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, 2017 (Year 16)

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

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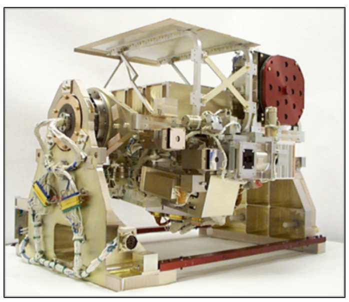
I) Summary of research originally proposed



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).

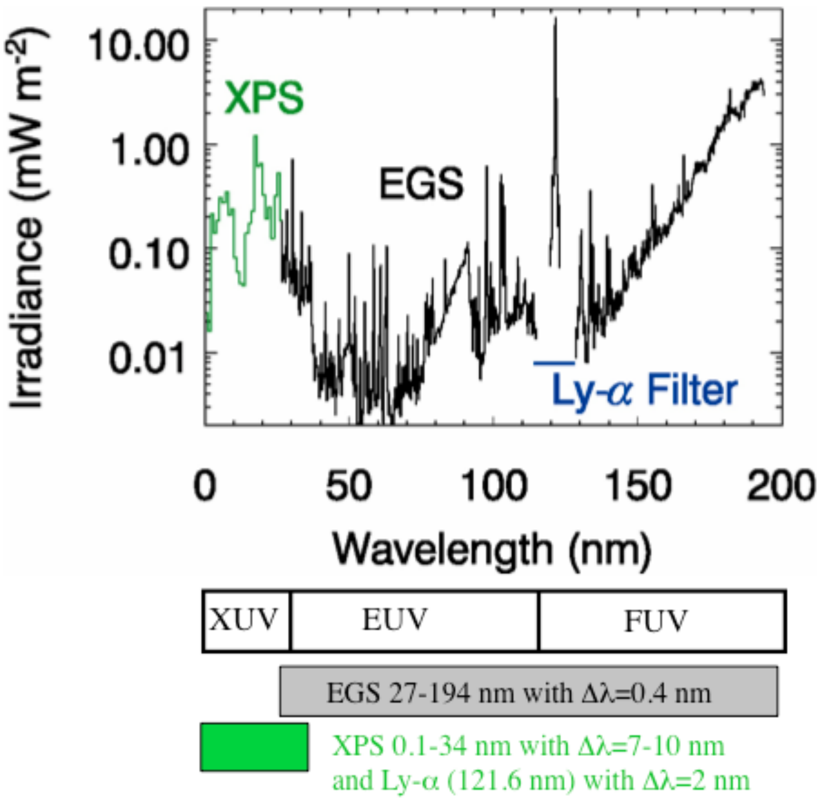


Figure 1. Example Solar Spectrum from TIMED SEE.

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. There have been no data gaps for SEE this past year. 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.

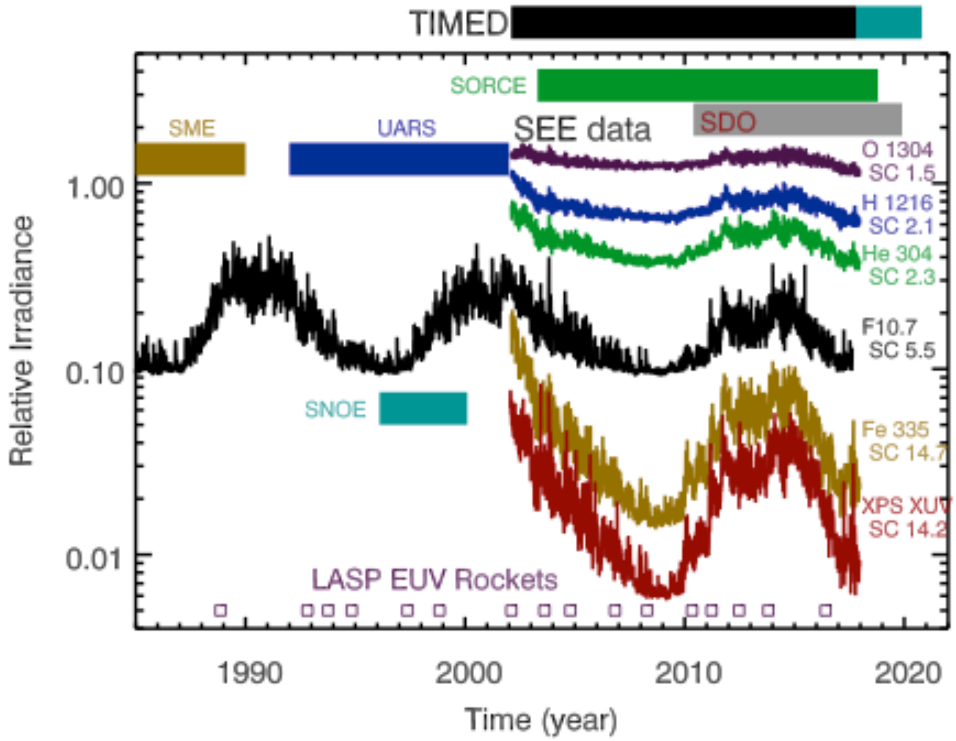


Figure 2. Solar variations during the TIMED mission as observed by SEE. The "SC" values are the solar cycle variations. The F10.7 is the 10.7 cm radio flux and is not measured by SEE. The TIMED measurements overlap with other solar EUV-FUV irradiance measurements from SORCE and SDO. The SEE Version 12 data are shown here. These data have new degradation trend corrections now through 2016 based on degradation analysis in Woods *et al.* [2017].

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 last year, 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 LASP shared data system (web site) is likely to be updated in 2018, so the TIMED SEE data products may be off-line for a couple days during that transition.

The SEE instrument operations computer, which sends weekly command loads to the TIMED MOC at JHU APL, is also a very old computer, and it will need to be replaced as funds are available in next year's budget.

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; consequently, there are no gaps in SEE daily data products during the past year.

IV) Summary of plans for the coming year

A paper [Woods *et al*., 2017] describing degradation analysis for SEE instrument trends was submitted in 2017 and is expected to be published in 2018. A paper describing the SEE solar irradiance Version 12 products and recent solar modeling results will be prepared.

The SEE instrument operation computer will be replaced.

V) Publications produced during the past year

The TIMED SEE grant supports mission operations and data processing but very little science analysis. Although this grant did not directly support the following publications, this list provides SEE-related papers published in 2017.

Peer-reviewed Articles

Dong, Y., X. Fang, D. A. Brain, J. P. McFadden, J. S. Halekas, J. E. P. Connerney, F. Eparvier, L. Andersson, D. Mitchlell, and B. M. Jakosky, Seasonal variability of Martian ion escape through the plume and tail from MAVEN observations, *J. Geophys. Res*., **122**, 4009-4022, doi: 10.1002/2017JA023517, 2017.

Dubinin, E., M. Fraenz, M. Patzold, J. McFadden, P. R. Mahaffy, F. Eparvier, J. S. Halekas, J. E. P. Connerney, D. Brain, B. M. Jakosky, O. Vaisberg, and L. Zelenyi, Effects of solar irradiance on the upper ionosphere and oxygen ion escape at Mars: MAVEN observations, *J. Geophys. Res*., **122**, 7142-7152, doi: 10.1002/2017JA02416, 2017.

Fontenla, J. M., M. Codrescu, M. Ferizzi, T. Fuller-Rowell, F. Hill, E. Landi, and T. Woods, Five Years of Synthesis of Solar Spectral Irradiance from SDID/SISA and SDO/AIA Images, *Astrophys. J.,* **834**, A54, doi: 10.3847/1538-4357/834/54, 2017.

Huang, J., Y. Hao, D. Zhang, and Z. Xiao, Revisiting interminima solar EUV change using adjusted SOHO SEM data, *J. Geophys. Res*., **122**, 3420-3429, doi: 10.1002/2016JA023664, 2017.

Johnasson, F. L., E. Odelstad, J. J. P. Paulsson, S. S. Harang, A. I. Eriksson, T. Mannel, E. Vigren, N. J. T. Edberg, W. J. Milch, C. Simon-Wedlund, E. Thiemann, F. Eparvier, and L. Andersson, Rosetta photoelectron emission and solar ultraviolet flux at comet 67P, *Mon. Not. Royal Astron. Soc*., **469**, S626-635, doi: 10.1093/mnras.stx2369, 2017.

Lee, C. O., T. Hara, J. S. Halekas, E. Thiemann, P. Chamberlin, F. Eparvier, R. J. Lillis, D. E. Larson, P. A. Dunn, J. R. Espley, J. Gruesbeck, S. M. Curry, J. G. Lhmann, and B. M. Jakosky, MAVEN observations of the solar cycle 24 space weather conditions at Mars, *J. Geophys. Res*., **122**, 2768-2791, doi: 10.1002/2017JA023495, 2017.

Mendillo, M., C. Narvaez, M. F. Vogt, M. Mayyasi, J. Forbes, M. Galand, E. Thiemann, M. Benna, F. Eparvier, P. Chamberlin, P. Mahaffy, and L. Andersson, Sources of Ionospheric Variability at Mars, *J. Geophys. Res*., **122**, 9670-9684, doi: 10.1002/2017JA024366, 2017.

Solomon, S. C., Global modeling of thermospheric airglow in the far ultraviolet, *J. Geophys. Res*., **122**, 7834-7848, doi: 10.1002/2017JA024314, 2017.

Thiemann, E. M. B., P. C. Chamberlin, F. Eparvier, B. Templeman, T. N. Woods, S. W. Bougher, and B. M. Jakosky, The MAVEN EUVM model of solar spectral irradiance variability at Mars: Algorithms and results, *J. Geophys. Res*., **122**, 2748-2767, doi: 10.1002/2017JA023512, 2017.

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*., in review, 2017.

Presentation Abstracts

Eparvier, F. G., E. Thiemann, and T. N. Woods, Improving Soft X-Ray Spectral Irradiance Models for Use Throughout the Solar System, *AGU Fall Meeting,* SH43B-2826, poster, 2017.

Elliott, J. P., B. Vanier, and T. N. Woods, XUV Photometer System (XPS): New Dark-Count Corrections Model and Improved Data Products, *AGU Fall Meeting*, SH43B-2817, poster, 2017.

Woods, T. N., Measurements of the Solar Spectral Irradiance Variability over Solar Cycles 21 to 24, *AGU Fall Meeting*, SH42A-04, oral, 2017.

Woods, T. N., Surprising Solar Flares: Studying the Sun as a Star, *USC Physics and Astronomy Dept. Seminar, Invited*, Nov. 27, 2017.

Woods, T. N., Solar Irradiance Variability from NASA Satellites, *NSO Seminar, Invited*, Oct. 3, 2017.

Woods, T. N., Surprising Solar Flares: Studying the Sun as a Star, *NOAA Seminar*, March 23, 2017.

Woods, T. N., Surprising Solar Flares: Studying the Sun as a Star, *LASP Public Lecture*, February 1, 2017.

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.*, 2017]. 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. 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 5 shows the solar EUV variability over the TIMED mission, which indicates that the solar cycle variability in cycle 23 is 45% more than that in cycle 24. Based on trending of the solar magnetic field, there are expectations that the next solar cycle 25 could be similar or even lower than cycle 24. The next cycle minimum is expected in 2019-2020. Furthermore, the TIMED SEE future measurements will obtain solar cycle minimum observations in 2019-2020 that can be compared to the TIMED SEE measurements at the last minimum in 2008-2009. Those comparisons at solar cycle minima will provide results on any long-term (secular) variations that are important for Earth's upper atmosphere long-term changes.

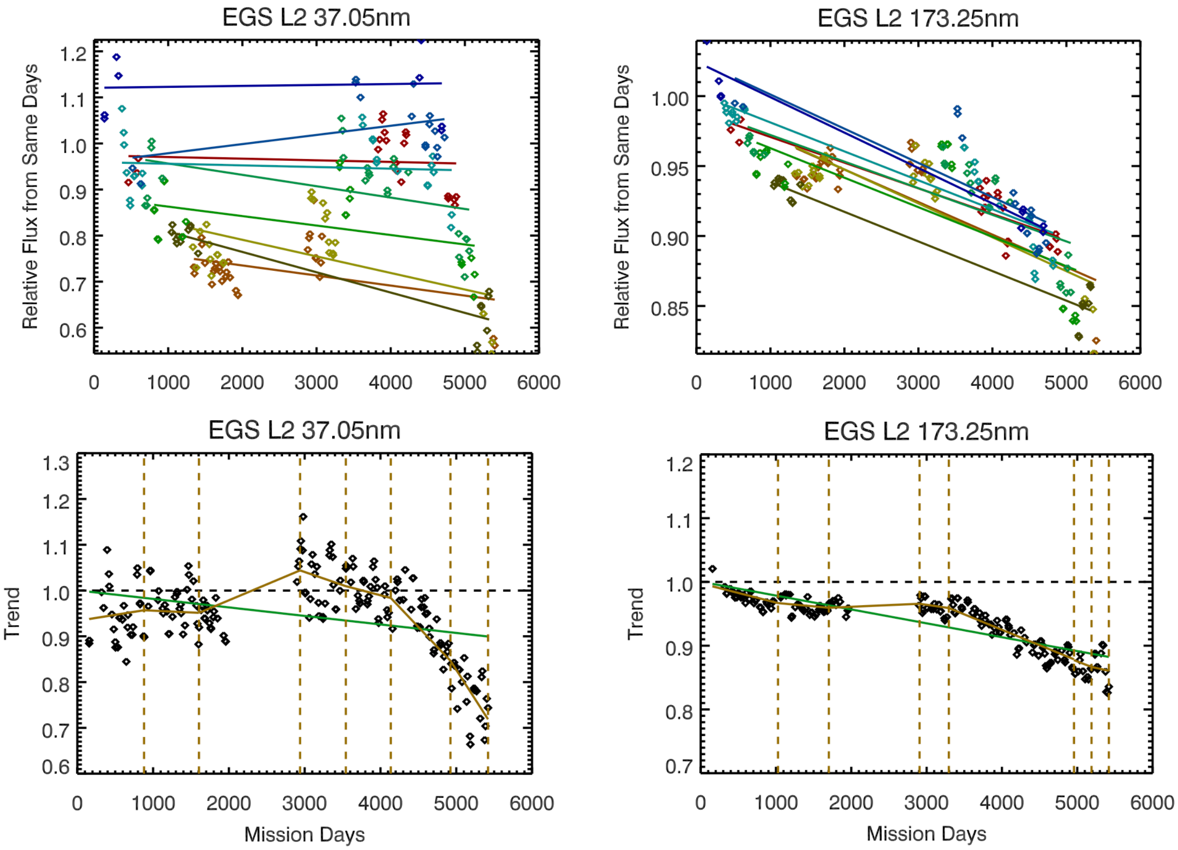


Figure 3. Example MuSIL analysis and trend fits for TIMED SEE data at 37.05 nm and 173.25 nm. The top plots show the trends for each irradiance level (each has different color) that has both solar cycle variability and instrument degradation. The lines in the top plots are linear fits per level, which 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).

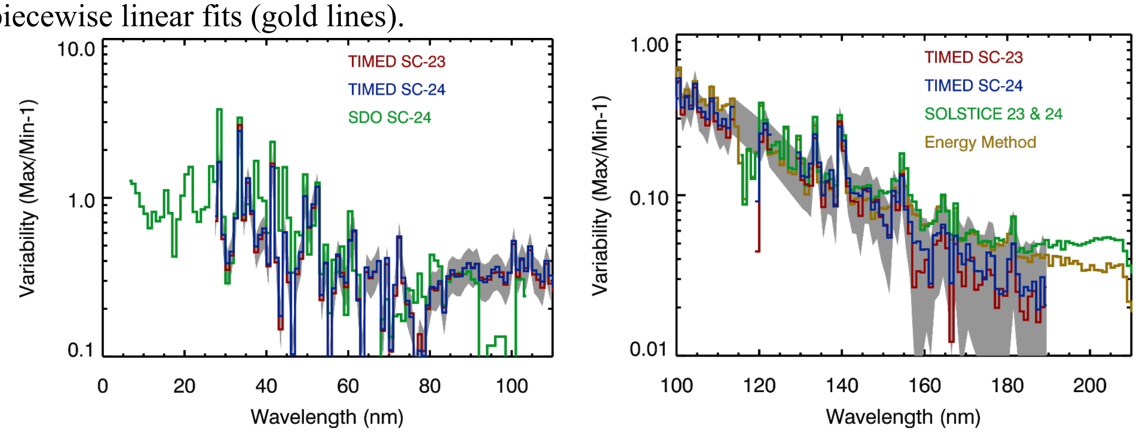


Figure 4. TIMED SEE EGS solar cycle variability comparisons after the MuSIL analysis results have been applied. Consistency of the solar cycle 23 (SC-23, red) and 24 (blue) variabilities is validation of the MuSIL technique. The grey shading is uncertainty for applying the MuSIL analysis results. The 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.

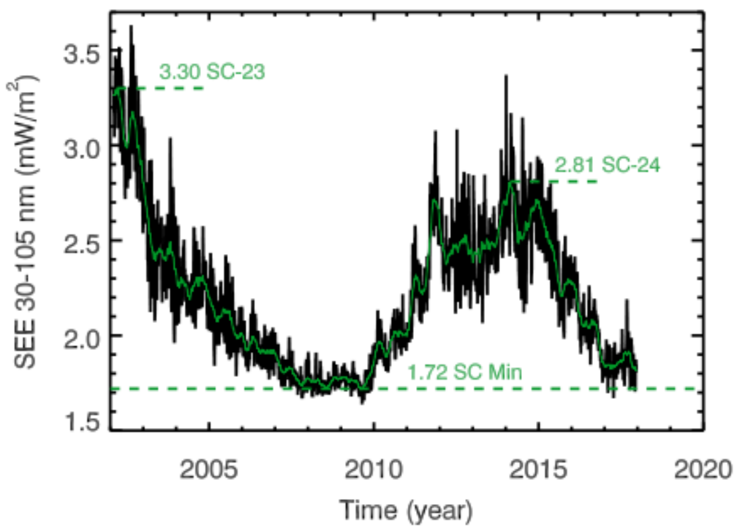


Figure 5. Solar EUV irradiance time series of the TIMED mission. The TIMED SEE spectral irradiance is integrated over 30 nm to 105 nm to illustrate the solar EUV variability. The variability, calculated as maximum irradiance minus minimum irradiance, is 1.58 W/m^2 for solar cycle 23 (SC-23) and is 1.09 W/m^2 for SC-24. This indicates that the solar cycle variability in cycle 23 is 45% more than that in cycle 24.