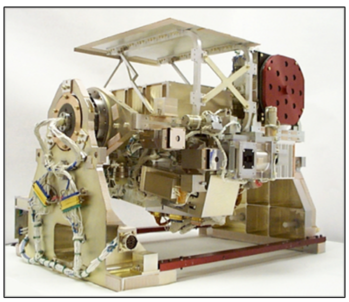
Annual Progress Report for award number: NASA 80NSSC19K0604

R&A Program Name: NASA Heliophysics Senior Review (MO&DS Extended Missions)
Dates covered by this report: January 1 – December 31, 2019 (Year 18)

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

PI Name: Dr. Thomas N. Woods
Institution/address: LASP / University of Colorado
3665 Discovery Dr.
Boulder, CO 80303
Email: tom.woods@lasp.colorado.edu
Phone: 303-492-4224

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 (for SEE operations) primarily supports only original objective #1 (measure the solar VUV spectral irradiance).

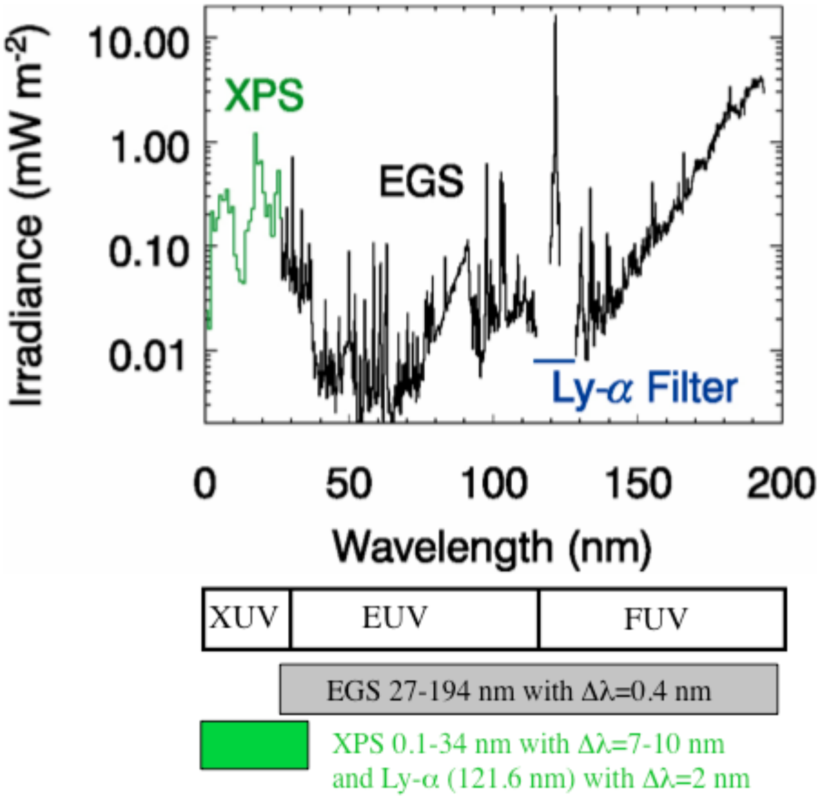


Figure 1. Example solar spectrum from TIMED SEE.

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). This update has been delayed as the rocket EVE calibrations are being finalized. The data gaps in SEE this past year include 18 days: 2019/021-2019/034, 2019/065, 2019/210, and 2019/287-2019/288; 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. The observations in 2019 have a unique relevance in measuring the solar cycle minimum levels that can be compared to the last cycle minimum in 2008-2009. These results are discussed more in the Science Highlights section below.

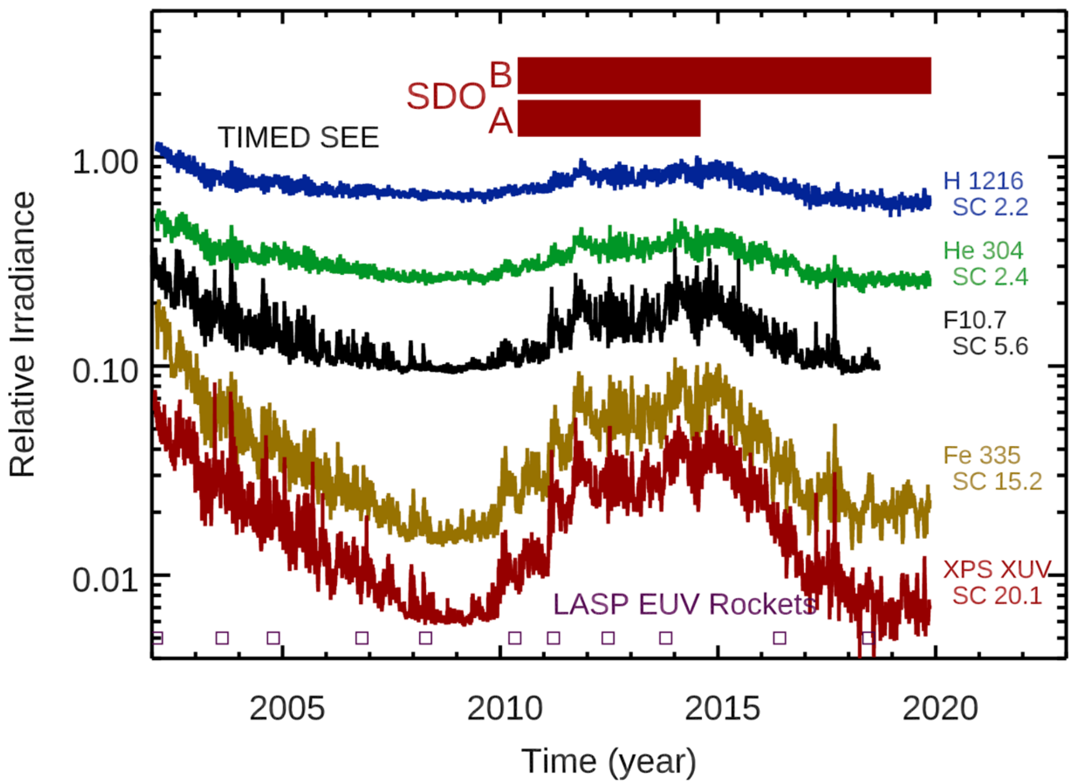


Figure 2. Solar variations during the TIMED mission as observed by SEE. The "SC" values are the solar cycle variations. The F10.7 is the 10.7 cm radio flux and is not measured by SEE. The TIMED measurements overlap with other solar EUV-FUV irradiance measurements from SORCE and SDO. The SORCE XPS is the 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 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 in 2018, so there 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. 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 (supported by SDO EVE).

Three papers are planned. One paper is about the new Flare Irradiance Spectral Model (FISM) version 2. Another paper is planned to discuss the 2019 solar cycle minimum campaign results (see Section VI for more information on this topic). The other paper is about the new analysis technique and related spectral model for processing the TIMED SEE XPS broadband measurements.

V) Publications produced during the past year

This list provides SEE-related papers and presentations in 2019.

Peer-reviewed Articles

Qian, L., W. Wang, A. G. Burns, P. Chamberlin, A. Coster, S-R Zhang, and S. C. Solomon, Solar Flare and Geomagnetic Storm Effects on the Thermosphere and Ionosphere During 6-11 September 2017, *J. Geophys. Res.*, **124**, 2298-2311, doi: 10.1029/2018JA026175, 2019.

Zhang, Y., L. J. Paxton, G. Lu, and S. Yee, Impact of nitric oxide, solar EUV and particle precipitation on thermospheric density decrease, *J. Atmos. Solar-Terr. Phys.*, **182**, 147-154., doi: 10.1016/j.jastp.2018.11.016, 2019.

Machol, J., M. Snow, D. Woodraska, T. Woods, R. Viereck, and O. Coddington, An Improved Lyman-alpha Composite, *Earth Space Science*, Article ID: ESS2420, doi: 10.1029/2019EA000648, 2019.

Qian, L., and T. N. Woods, Solar Flare Effects on the Thermosphere and Ionosphere, in *AGU book*, in press, 2019.

Schillings, A., R. Slapak, H. Nilsson, M. Yamauchi, I. Dandouras, and L-G Westerberg, Earth atmospheric loss through the plasma mantle and its dependence on solar wind parameters, *Earth, Planets and Space,* 71, 70, https://doi.org/10.1186/s40623-019-1048-0, 2019.

Presentation Abstracts

Woods, T., Solar Irradiance Variability Observations during Solar Cycles 21 to 24, *Space Climate 7 Symposium*, Canton Orford, Canada, July 2019 [invited].

Knoer, V., E. Thiemann, F. G. Eparvier, P. Chamberlin, and T. Woods, Predicting solar spectra using broadband EUV irradiance measurements, *SHINE Workshop*, Boulder, CO, August 2019.

Snow, M. A., S. Béland, E. C. Richard, T. N. Woods, F. Epavier, and P. Chamberlin, Solar Spectral Irradiance during WHPI and comparison to WHI and WSM, *AGU Fall Meeting*, San Francisco, CA, SH43A-01, December 2019.

VI) Science highlights

The international Whole Heliosphere and Planetary Interaction (WHPI) have three campaigns planned to study the solar cycle minimum conditions of the Sun, at Earth, and throughout our planetary system. Another WHPI program objective is to compare the current minimum with the previous cycle minimum in 2008-2009. The three WHPI campaign periods are March 12 – April 8, 2019 (Carrington Rotation 2215), June 29 – July 26, 2019 (Carrington

Rotation 2219), and January 11 – February 7, 2020 (Parker Solar Probe fourth perihelion campaign). The first two campaigns have been completed, and the third campaign is in early 2020. The WHPI preliminary science results will be presented at the fall 2019 AGU meeting in the SH43A & SH41D sessions, titled Space Weather Across the Solar System: New Progress and the Whole Heliosphere and Planetary Interactions (WHPI).

The TIMED SEE contribution for the 2019 campaigns is shown in Figure 3. The June-July 2019 campaign data has slightly lower irradiance than the March-April 2019 campaign data, especially in the XUV (0-30 nm) range. Time will tell when the solar cycle minimum actually occurred, but for now, the July 2019 period is a candidate for the cycle minimum.

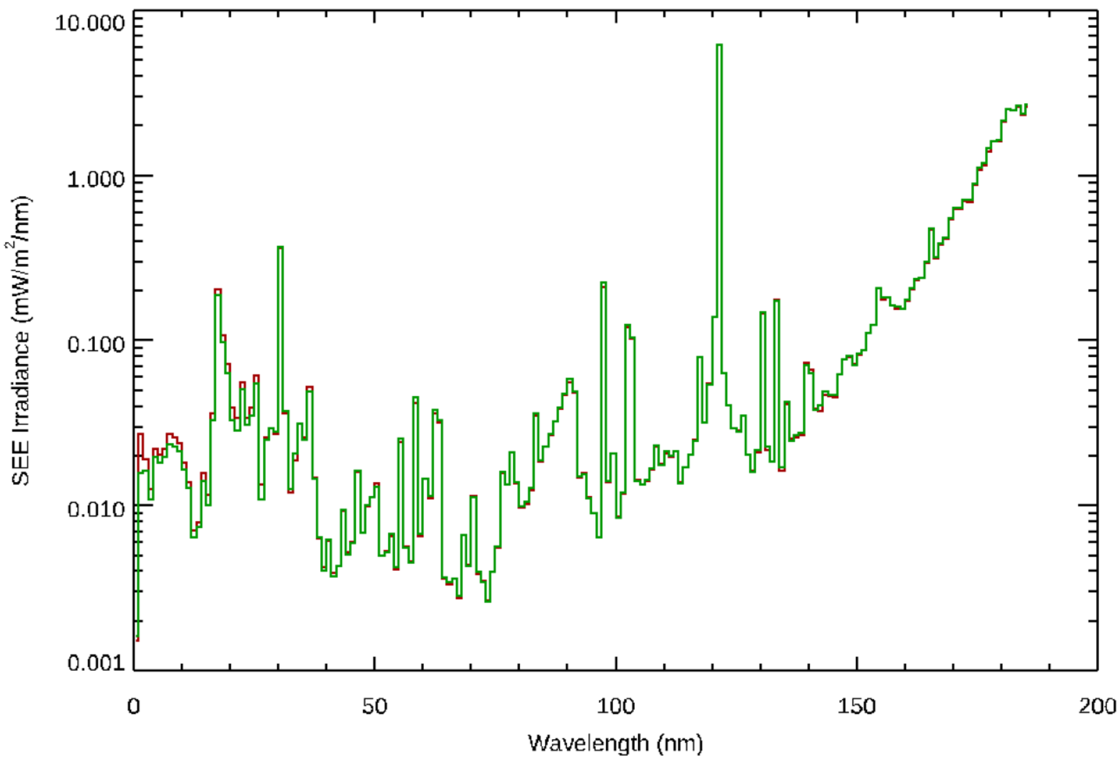


Figure 3. The TIMED SEE reference spectra for the WHPI campaigns in March-April 2019 (red) and June-July 2019 (green). These are based on SEE Level 3 Version 12 data product with 1-nm spectral resolution.