Annual Progress Report for award number: NASA NNX14AC83G

R&A Program Name: NASA Heliophysics Senior Review (MO&DS Extended Missions)
Dates covered by this report: January 1 – December 31, 2018 (Year 17)

Program Title: TIMED Solar EUV Experiment (SEE) Extended Mission

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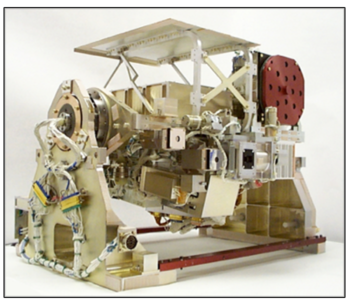
I) Summary of research originally proposed



The NASA Thermosphere-Ionosphere-Mesosphere-Energetics-Dynamics mission was launched on December 7, 2001, and normal science operations began in January 2002. The Solar Extreme ultraviolet Experiment (SEE) is one of the four instruments aboard the TIMED spacecraft. The SEE instrument is designed to daily observe the solar extreme ultraviolet (EUV) and soft X-ray (XUV) irradiance. The SEE channels include the EUV Grating Spectrograph (EGS) that measures the solar EUV spectrum from 27 nm to 195 nm with about 0.4 nm spectral resolution and the XUV Photometer System (XPS) that measures the solar XUV radiation in broadbands below 40 nm. Woods *et al.* [2015] provide detailed overviews of the SEE science goals, instrument design, pre-flight calibrations, data processing algorithms, and first results. An example of the solar spectrum from TIMED SEE is shown in Figure 1.

The original objectives for SEE are:

(1) Accurately and precisely determine the time-dependent solar vacuum ultraviolet (VUV) spectral irradiance
(2) Study the solar-terrestrial relationships utilizing atmospheric models
(3) Determine the thermospheric neutral densities from solar occultations
(4) Study solar VUV variability and its sources
(5) Improve proxy models of the solar VUV irradiance

During the TIMED extended mission, the SEE science team has not been supported, and we depend on ROSES, other opportunities, and international collaborators to provide TIMED-related science analysis and modeling. During the extended mission the TIMED SEE grant to the University of Colorado primarily supports only original objective #1 (measure the solar VUV spectral irradiance).

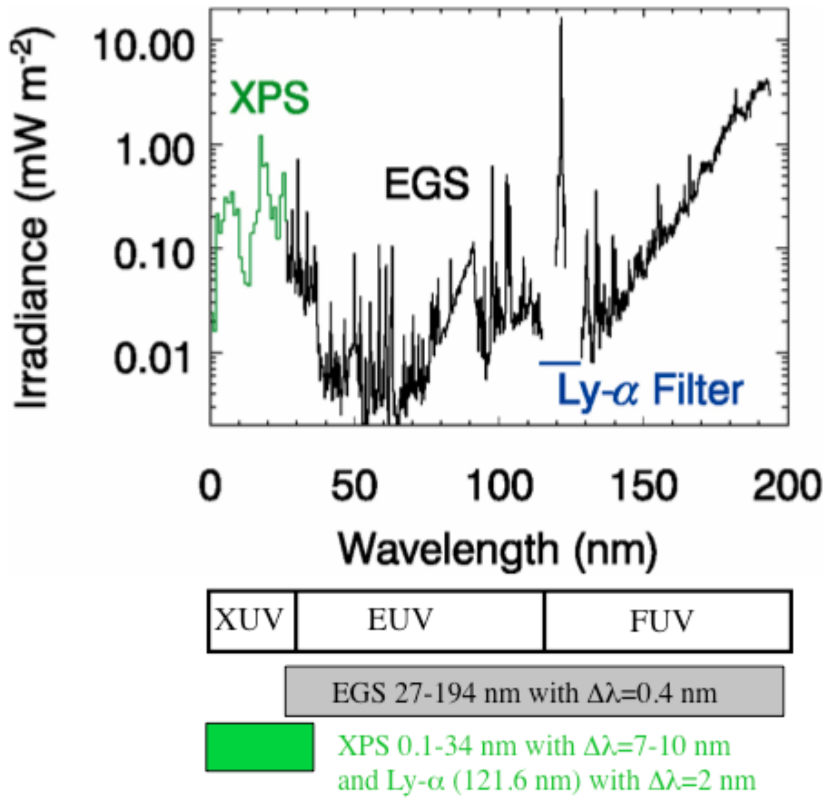


Figure 1. Example Solar Spectrum from TIMED SEE.

There are very few observation gaps in the daily record of the solar UV irradiance from TIMED SEE, and there has only been one instrument anomaly that has limited SEE's observations. This anomaly is the XPS filter wheel mechanism became stuck in position 6 on day 2002/205; consequently, the XPS solar observations are limited to 3 XUV channels instead of its 9 channels. Nonetheless, these 3 XPS channels have been adequate to provide the solar XUV irradiance below 27 nm throughout the TIMED full mission.

II) Summary of accomplishments made during this grant period

The primary activities for the SEE extended mission include generating the weekly operational plans which includes sending uplink commands to the TIMED MOC at JHU APL and the daily production of the SEE solar irradiance data products. There was a major release of the SEE Version 12 data products in 2017, and version 13 is being planned with updates for new degradation trends based on the June 18, 2018 calibration rocket flight for SDO EUV Variability Experiment (EVE). The data gaps in SEE this past year include 4 days: 2018/103, 2018/115, 2018/125, and 2018/126; all gaps are due to spacecraft events. Example time series plot of some solar emission lines are shown over the TIMED mission in Figure 2.

The primary science study for SEE during this past year has been studying the solar irradiance variability with emphasis on solar cycle variability and improvements of the Flare Irradiance Spectral Model (FISM) using TIMED SEE, SDO EVE, and SORCE SOLSTICE data. These are discussed more in the Science Highlights section below.

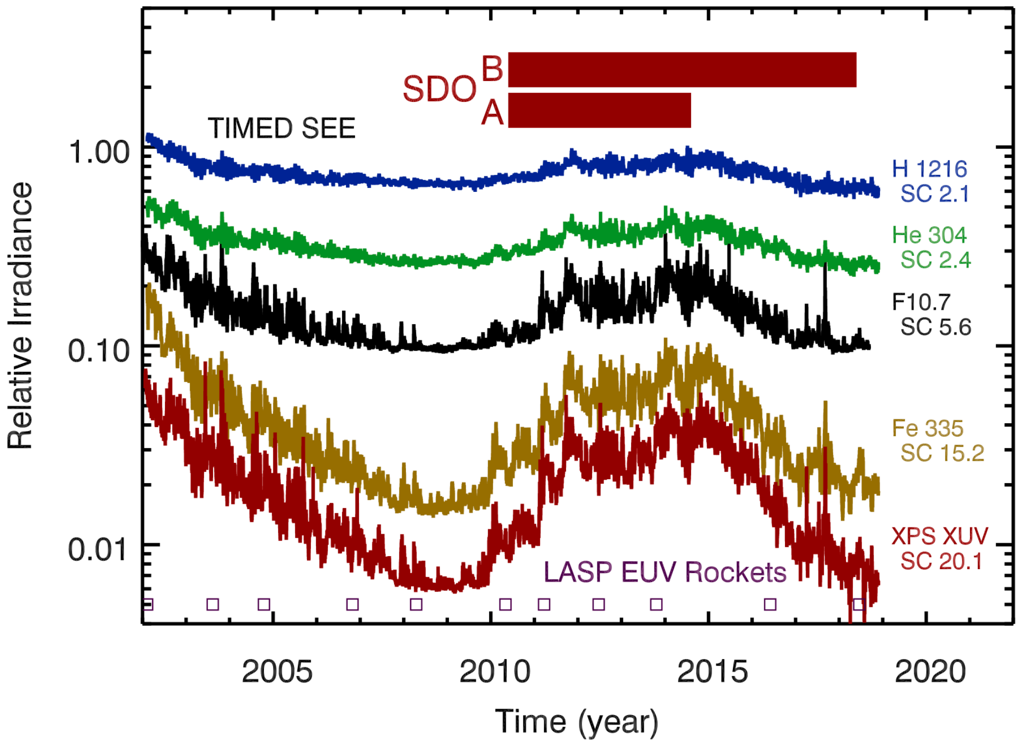


Figure 2. Solar variations during the TIMED mission as observed by SEE. The "SC" values are the solar cycle variations. The F10.7 is the 10.7 cm radio flux and is not measured by SEE. The TIMED measurements overlap with other solar EUV-FUV irradiance measurements from SORCE and SDO. The SORCE XPS is same instrument as TIMED SEE XPS. The SDO MEGS-B range is 37-106 nm, and SDO MEGS-A range is 6-37 nm. The SEE Version 12 data are shown here. These data have new degradation trend corrections now through 2016 based on degradation analysis in Woods *et al.* [2018].

III) Summary of risks or obstacles, plus mitigation strategies

There have been no new anomalies for the SEE instrument this year.

The SEE data processing computer was replaced in 2016, so there is not much risk in that system having problems in the coming year. The SEE data products are produced daily, and the data products are then transferred to the SEE public web page at http://lasp.colorado.edu/home/see/.

The SEE instrument operations computer was updated this year, so it is not much risk for the upcoming year.

Both data processing and weekly operation plans are fully automated, being a necessity of very low funding for SEE operations. There are risks for extended down time for SEE because the ground system computers are single string and because there are limited funds to support the SEE operations team at a small fraction of their time. Fortunately, there were no instrument anomalies and only minor ground system anomalies during this past year.

IV) Summary of plans for the coming year

We plan to update SEE data product to version 13 with updated degradation trend based on the June 18, 2018 calibration rocket measurements.

Two papers are planned. One paper will describe the SEE solar irradiance latest products and solar cycle variability over solar cycle 24 (2008-2019). The other paper is about the new Flare Irradiance Spectral Model (FISM) version 2.

V) Publications produced during the past year

This list provides SEE-related papers and presentations in 2018.

Peer-reviewed Articles

Chamberlin, P. C., T. N. Woods, L. Didkovsky, F G. Eparvier, A. R. Jones, J. L. Machol, J. P. Mason, M. Snow, E. M. B. Thiemann, R. A. Viereck, and D. L. Woodraska, Solar Ultraviolet Irradiance Observations of the Solar Flares During the Intense September 2017 Storm Period, *Space Weather*, **16**, 1470, doi: 10.1029/2018SW001866, 2018.

Woods, T. N., F. G. Eparvier, J. Harder, and M. Snow, Decoupling Solar Variability and Instrument Trends using the Multiple Same-Irradiance-Level (MuSIL) Analysis Technique, *Solar Phys.,* **293**, 76, doi: 10.1007/s11207-018-1294-5, 2018.

Presentation Abstracts

Woods, T., F. Eparvier, J. Harder, and M. Snow, Decoupling Solar Variability and Instrument Trends using the Multiple Same-Irradiance-Level (MuSIL) Analysis Technique, Sun-Climate Symposium, Lake Arrowhead, CA, March 19-23, 2018.

VI) Science highlights

Precisely understanding solar cycle variability requires accurate measurements of the solar irradiance over many years and also understanding and correcting for instrument degradation trends accurately. A new analysis technique of identifying days when the solar irradiance could be at the same level and then trending those days and for many different irradiance levels was developed to obtain new results for TIMED SEE instrument trends [Woods *et al.*, 2018]. Examples of this trending analysis, called the Multiple Solar Irradiance Level (MuSIL) technique, are shown in Figure 3 for a couple wavelengths from the SEE EGS data. These improved SEE instrument trends are included in the SEE Version 12 data products and are also illustrated for the solar cycle variability results in Figures 2 and 4.

Figure 4 shows the solar spectral variability results at 1 nm resolution and up to 200 nm from TIMED SEE, SORCE SOLSTICE, and SDO EVE measurements [Woods *et al*., 2018]. These results are for the same irradiance level in solar cycles 23 and 24. ***Because these are over two different solar cycles, an important conclusion is that solar EUV and FUV variability appears to have the same spectral behavior independent of solar activity level.*** These improved solar cycle variability results will be important for modeling the ionosphere and thermosphere response during solar cycles 23 and 24.

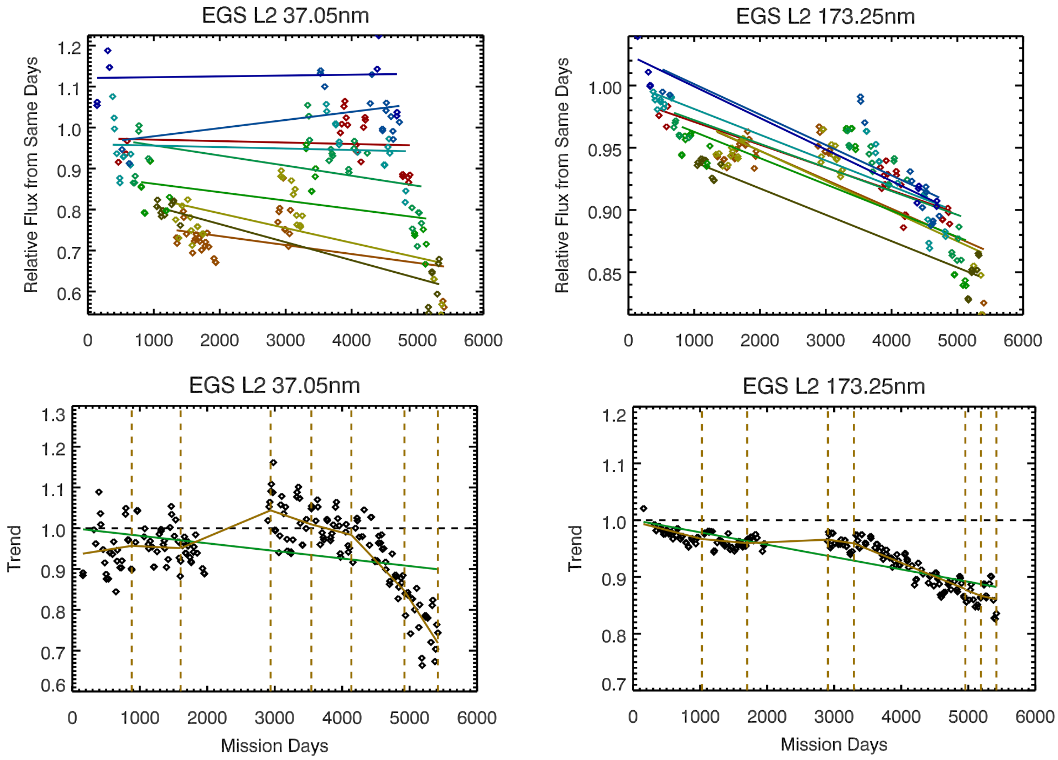


Figure 3. Example MuSIL analysis and trend fits for TIMED SEE data at 37.05 nm and 173.25 nm [Woods et al., 2018]. The top plots show the trends for each irradiance level (each has different color) that has both solar cycle variability and instrument degradation. The lines in the top plots are linear fits per level, which ideally would be flat lines if there was no instrument degradation. The bottom plots show those data merged into single instrument degradation trend. The green line in the bottom plot is a single linear fit over the full mission. The MuSIL result is the mission-long fit as piecewise linear fits (gold lines).

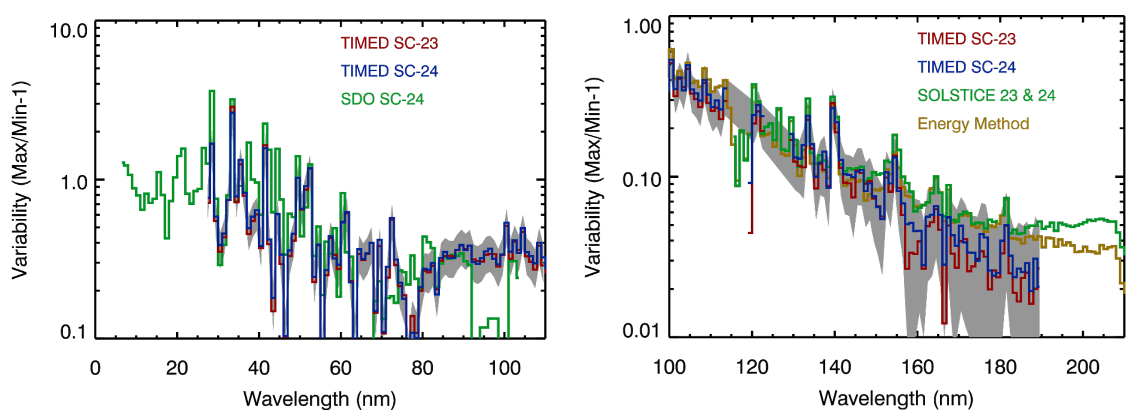


Figure 4. TIMED SEE EGS solar cycle variability comparisons after the MuSIL analysis results have been applied [Woods et al., 2018]. Consistency of the solar cycle 23 (SC-23, red) and 24 (blue) variabilities is validation of the MuSIL technique. The grey shading is uncertainty for applying the MuSIL analysis results. The energy method model for solar cycle variability [Woods *et al*., *Solar Phys*., **290**, 2649, 2015] has similar spectral variability as these results with the MuSIL analysis. The SDO variability result has not had any MuSIL analysis yet, but the SOLSTICE result has had the MuSIL analysis results applied.

Considering that SEE's duty cycle for solar observations is just 3%, SEE was fortunate to observe the two largest flares during solar cycle 24, being the X9.3 flare on 6 September 2017 and the X8.2 flare on 10 September 2017. Figure 5 illustrates an important flare result with the SEE observations [Chamberlin et al., 2018]. ***SEE provides the first spectral measurement of the flare footpoint with an irradiance instrument.*** It is evident in the SEE spectra and differences shown in Figure 5 that the 1-nm bins that are dominated by coronal emissions, for example, from 8 to 14 nm, for the 10 September flare have larger absolute changes than the 6 September flare. Many of the emissions show that the 10 September flare energies are significantly reduced in the cooler emissions formed in the lower solar atmosphere, such as the He II 30.4 nm emission line and the H and He free-bound continua, due to footpoints of the flare being occulted as confirmed by the significantly reduced cool emission and also in solar images. These cooler emission lines from the chromosphere and transition region, along with the core of the strong HI Lyman Alpha emission line at 121.6 nm, show up and dominate the foot point spectra (Figure 5c).

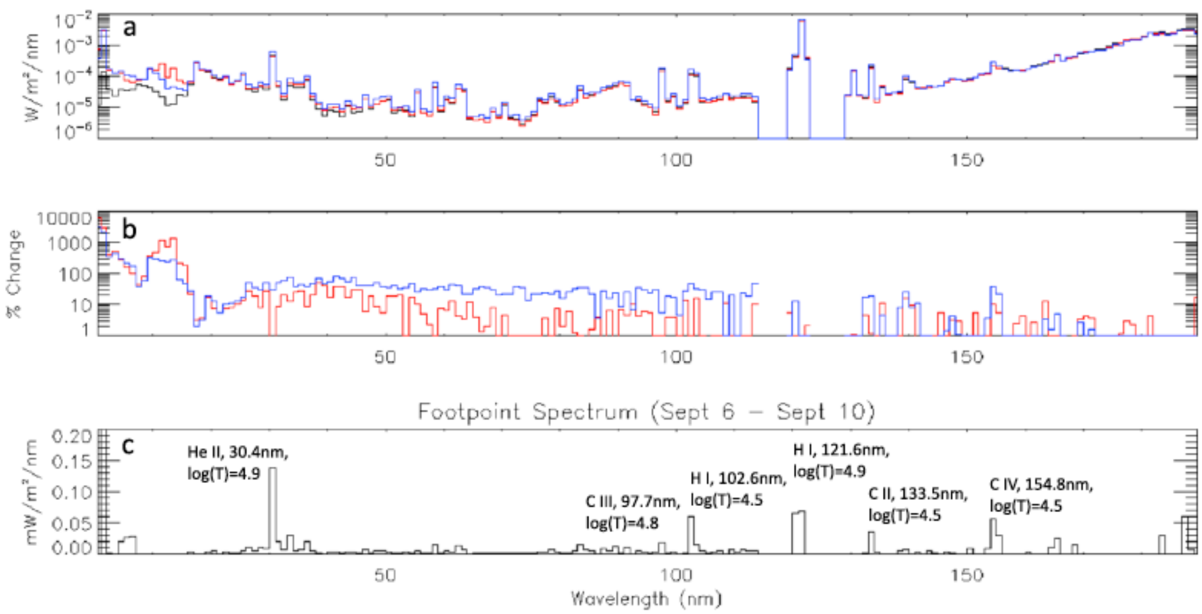


Figure 5. TIMED SEE spectra of the 6 and 10 September 2017 flares [Chamberlin et al., 2018]. The spectra that were taken just after the flare peaks are shown in panel (a) for the 6 September (blue) and 10 September (red) flares, as well as the daily average spectra on 10 September 2017 (black). The spectra are measured in SEE from 27 to 190 nm at 1-nm resolution, while the results shown from 0.5 to 27 nm are the SEE Level 4 modeled spectra at 1-nm resolution. Panel (b) shows the percent change of each flare spectra over its respective daily average spectrum. The subtraction of the over-the-limb, coronal-loops-only 10 September spectrum from the on-disk 6 September spectrum is shown in panel (c) to give an estimation of what a spatially resolved measurement of the footpoints. The strongest emission lines, along with their formation temperature, are labeled for the footpoint spectrum.