurate model for EUV irradiance
- EUV is difficult to measure, so proxies are used
  - Sunspot number
  - F10.7 (and 81 day average)
  - Mg II (and 81 day average)

Motivation

Sunspot number versus SOHO SEM 30.4nm data

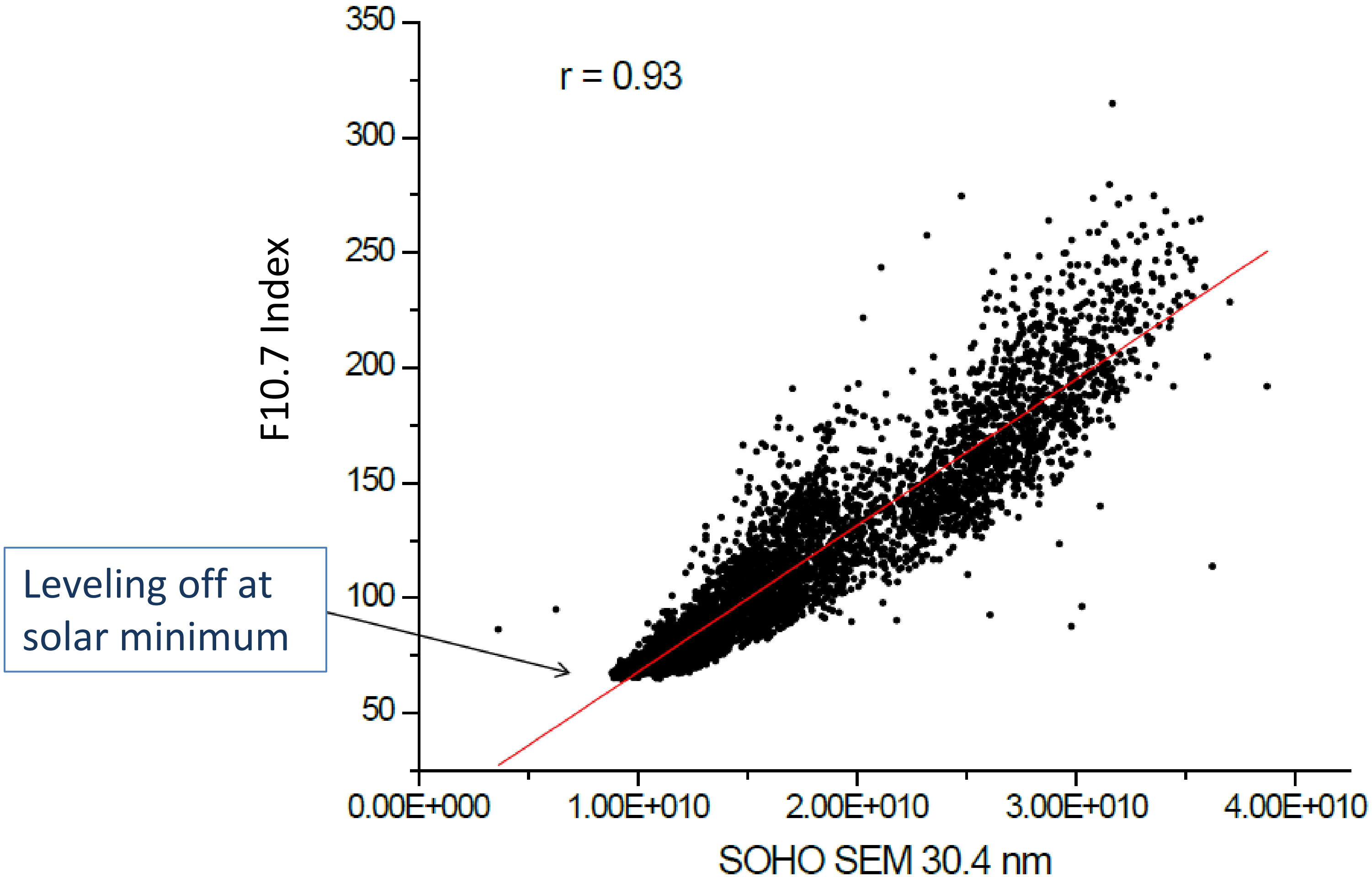


Leveling off at solar minimum

Viereck, 2013

Motivation

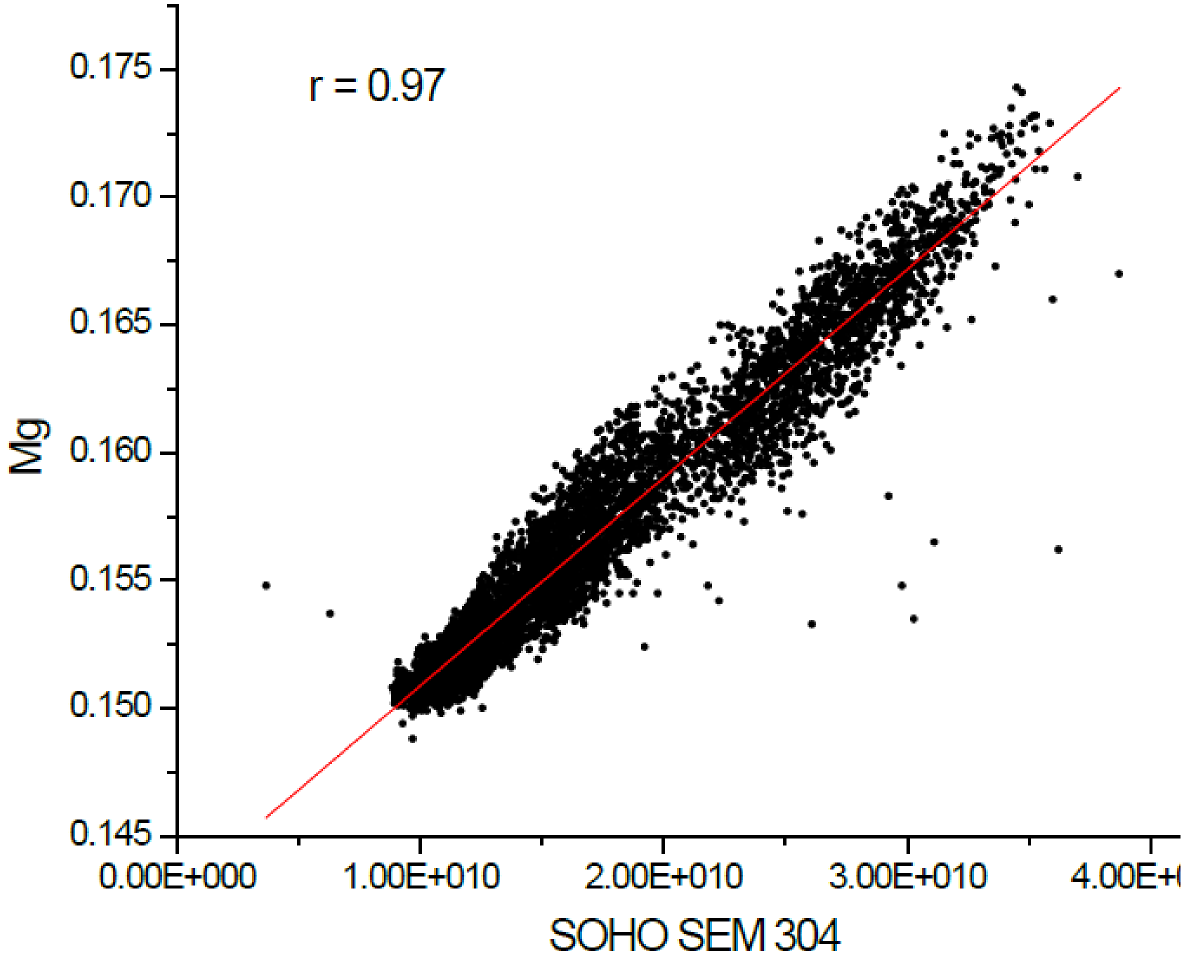
F10.7 versus SOHO SEM 30.4nm data



Viereck, 2013

Motivation

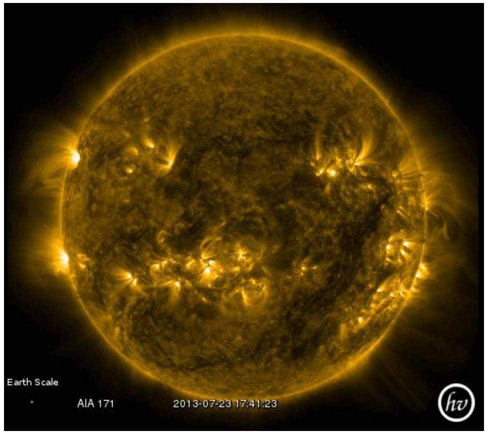
Mg II versus SOHO SEM 30.4nm data



Viereck, 2013

Motivation

- While proxies, especially Mg II, can be useful…
  - They are not actually EUV data
  - They do not capture the latest solar cycle trend well
  - Inclusion of 81-day average makes them impractical in real-time calculations required for operational use
- Best solution is to use actual EUV data
  - Operational measurements: GOES-15 EUVS
  - Scientific measurements: SDO EVE, TIMED SEE



Helioviewer.org

Objectives

- Create a model of the solar spectrum at 5-nm resolution using operational data from GOES and proxies such as F10.7 and Mg II
- Because this proxy uses real EUV data, it will be more effective than ground-based EUV proxies
- Make the proxy in a way that will cater to the needs of I/T modelers
  - Accurate
  - Similar inputs to current models
  - Readily available and easy to use

Procedures

- Use a least squares fitting technique to recreate the observed EUV spectrum from the broad-band GOES data and the F10 and Mg II proxies
- Use 2012 to “train” the model and determine the linear fitting coefficients.
- Examine data from 2011 and 2013 to see how well the model works

$$S(\boldsymbol{\beta}) = \sum_{i=1}^{m} [y_i - f(x_i,\ \boldsymbol{\beta})]^2$$

The Levenberg-Marquardt algorithm, our least squares fitting technique

Considerations

Torr et al.: Ionization Frequencies

TABLE 3. Solar UV Flux Data

UV Spectrum from 50–1050A

Intensity Incident on Earth (10^9 Photons $cm^{-2} s^{-1}$)

SOLAR FLUX PERIOD			74113	76200	78348	79022	79050
Interval	Wavelength A	ION					
1	50– 100		.3984	.4382	1.0337	1.2904	1.3710
2	100– 150		.1497	.1687	.3623	.4419	.4675
3	150– 200		2.3683	1.8692	4.1772	5.3708	5.7024
4	200– 250		1.5632	1.3951	4.7953	6.6473	7.1448
5	256.3	HeII, SiX	.4600	.5064	.8805	1.0331	1.0832
6	284.15	FeXV	.2100	.0773	3.2613	5.2352	5.7229
7	250– 300		1.6794	1.3556	7.5081	11.2278	12.1600
8	303.31	SiXI	.8000	.6000	2.9100	4.3380	4.6908
9	303.78	HeII	6.9000	7.7625	12.3424	13.8172	14.3956
10	300– 350		.9650	.8671	4.3119	6.3164	6.8315
11	368.07	MgIX	.6500	.7394	1.2891	1.4661	1.5355
12	350– 400		.3140	.2121	1.5298	2.3413	2.5423
13	400– 450		.3832	.4073	1.0922	1.4330	1.5310
14	465.22	NeVII	.2900	.3299	.6102	.7004	.7358
15	450– 500		.2851	.3081	1.2120	1.6912	1.8228
16	500– 550		.4520	.5085	1.2303	1.5496	1.6486
17	554.37	OIV	.7200	.7992	1.2943	1.4537	1.5163
18	584.33	HeI	1.2700	1.5875	3.4608	4.0646	4.3005
19	550– 600		.3568	.4843	.8732	.9985	1.0477
20	609.76	MgX	.5300	.6333	1.6782	2.3242	2.4838
21	629.73	OV	1.5900	1.8484	3.2443	3.6938	3.8701
22	600– 650		.3421	.4002	.9606	1.2842	1.3672
23	650– 700		.2302	.2623	.4521	.5149	.5388
24	703.31	OIII	.3600	.3915	.6363	.7152	.7461
25	700– 750		.1409	.1667	.3439	.4046	.4287
26	765.15	NIV	.1700	.1997	.3647	.4178	.4386
27	770.41	NeVIII	.2600	.2425	.7760	1.1058	1.1873
28	789.36	OIV	.7024	.7831	1.2870	1.4501	1.5140
29	750– 800		.7581	.8728	1.8909	2.3132	2.4541
30	800– 850		1.6250	1.9311	3.9278	4.5911	4.8538
31	850– 900		3.5370	4.4325	9.7798	11.5292	12.2187
32	900– 950		3.0003	3.6994	7.9445	9.3134	9.8513
33	977.02	CIII	4.4000	4.8400	8.5523	9.7478	10.2165
34	950–1000		1.4746	1.7155	3.3468	3.8723	4.0779
35	1025.72	HI	3.5000	4.3750	9.5375	11.2000	11.8519
36	1031.91	OVI	2.1000	1.9425	4.2929	5.7459	6.1049
37	1000–1050		2.4665	2.4775	4.7145	5.7798	6.0928
F10.7	($10^{-22} Wm^{-2}H_z^{-1}$)		71.0	68.0	206.0	234.0	243.0

- Which wavelength bins to use:
  - Want to make bins similar to what models already take as inputs
  - Could have used ‘Hinteregger’s 37 wavelengths’
    - 17 lines plus 20 bands spanning 5-105nm
    - First detailed in 1979 Torr, Torr, Ong, and Hinteregger paper [1]
    - Not very practical since many observations don’t resolve the lines
- Decided to create the full spectrum at 5-nm resolution

[1] Torr et al, ‘Ionization frequencies for major thermospheric constituents as a function of solar cycle 21.’ 1979. Geophysical Research Letters, 6: 771–774. doi: 10.1029/GL006i010p00771

The Model

- Create 5nm bins of EUV data from 5-105nm from SDO EVE and TIMED SEE
  - Because these are scientific missions, the data will not necessarily be available forever
- Recreate the EUV irradiance in each bin by using least-squares analysis to fit observed irradiance to broadband GOES-15 EUVS & XRS data and current proxies

The Model

- Give fit algorithm EVE/SEE irradiance and all input data, and it will produce an array of weights:

EVE or SEE irradiance in a 5nm band =

weight1 (offset) +

weight2*XRSA +

weight3*XRSB +

weight4*EUVSA +

weight5*EUVSB +

weight6*EUVSE +

weight7*F10.7 index +

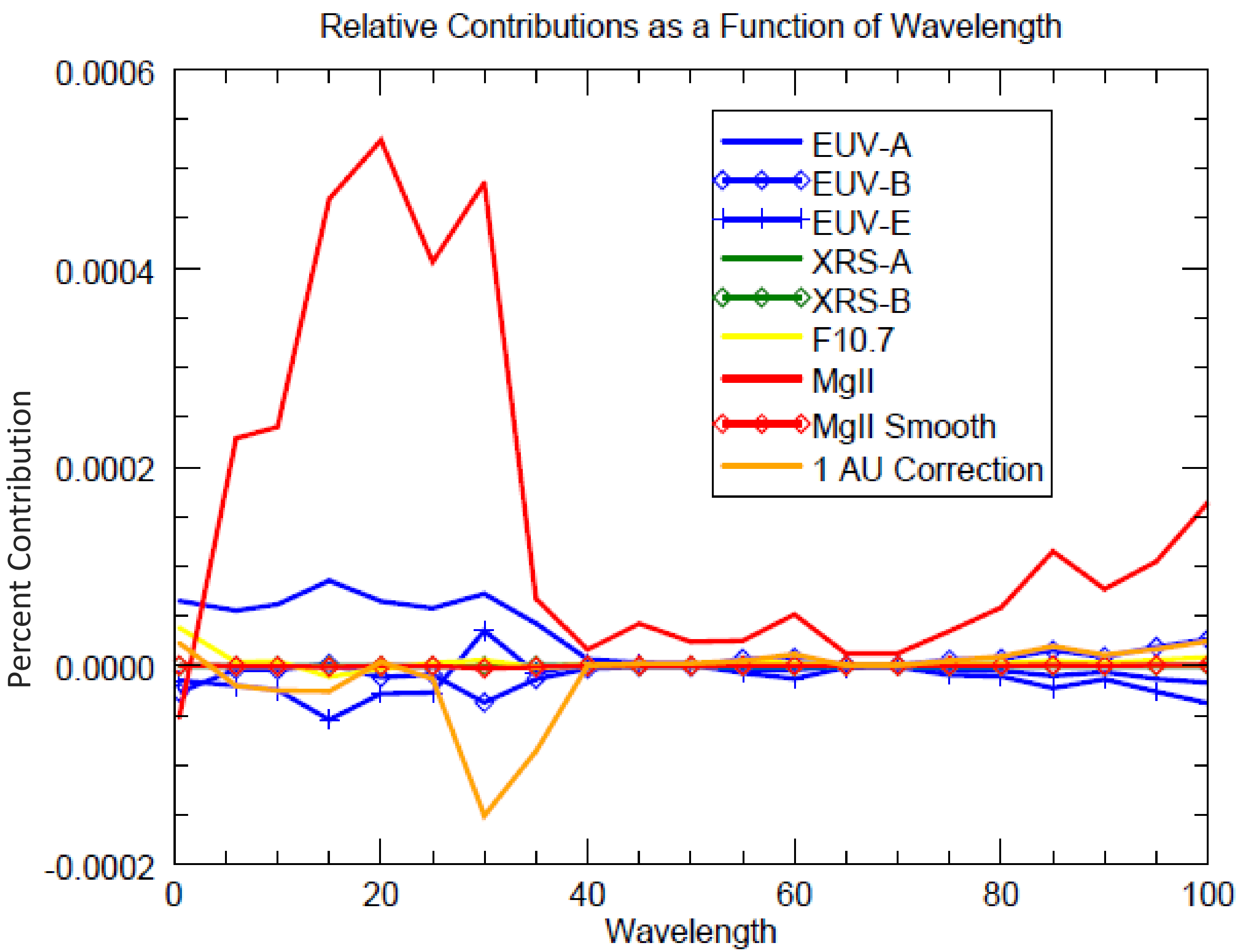
weight8*Mg II index +

weight9*Mg II Smooth index +

weight10* 1 AU Correction

The Model

- Results of the equation from the previous slide:

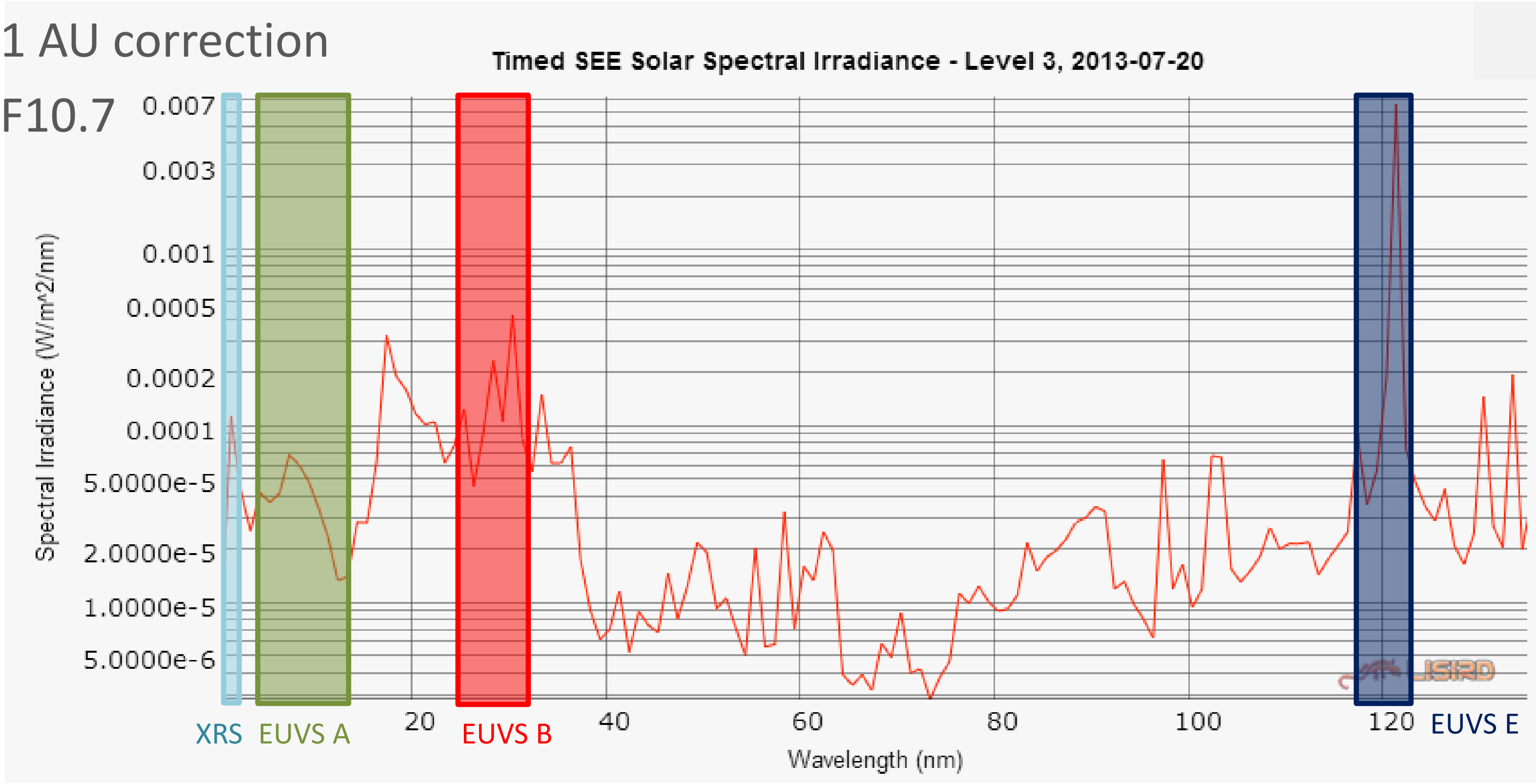


Methods

- Gather scientific EUV measurements from the SDO EVE instrument
- Gather EUV and XRS data from GOES-15, along with F10.7 and Mg II daily values
- Use Levenberg–Marquardt least squares fitting algorithm to determine weights that will create EVE data from GOES data (fit to year 2012)
- Test, refine, and validate the model
  - See how well coefficients predict 2011 and 2013 data
  - Make sure relative contributions of coefficients make sense
- Make the coefficients and/or the modeled spectrum available to the public

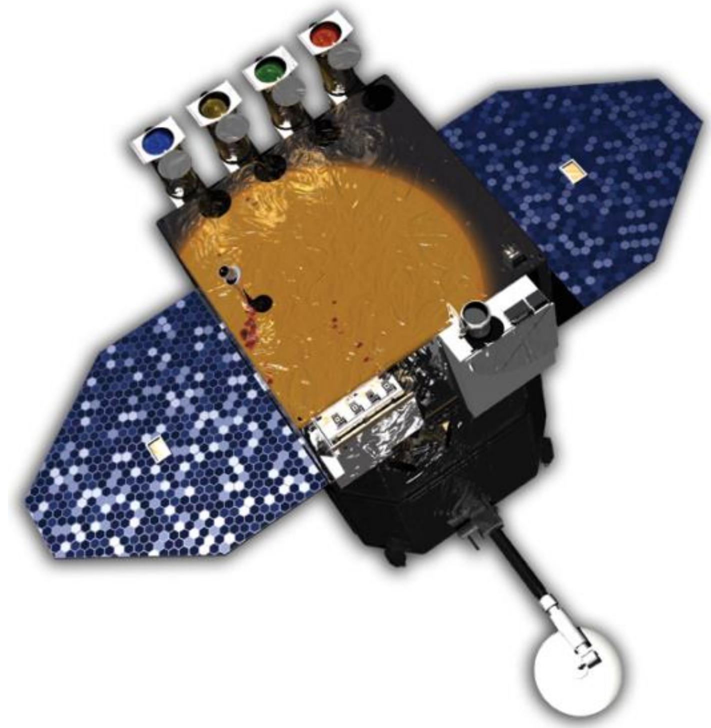
Materials

- Input data sets (what I was using to fit)
  - GOES XRS A (0.05 – 0.4 nm) and XRS B (0.1 – 0.8 nm)
  - GOES-15 EUVS A (5 – 17 nm) and EUVS B (26 – 34 nm) and EUVS E (118 – 122 nm)
  - Mg II and Mg II (70-day smooth)
  - 1 AU correction
  - F10.7



Materials

- Output data sets (what I was fitting to)
  - SDO EVE
    - Spectrum from 6-105nm with 0.1 nm resolution
  - TIMED SEE
    - Spectrum from 0.1-190nm with 1nm resolution (daily average from Level 3)



LASP & NASA/GSFC

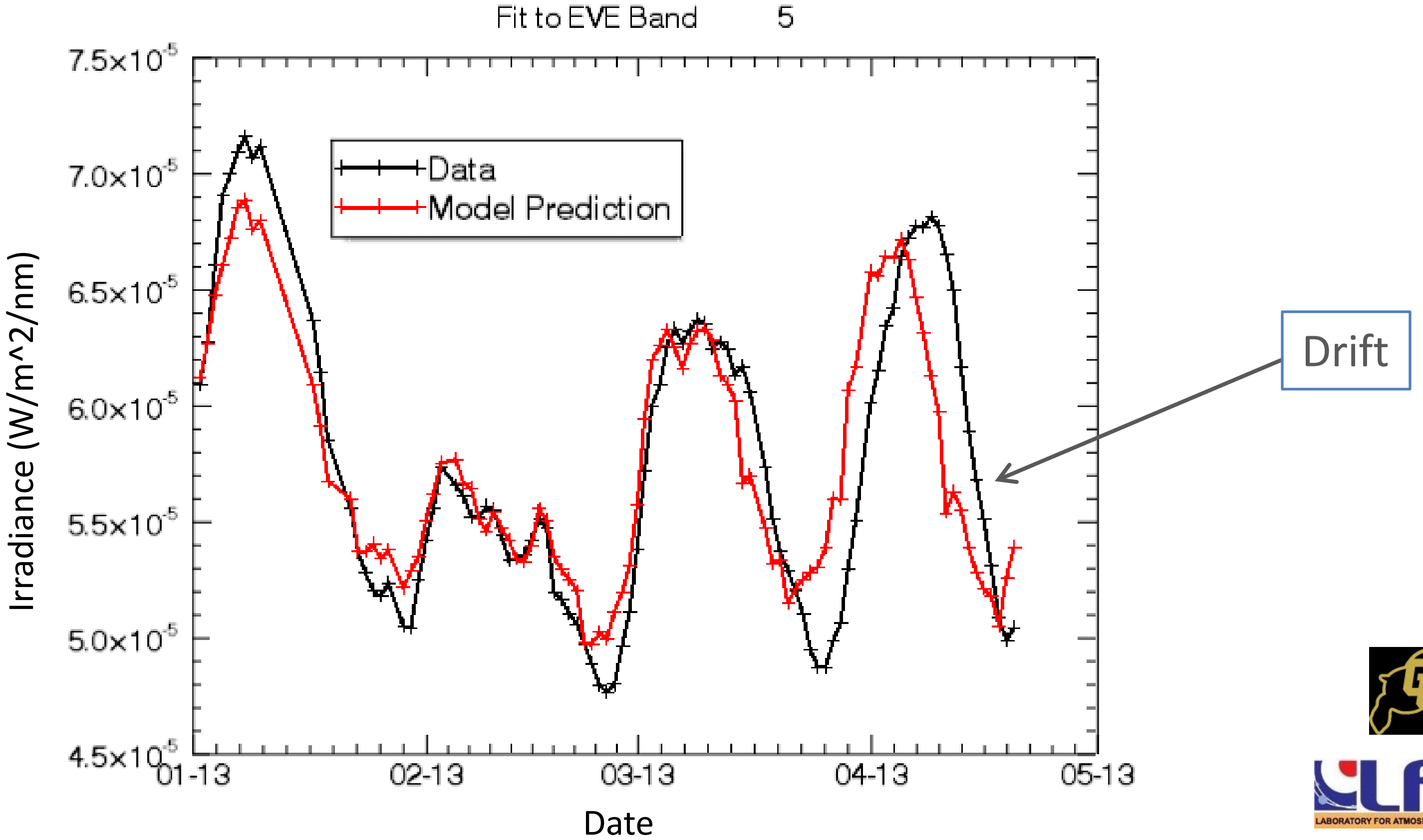
Materials

- Fitting algorithm:
  - Used mpfit [1], a more robust and reliable fitting algorithm than IDL's built in function, curvefit
  - Uses the Levenberg-Marquardt algorithm (damped least-squares method)
  - Takes input data and desired output function (in this case, a linear combination of the outputs) and produces an array of parameters/weights that make the function best fit the data
  - Allowed parameters/weights to be negative
    - This allows us to subtract out the background to get lines that are important in a specific bin, or vice versa

[1] 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, eds. D. Bohlender, P. Dowler & D. Durand (Astronomical Society of the Pacific: San Fransisco), p. 251-254.

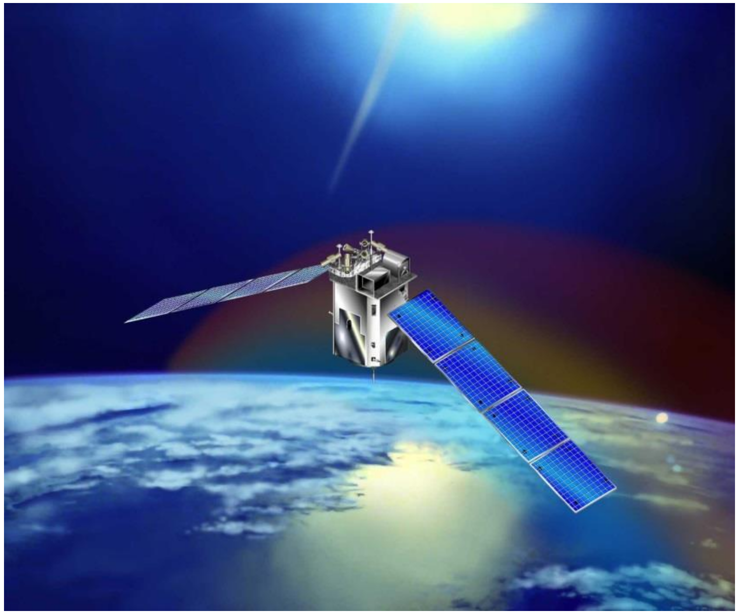
Initial Results

- Used 2012 EVE data as output
  - 60-90% correlation between input and output data sets
  - 1-90% correlation between 2013 fit and 2013 data
    - 70-90% correlation from 5-40nm, 1-60% correlation 40-105nm



Initial Results

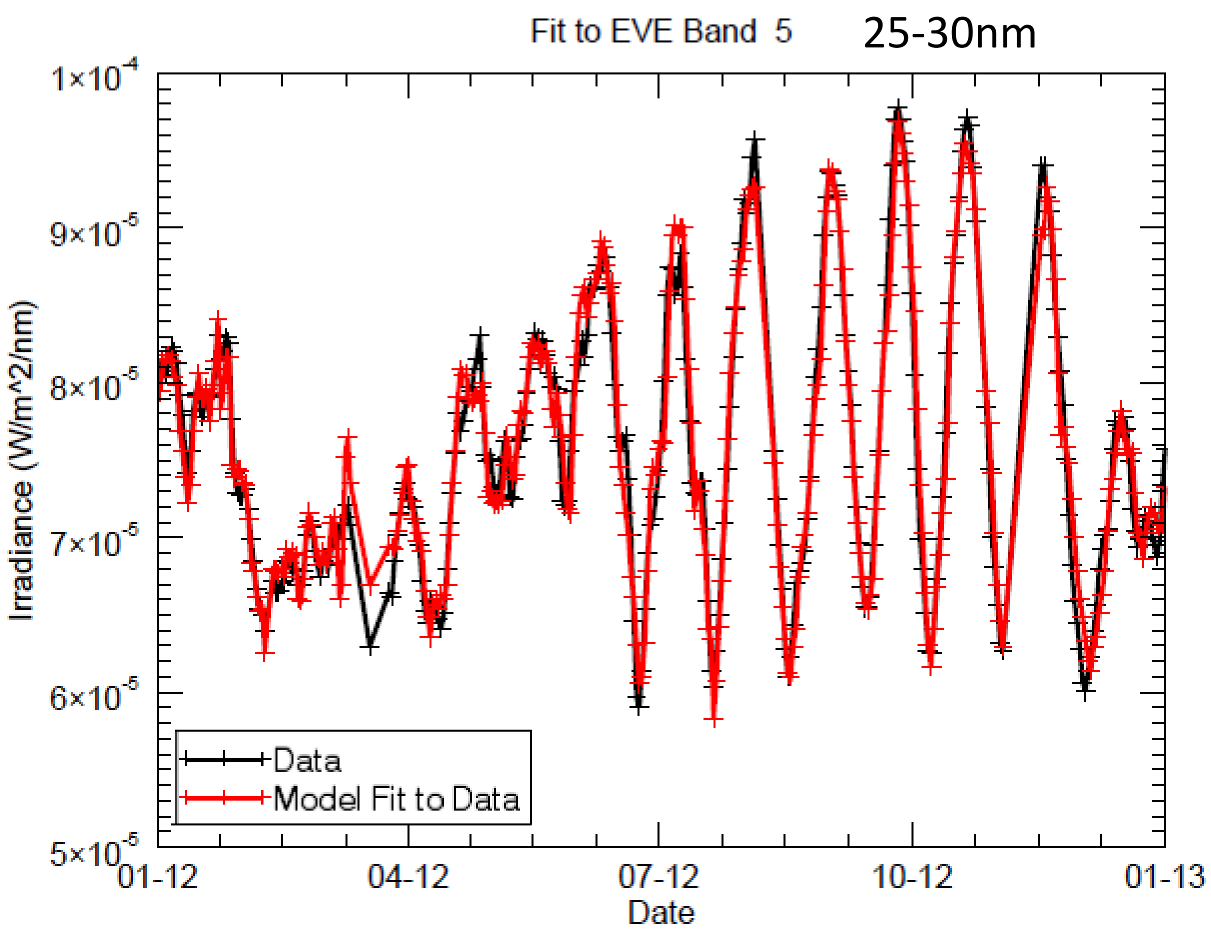
- Eventually found the cause– calibration
- Began using TIMED SEE data for longer wavelengths
  - EVE for 6-40nm
  - SEE for 40-105nm and 0.5-6nm
- Challenges:
  - Different cadence
  - How can we look at flares?



NASA 2010

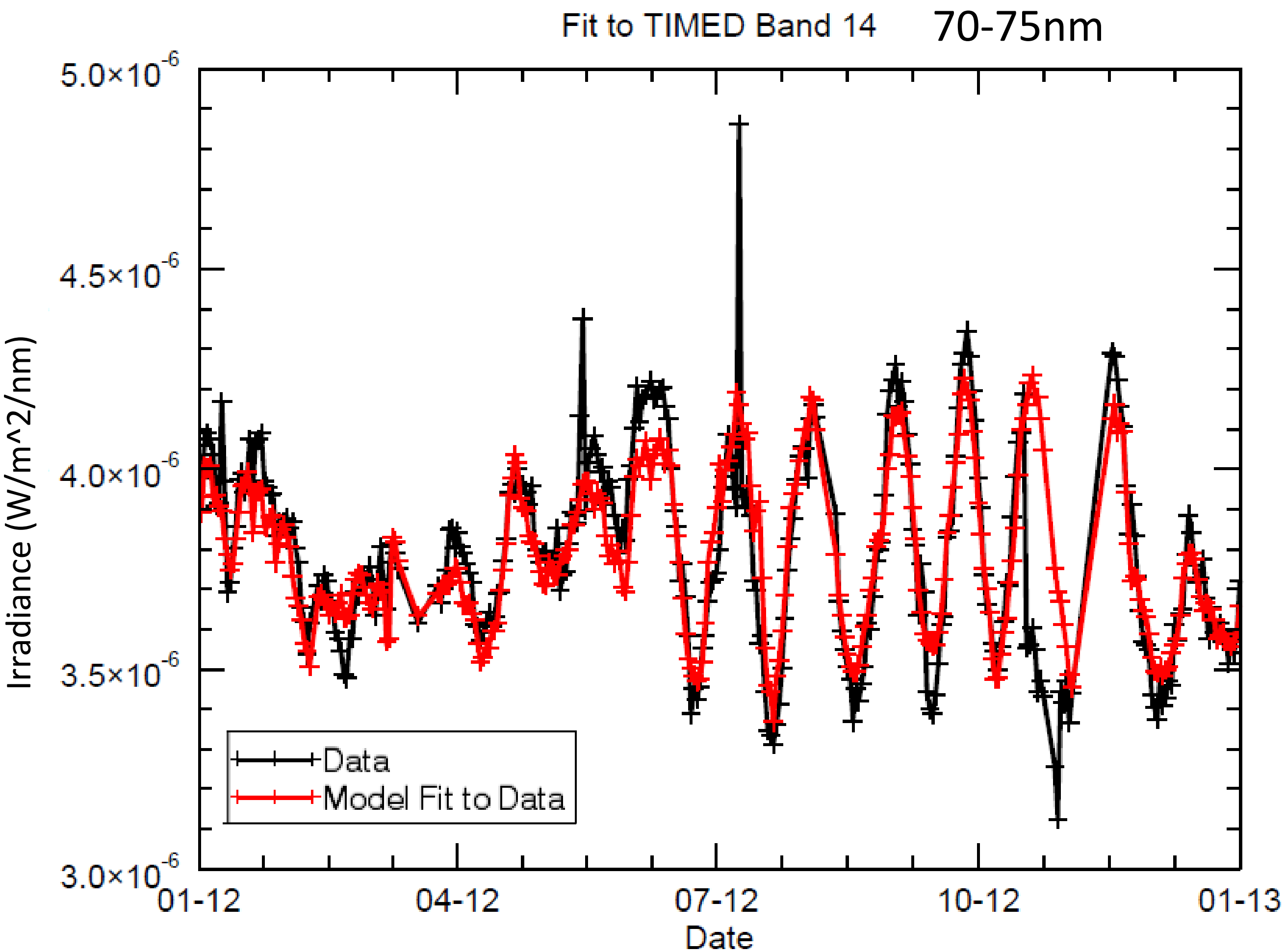
Results

- Fit is very close to actual data at short wavelengths



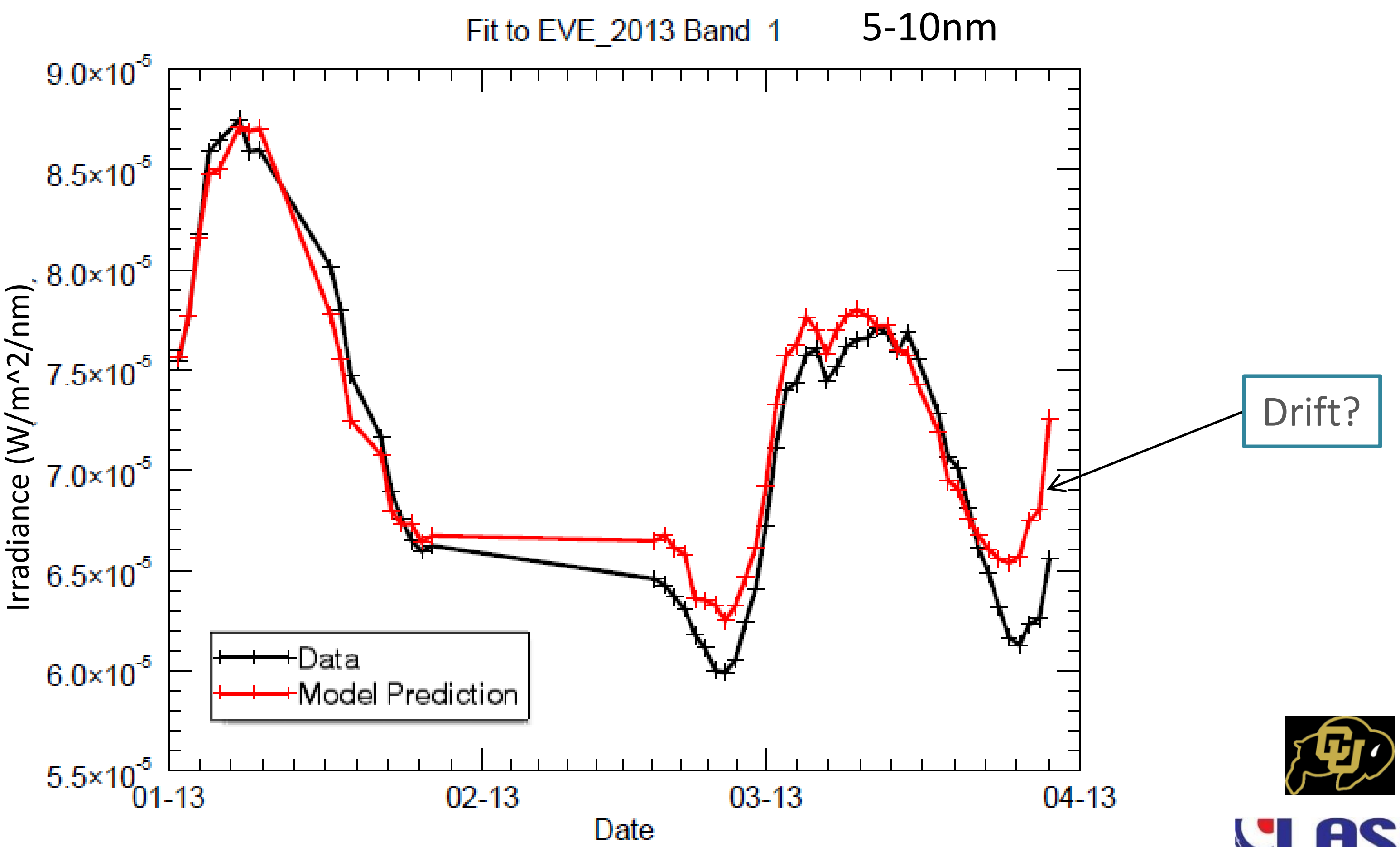
Results

- Fit is slightly less accurate at longer wavelengths, but still matches up well



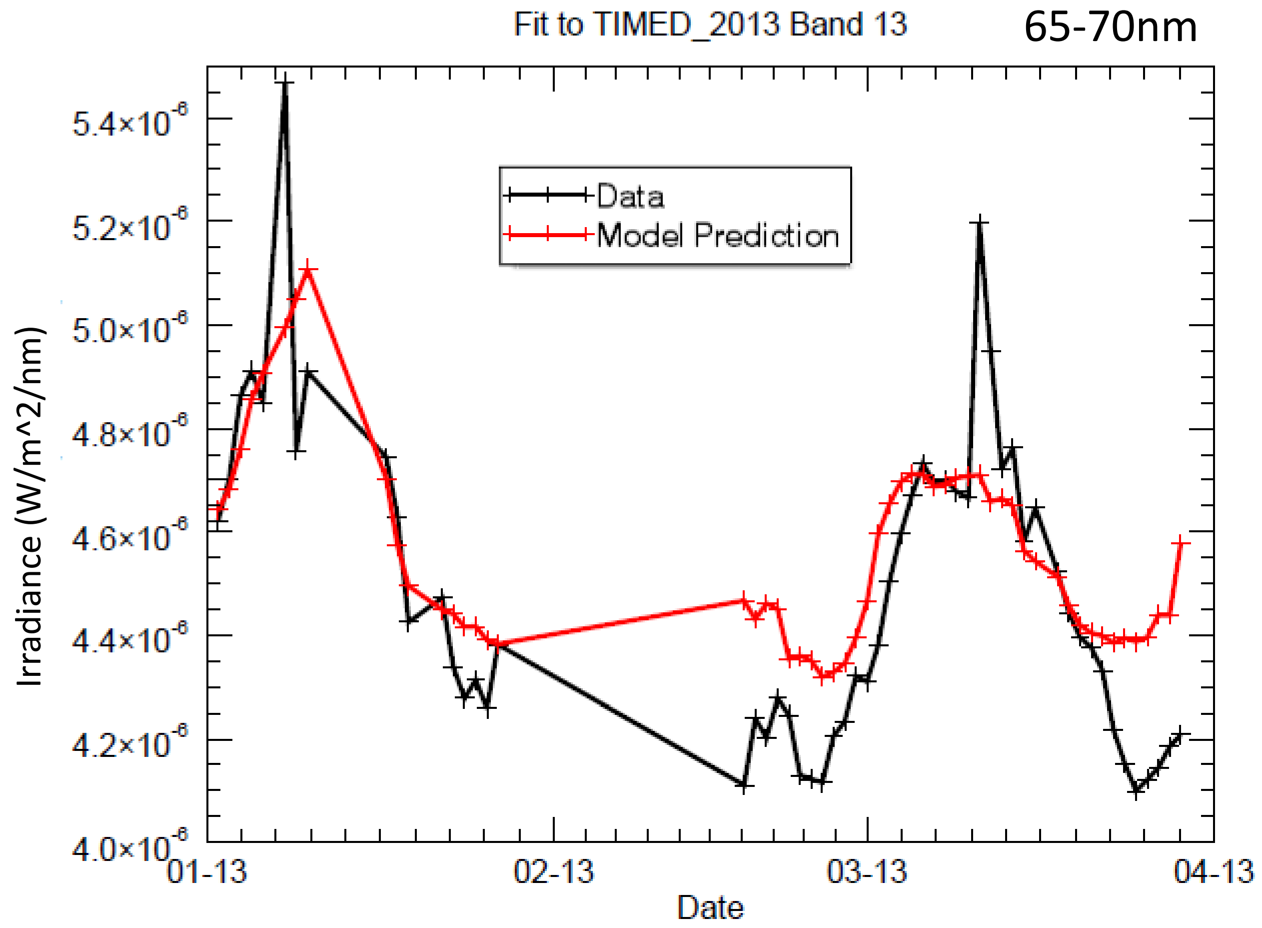
Results

- Then, found how well the 2012 coefficients predicted 2013 data



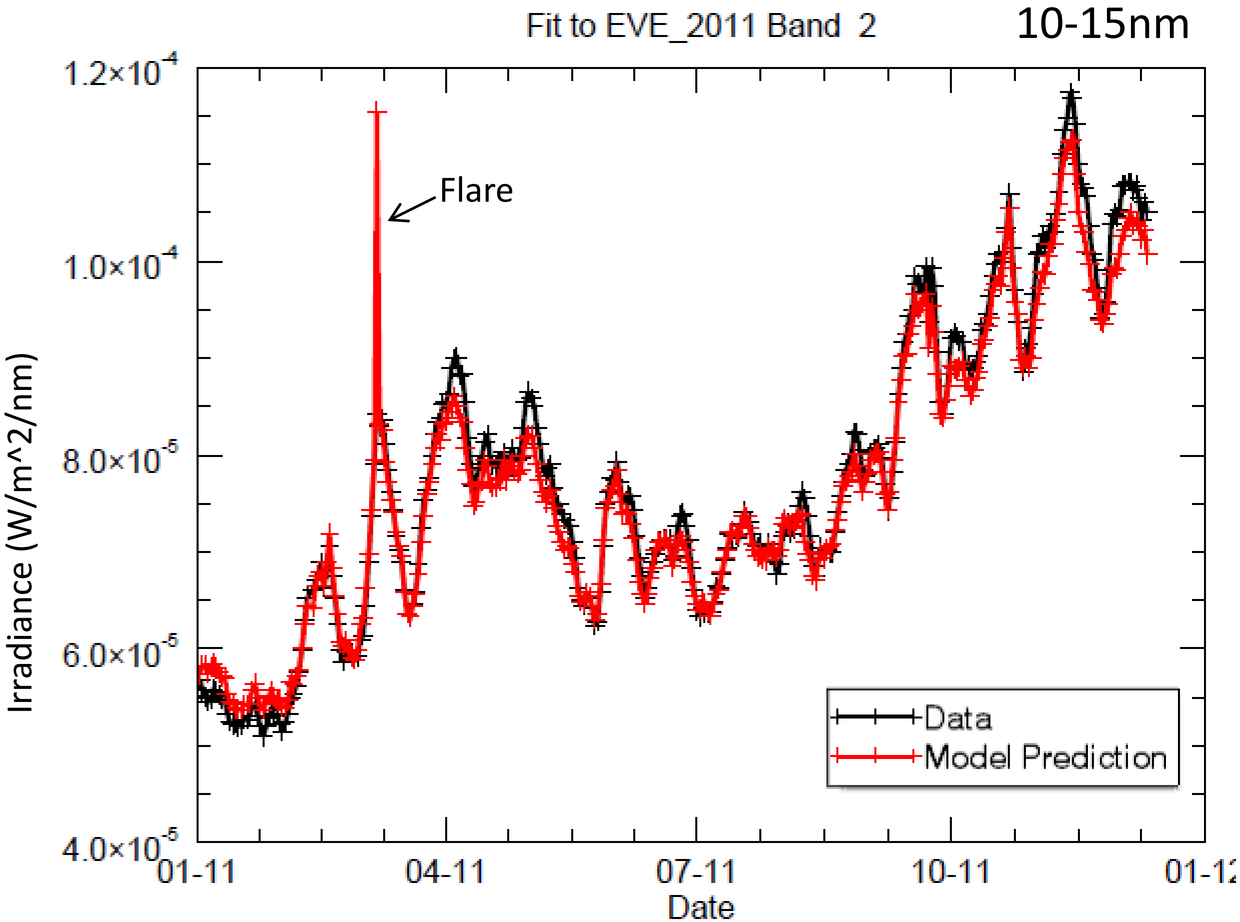
Results

65-70nm



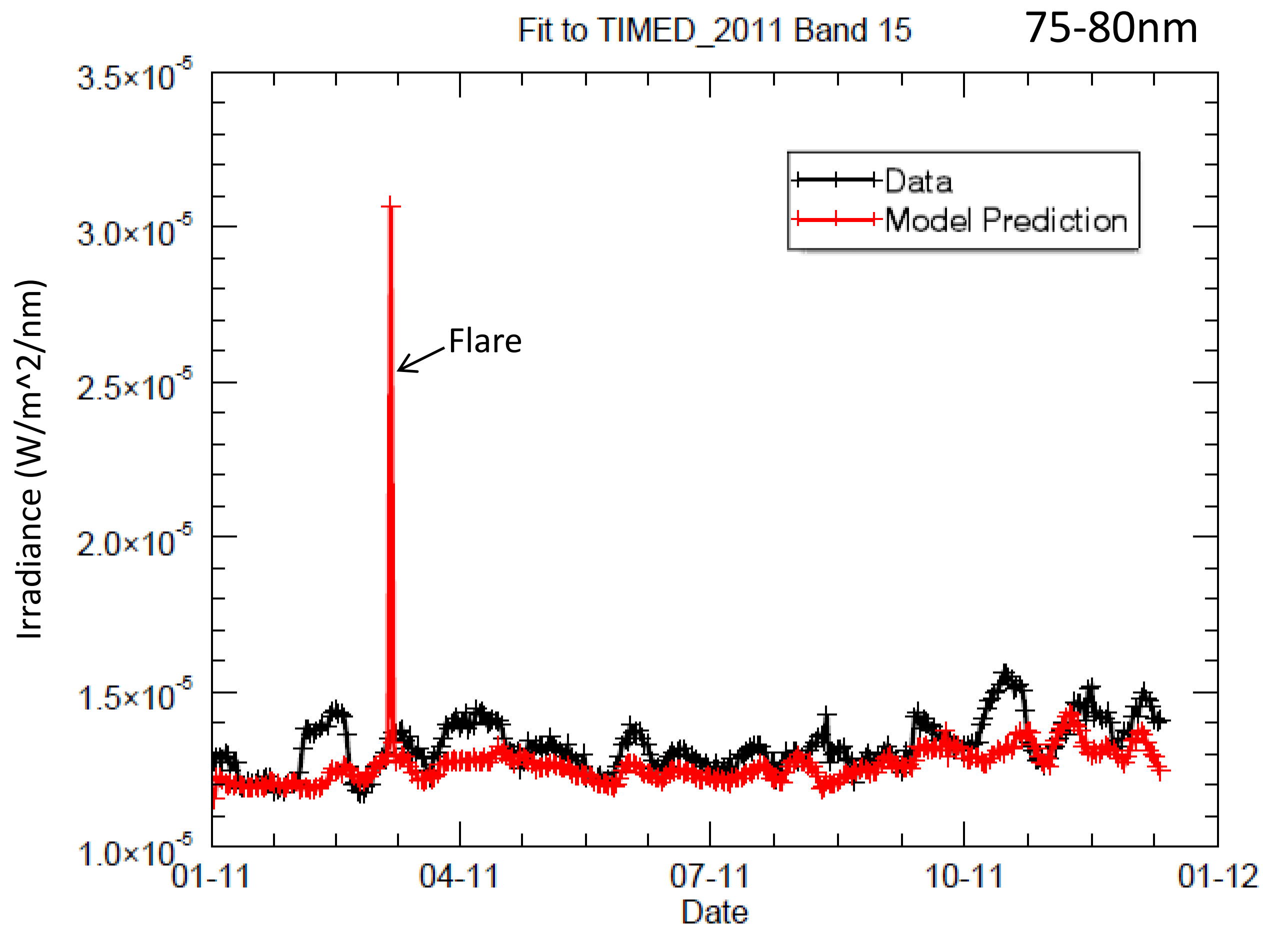
Results

- Then, saw how well 2012 coefficients predicted 2011 data
- Flare during March 2011



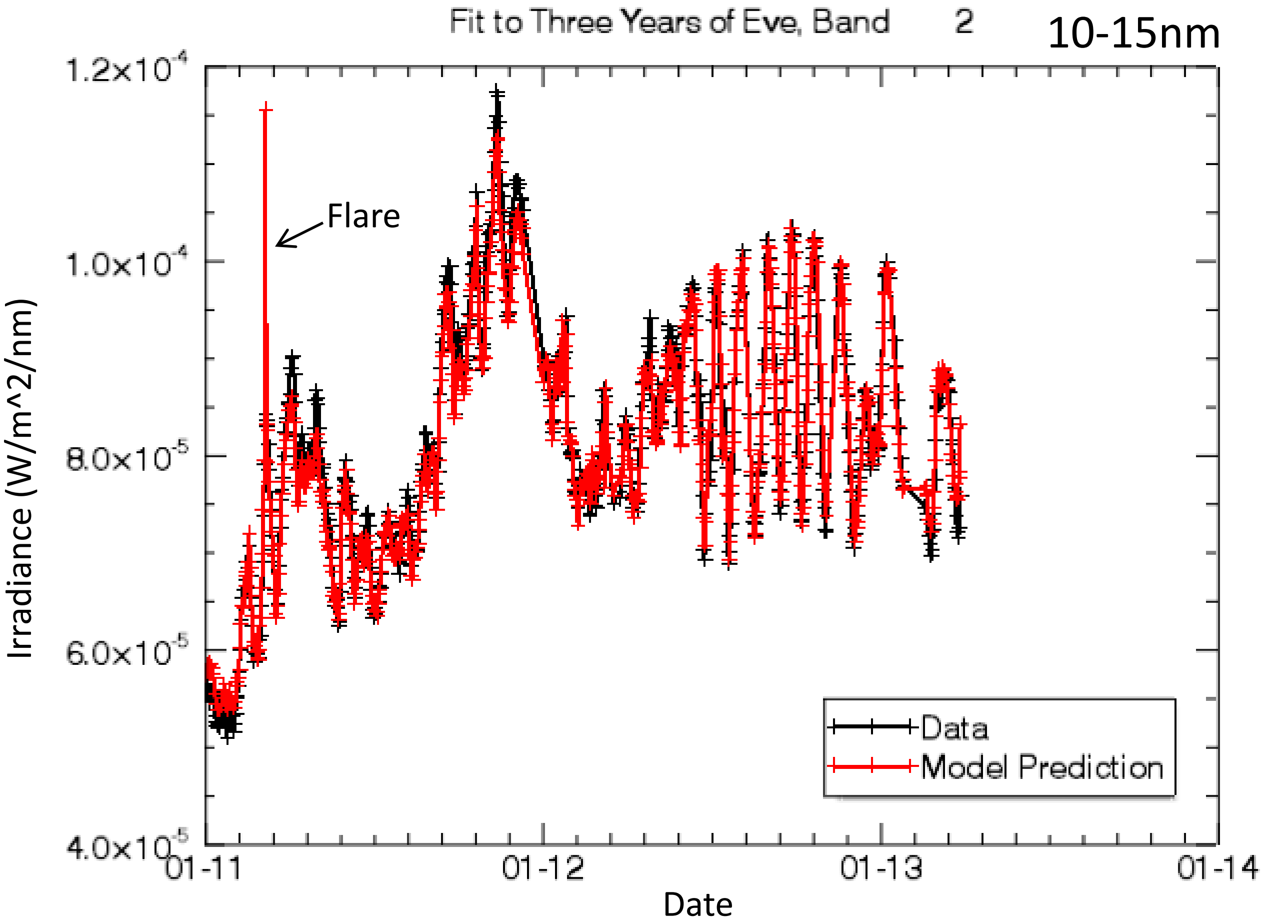
Results

- Again, fit not as good at longer wavelengths

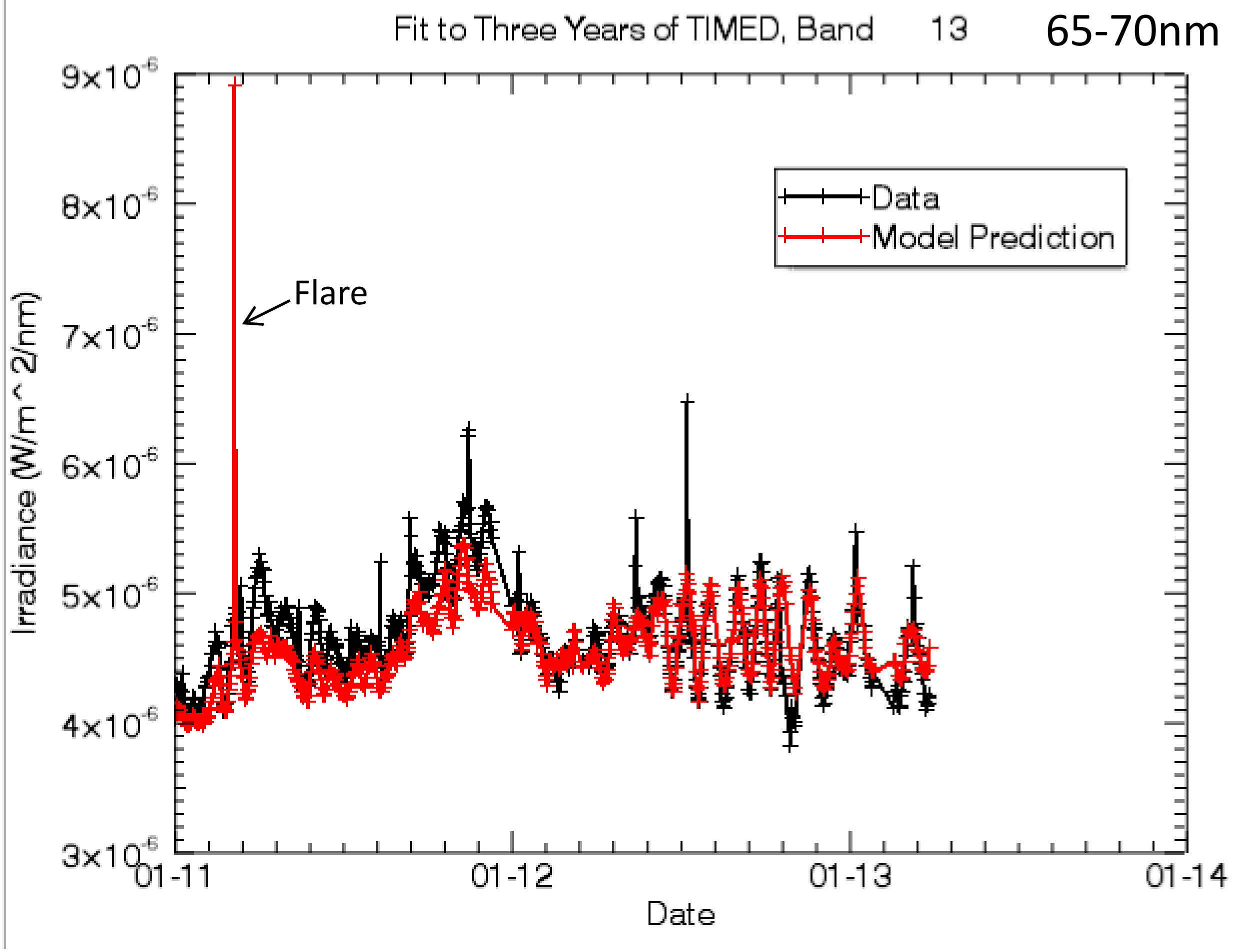


Results

- All three years of data

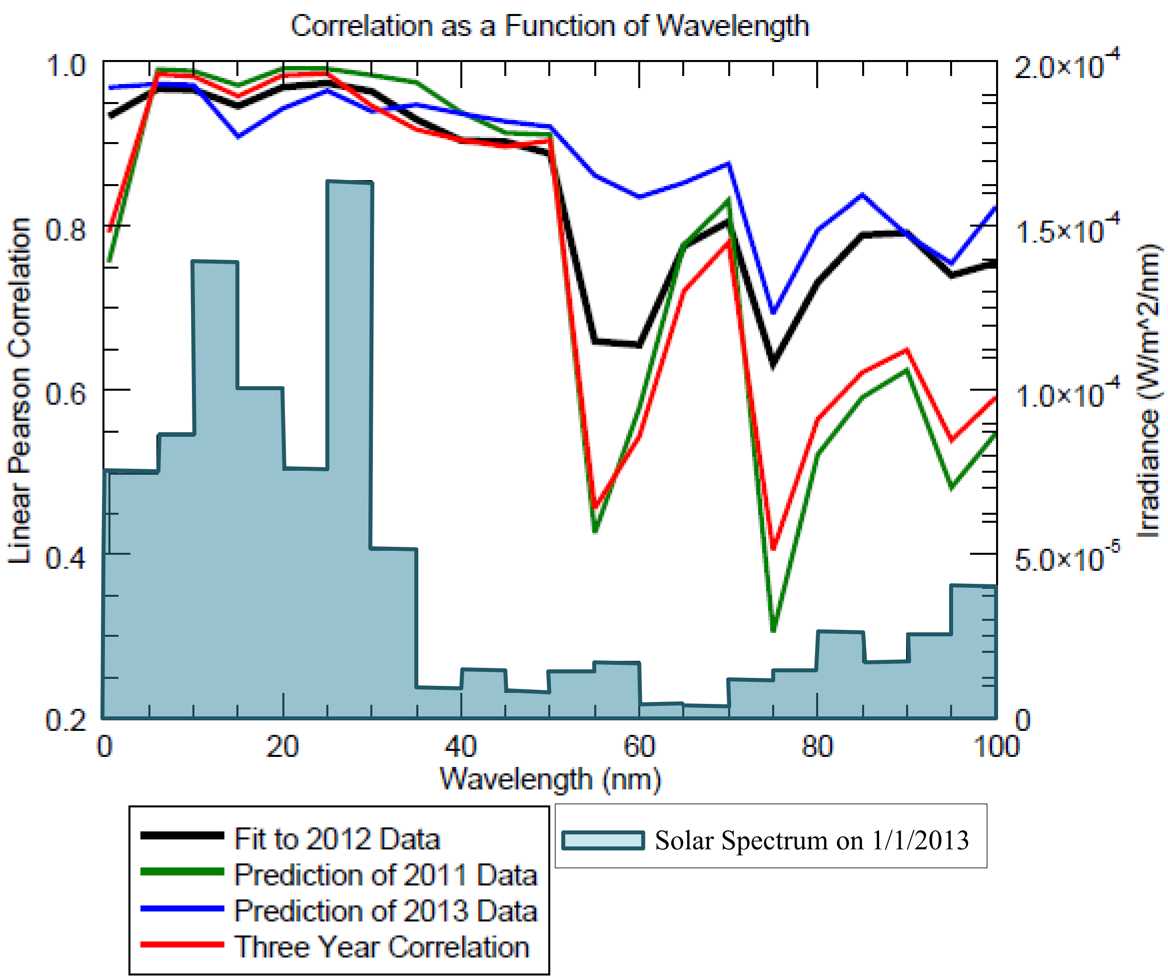


Results


Fit to Three Years of TIMED, Band 13
65-70nm
Data
Model Prediction
Flare
Irradiance (W/m ^ 2/nm)
9x10^-6
8x10^-6
7x10^-6
6x10^-6
5x10^-6
4x10^-6
3x10^-6
01-11
01-12
01-13
01-14
Date

Discussion

- Found linear Pearson correlation between data and each fit, along with two- and three-year fits

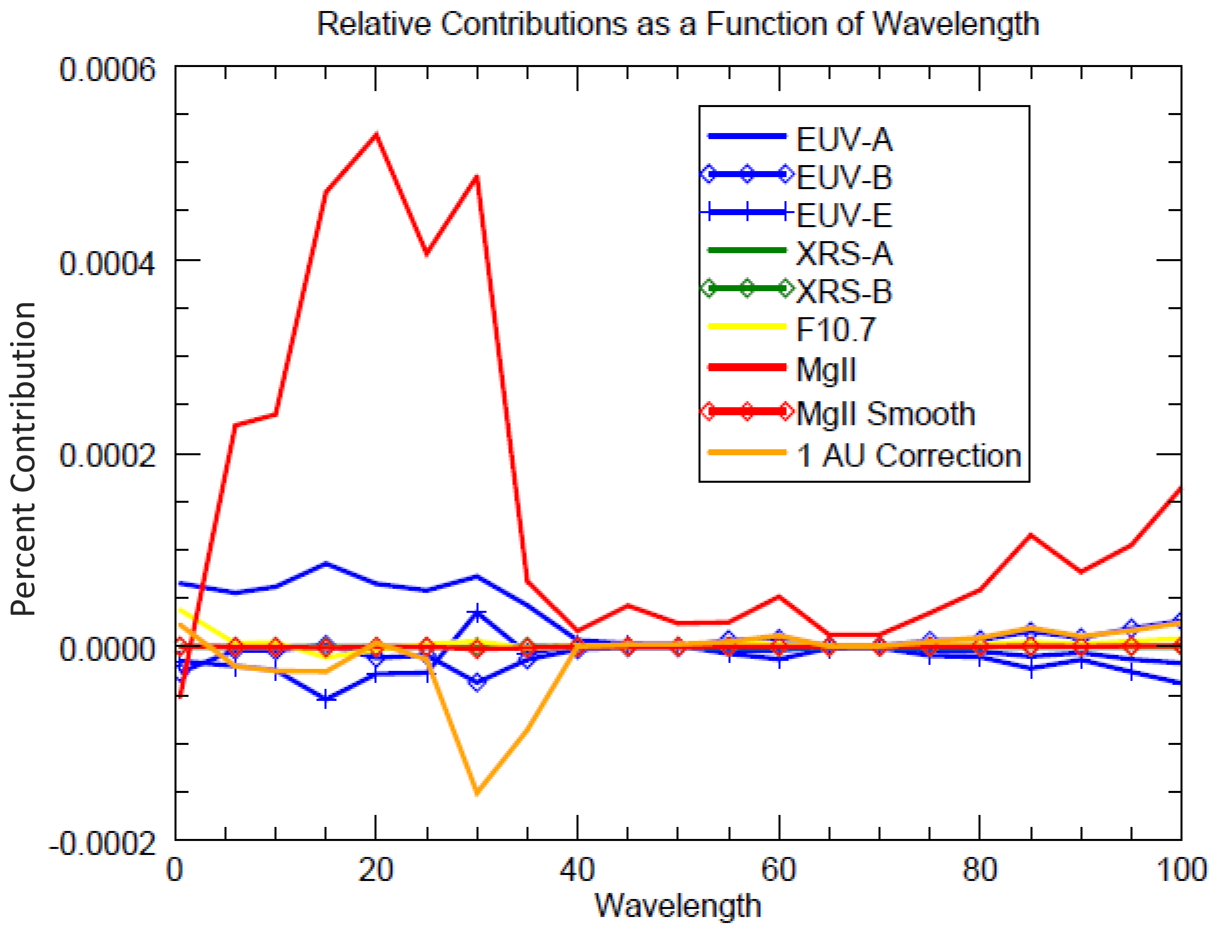


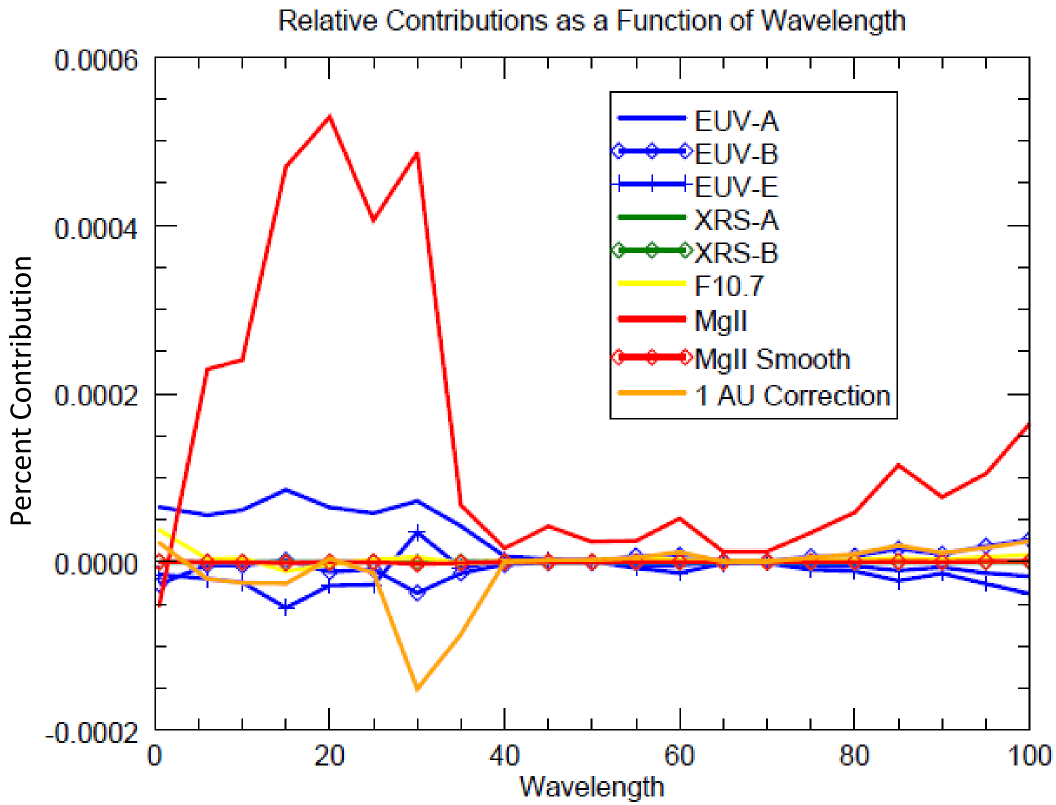
Discussion

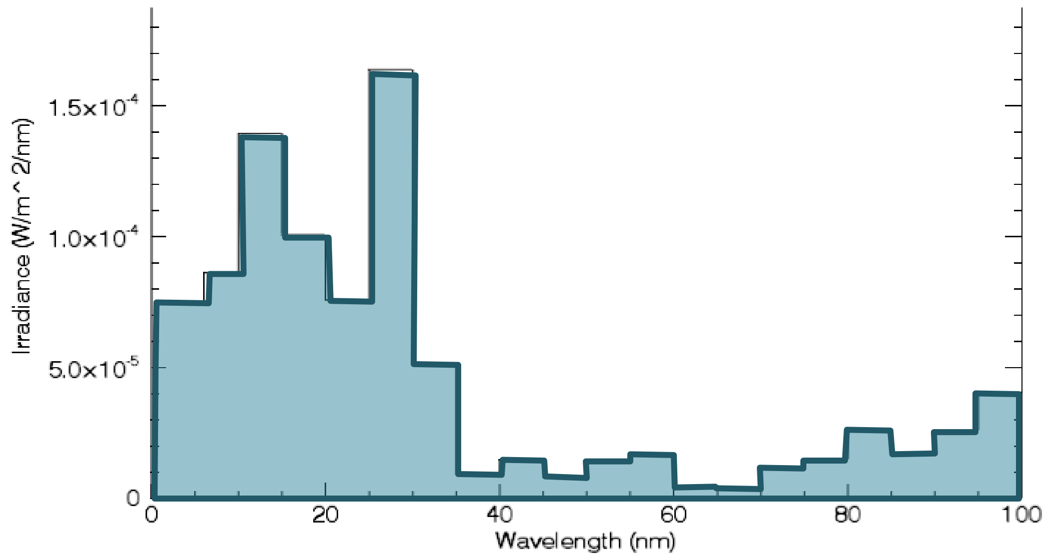
- Fit and predictions are very good for short wavelengths (<45nm)
- Not so good for wavelengths past ~45nm
  - These wavelengths not as important in the models as the amount of energy and the amount of variability at the long wavelengths is less.

Discussion

- Wanted to check if the relative contributions from each input made sense– shorter channels should be more important at shorter wavelengths




Relative Contributions as a Function of Wavelength
0.0006
0.0004
0.0002
0.0000
-0.0002
Percent Contribution
0
20
40
60
80
100
Wavelength
EUV-A
EUV-B
EUV-E
XRS-A
XRS-B
F10.7
MgII
MgII Smooth
1 AU Correction


1.5x10-4
1.0x10-4
5.0x10-5
0
Irradiance (W/m^2/nm)
0
20
40
60
80
100
Wavelength (nm)

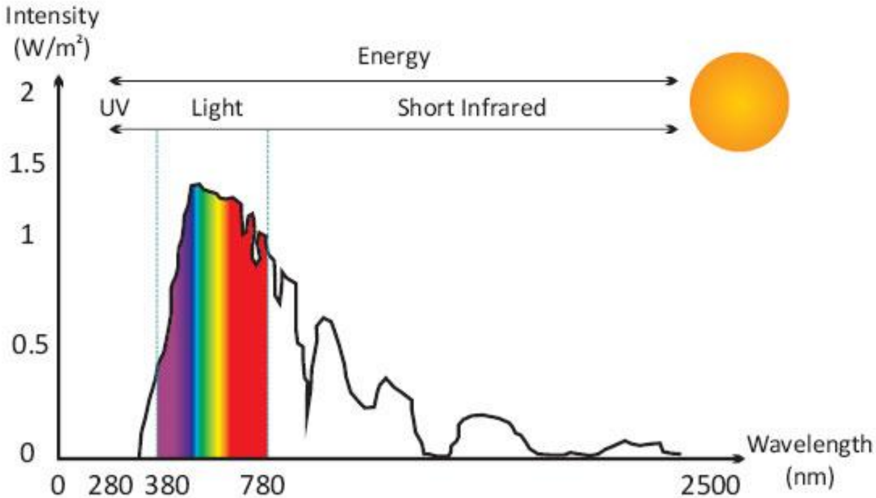
Future Work

- Would be interesting to see how coefficients change during a flare
  - In progress
- Make coefficients and methods available on NOAA website for convenience, ease of use, and better implementation of the method

Our EUV model here!

Conclusions

- Using EUV data as part of an EUV proxy is a very good idea
- Current project showed that predicted values are very close to real values at short wavelengths
- More data is likely necessary to improve the proxy at long wavelengths



FG Glass, 2013

Conclusions

- Our proxy model will likely capture long-term trends as well as instantaneous variability
- This will allow us to better model the I/T system and predict space weather and its effects

Acknowledgements

- LASP, CU, NSF, SORCE, and NOAA SWPC
- Rodney, Janet, Marty, and Erin
- REU and Hollings Scholars

Thanks for making this summer so much fun (and of course educational) !

Questions?