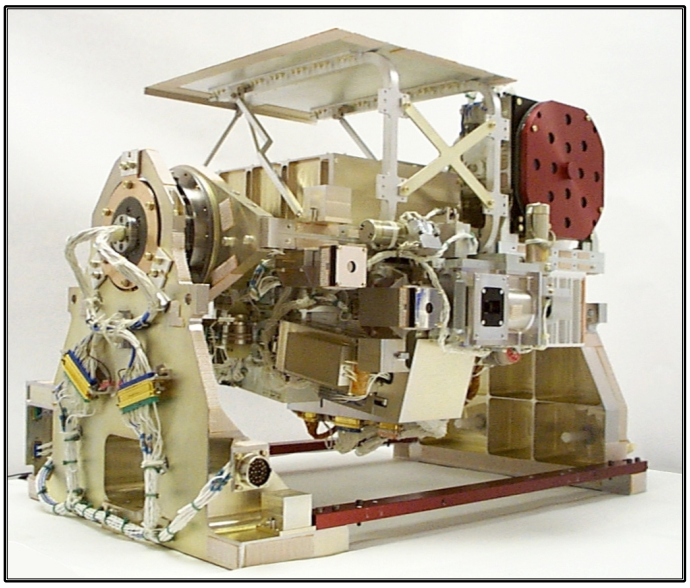
TIMED Solar EUV Experiment (SEE)
Phase E Final Report
December 16, 2011



Submitted for NASA Grant NNX07AB68G
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Mitch Furst, SEE Collaborator - NIST Calibrations of SEE / Rocket (NIST – SURF)
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Robert Meier, SEE Collaborator – GUVI airglow scientist (George Mason Univ.)
Phil Richards, SEE Collaborator – ionosphere / solar modeling (George Mason Univ.)
Liying Qian, SEE Collaborator – thermosphere/ionosphere modeling (NCAR High Altitude Observatory)
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Harry Warren, SEE Collaborator – solar irradiance modeling (Naval Research Laboratory)

Report Outline:
1. SEE Science Overview
2. SEE Mission Operations and Data Processing System Overview
3. List of SEE Personnel and Students (13 students, 3 PhD dissertations)
4. List of SEE-related Publications (111 papers)

1. Solar EUV Experiment (SEE) Science Overview

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. The Woods et al. [2005] paper provides detailed overview 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 1.1.

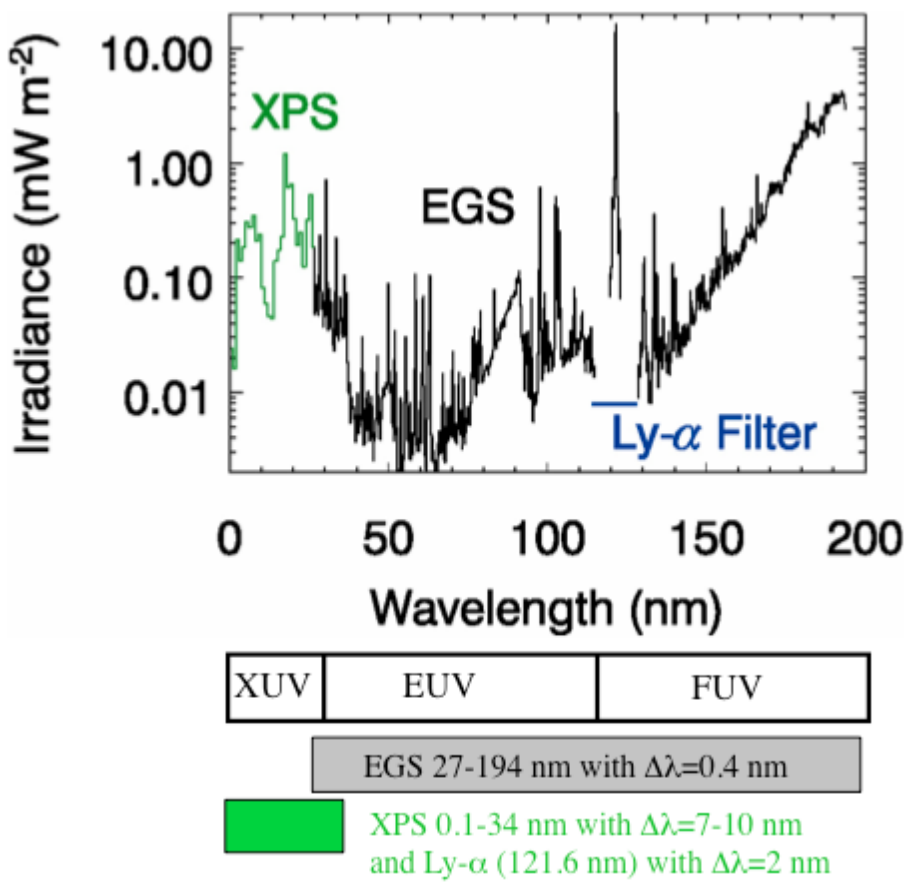

Figure 1.1. Example Solar Spectrum from TIMED SEE.

There are very few observation gaps in the daily record of the solar UV irradiance from TIMED SEE (more details given in Section 2), 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 as planned with the full set of XPS channels.

The TIMED SEE program has exceeded all expectations in achieving its science goals. As originally proposed, the SEE science objectives are to:

(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

The SEE-related papers listed in Section 4 provide the many details on the results that address these objectives. The following provides a brief summary of key results for each objective and which papers most directly address each of these objectives.

1.1. Measure the solar VUV irradiance and its variability

The TIMED SEE program has been extremely successful in measuring the daily solar vacuum ultraviolet (VUV: 0-200 nm) irradiance. While our original intention was to only provide daily irradiance data products for studies of 27-day solar rotation and 11-year solar cycle variations, it was recognized early in the program that the individual observations were also needed by the science community in order to study solar flares and their effects on Earth's upper atmosphere. Consequently, the SEE data products include both daily averages and observations during each orbit. Note that the SEE solar observations are limited to 3% duty cycle due to having a single-axis solar pointing platform on a nadir-viewing TIMED spacecraft. Nonetheless, the 3-minute observations per orbit for SEE have provided dozens of solar flare observations.

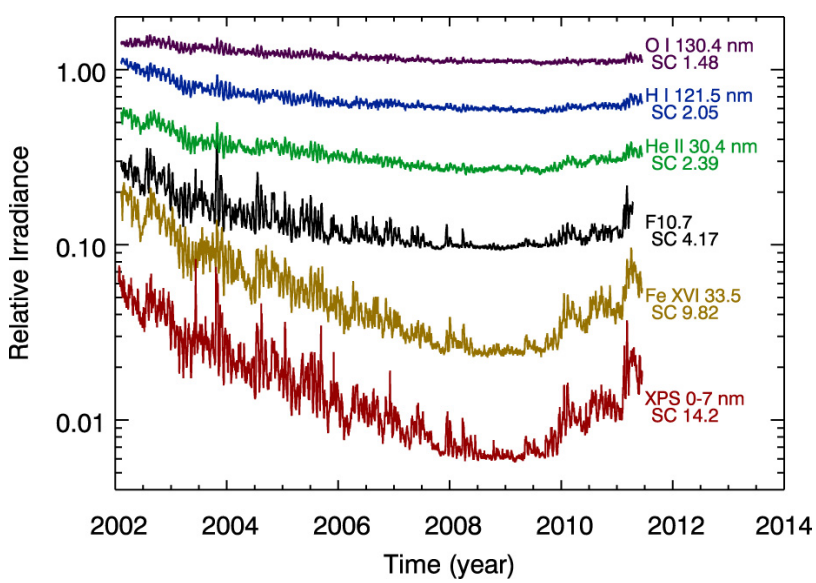

Figure 1.2. Solar variations during the TIMED mission as observed by SEE. The "SC" values are the solar cycle variations. The F10.7 is the 10.7 cm radio flux and is not measured by SEE.

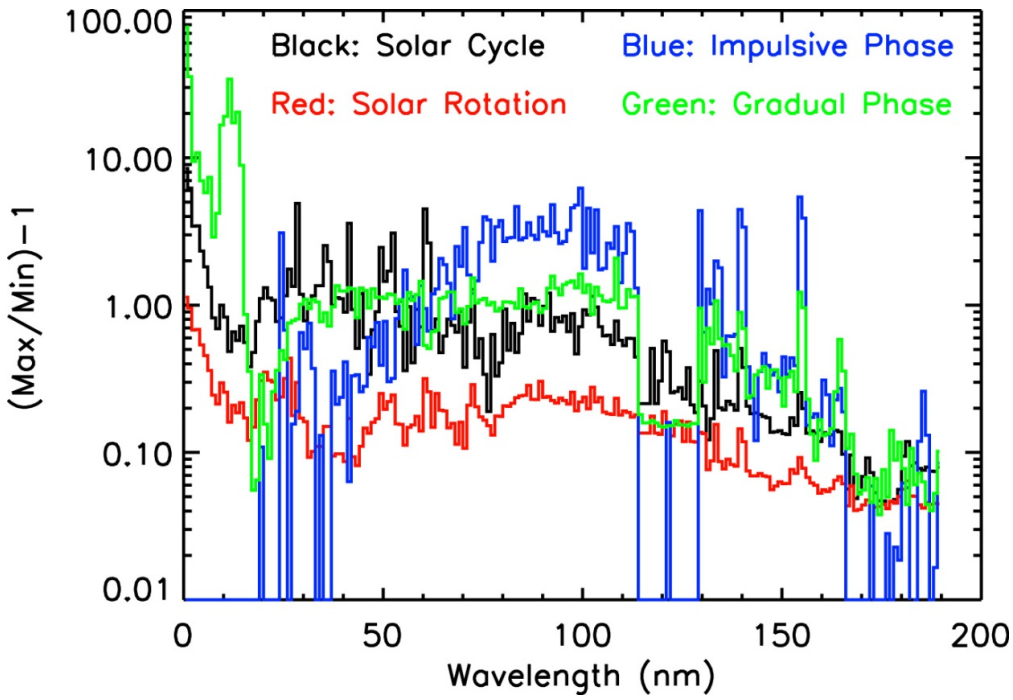

Figure 1.3. Examples of solar UV spectral variations: 27-day solar rotation, 11-year solar cycle, impulsive phase component of flare, and gradual phase component of flare. These four variations are part of Phil Chamberlin's Flare Irradiance Spectral Model (FISM).

<u>Key papers for solar rotation and solar cycle variation results with SEE:</u>

Woods, T. N., F. G. Eparvier, S. M. Bailey, P. C. Chamberlin, J. Lean, G. J. Rottman, S. C. Solomon, W. K. Tobiska, and D. L. Woodraska, The Solar EUV Experiment (SEE): Mission overview and first results, *J. Geophys. Res.,* 110, A01312, doi: 10.1029/2004JA010765, 2005.

Chamberlin, P. C., T. N. Woods, and F. G. Eparvier, Flare Irradiance Spectral Model (FISM): Daily component algorithms and results, *Space Weather,* 5, 7, S07005, doi: 10.1029/2007SW000316, 2007.

Woods, T. N., P. C. Chamberlin, J. W. Harder, R. A. Hock, M. Snow, F. G. Eparvier, J. Fontenla, W. E. McClintock, and E. C. Richard, Solar Irradiance Reference Spectra (SIRS) for the 2008 Whole Heliosphere Interval (WHI), *Geophys. Res. Lett.*, 36, L01101, doi: 101029/2008GL036373, 2009.

Lean, J. L., T. N. Woods, F. G. Eparvier, R. R. Meier, D. J. Strickland, J. T. Correira, and J. S. Evans, Solar extreme ultraviolet irradiance: Present, past and future, *J. Geophys. Res*., 116, A01102, doi: 10.1029/2010JA015901, 2011.

<u>Key papers for solar flares with SEE:</u>

Woods, T. N., S. M. Bailey, W. K. Peterson, H. P. Warren, S. C. Solomon, F. G. Eparvier, H. Garcia, C. W. Carlson, and J. P. McFadden, Solar extreme ultraviolet variability of the X-class flare on April 21, 2002 and the terrestrial photoelectron response, *Space Weather,* 1, 1001, doi:10.1029/2003SW000010, 2003.

Woods, T. N., F. G. Eparvier, J. Fontenla, J. Harder, G. Kopp, W. E. McClintock, G. Rottman, B. Smiley, and M. Snow, Solar irradiance variability during the October 2003 solar storm period, *Geophys. Res. Lett.,* 31, L10802, doi: 10.1029/2004GL019571, 2004.

Woods, T. N., G. Kopp, and P. C. Chamberlin, Contributions of the solar ultraviolet irradiance to the total solar irradiance during large flares, *J. Geophys. Res.*, 111, A10S14, doi: 10.1029/2005JA011507, 2006.

Rodgers, E. M., S. M. Bailey, H. P. Warren, T. N. Woods, and F. G. Eparvier, Soft X-ray irradiances during a solar flare observed by TIMED-SEE, *J. Geophys. Res.*, 111, A10S13, doi: 10.1029/2005JA011505, 2006.

Chamberlin, P. C., T. N. Woods, and F. G. Eparvier, Flare Irradiance Spectral Model (FISM): Flare component algorithms and results, *Space Weather*, **6**, S05001, doi: 10.1029/2007SW000372, 2008.

Woods, T. N., P. C. Chamberlin, W. K. Peterson, R. R. Meier, P. G. Richards, D. J. Strickland, G. Lu, L. Qian, S. C. Solomon, B. A. Iijima, A. J. Mannucci, and B. T. Tsurutani, XUV Photometer System (XPS): Improved irradiance algorithm using CHIANTI spectral models, *Solar Physics,* 249, doi: 10.1007/s11207-008-9196-6, 2008.

1.2. Solar-terrestrial relationships utilizing atmospheric models

The second SEE objective is to study the solar influences on Earth's upper atmosphere (thermosophere and ionosphere). This study involves inputting the SEE solar irradiance observations into thermosphere-ionosphere models and then comparing to atmospheric observations (such as from the other TIMED instruments) to better understand the physical processes on how the solar radiation can affect the neutral densities and ionized plasma in Earth's atmosphere. Two results that surprised us are that solar flares are equally important as the slower daily variations on influencing Earth's upper atmosphere and that neutral density response to solar variations can be hours and not the 1-3 days that we had assumed before the TIMED mission.

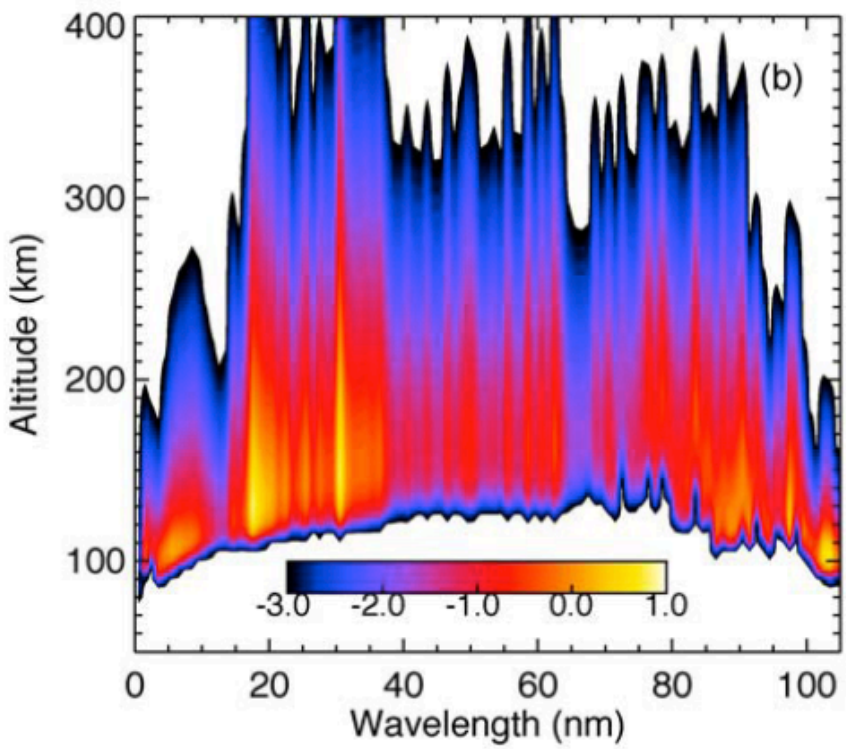

Figure 1.4. This plot shows the altitude where the solar EUV irradiance is deposited. This is a key first step in modeling solar influence on Earth's atmosphere (from Solomon & Qian, 2005).

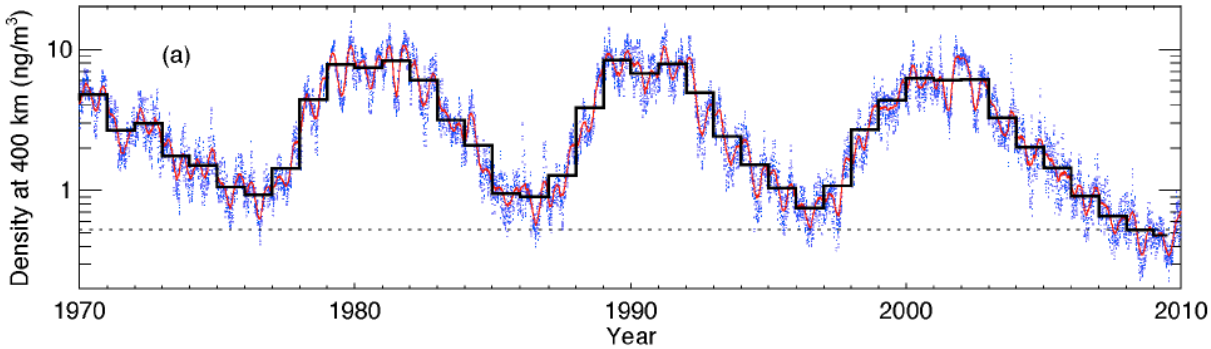

Figure 1.5. The 30% lower thermosphere density at 400 km during the recent solar cycle minimum in 2008-2009 is understood as being caused by lower solar EUV irradiance in 2008 as confirmed with NCAR's thermosphere general circulation model (from Solomon et al., 2011).

<u>Key papers for modeling of the solar influence on Earth's atmosphere:</u>

Solomon, S. C. and L. Qian, Solar extreme-ultraviolet irradiance for general circulation models, *J. Geophys. Res.*, 110, A10306, doi: 10.1029/2005JA011160, 2005.

Tsurutani, B. T., D. L. Judge, F. L. Guarnieri, P. Gangopadhyay, A. R. Jones, J. Nuttall, G. A. Zambon, L. Didkovsky, A. J. Mannucci, B. Iijima, R. R. Meier, T. J. Immel, T. N. Woods, S. Prasad, J. Huba, S. C. Solomon, P. Straus, and R. Viereck, The October 28, 2003 extreme EUV solar flare and resultant extreme ionospheric effects: Comparison to other Halloween events and the Bastille Day event, *Geophys. Res. Lett.,* 32, L03S09, doi: 10.1029/2004GL021475, 2005.

Strickland, D. J., J. L. Lean, R. E. Daniell, H. K. Knight, W. K. Woo, R. R. Meier, P. R. Straus, T. N. Woods, F. G. Eparvier, D. R. McMullin, A. B. Christensen, D. Morrison, and L. J. Paxton, Constraining and validating the Oct./Nov. 2003 X-class EUV flare enhancements with observations of FUV dayglow and E-region electron densities, *J. Geophys. Res.*, 112, A11, 6313, doi: 10.1029/2006JA012074, 2007.

Smithtro, C. G., and S. C. Solomon, An improved parameterization of thermal electron heating by photoelectrons, with application to an X17 flare, *J. Geophys. Res.*, *113*, A08307, doi: 10.1029/2008JA013077, 2008.

Qian, L., R. G. Roble, S. C. Solomon, and T. J. Kane, Model simulations of global change in the ionosphere, *Geophys. Res. Lett.*, 35, L07811, doi: 10.1029/2007GL033156, 2008.

Qian, L., S. C. Solomon, R. G. Roble, B. R. Bowman, and F. A. Marcos, Thermospheric neutral density response to solar forcing, *Adv. Space Res.*, 42, 5, 926-932, doi: 10.1016/j.asr.2007.10.019, 2008.

Solomon, S. C., T. N. Woods, L. V. Didkovsky, J. T. Emmert, and L. Qian, Anomalously low solar extreme-ultraviolet irradiance and thermospheric density during solar minimum, *Geophys. Res. Lett*., 37, doi: 10.1029/2010GL044468, 2010.

Solomon, S. C., L. Qian, L. V. Didkovsky, R. A. Viereck, and T. N. Woods, Causes of low thermospheric density during the 2007–2009 solar minimum, *J. Geophys. Res.,* **116**, A00H07, doi: 10.1029/2011JA016508, 2011.

Qian, L., A. G. Burns, P. C. Chamberlin, and S. C. Solomon, Variability of the thermosphere and ionosphere response to solar flares, *J. Geophys. Res.*, 116, A10309, doi: 10.1029/2011JA016777, 2011.

1.3. Thermosphere neutral densities / satellite drag

Understanding the thermosphere neutral density and its variations with solar activity is especially important for tracking satellites as part of our national space weather operations. During some orbits, SEE is able to observe the sun setting or rising and consequently sound the thermosphere during these solar occultation experiments. These special occultation measurements are provided in the SEE Level 2B data products and are useful for deriving the thermosphere neutral density. The other TIMED instruments also provide thermosphere neutral density observations with much better global coverage than SEE with its limited number of solar occultation experiments. As one example, Bruce Bowman used the SEE data to develop a new thermosphere density model that is now used operationally by the Air Force in predicting satellite drag on a daily basis.

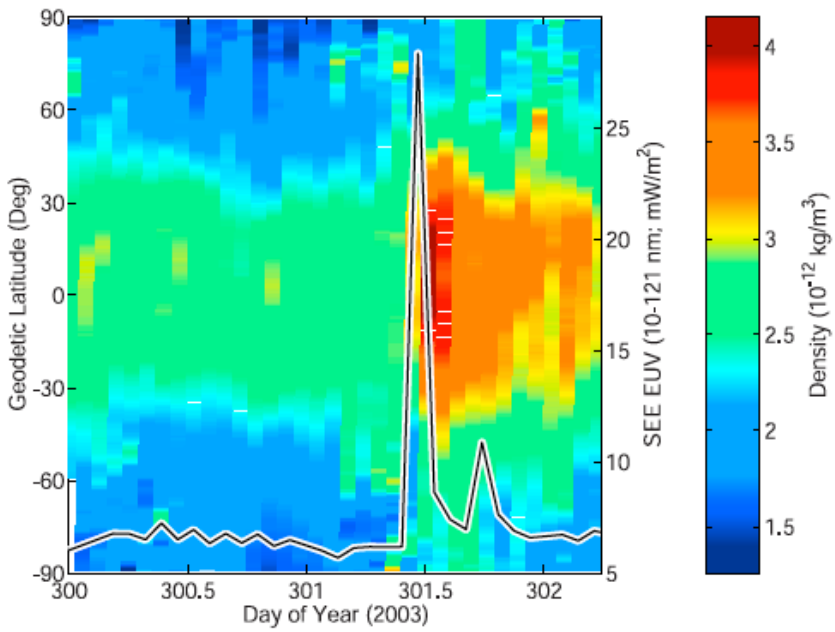

Figure 1.6. The thermosphere neutral density responds quickly to a large solar flare. (from Figure 3 in Sutton et al., 2006).

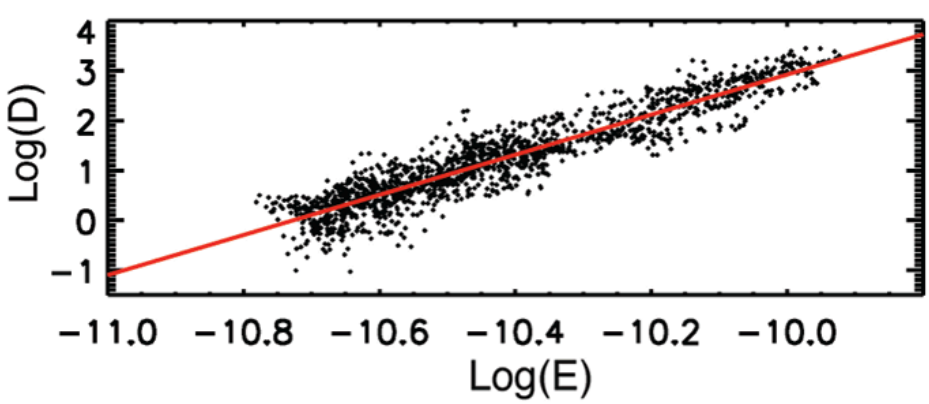

Figure 1.7. Satellite drag (D) is highly correlated with solar EUV irradiance (E). (from Figure 8 in Woodraska et al., 2007).

Key papers concerning thermosphere neutral densities / satellite drag using SEE data:

Forbes, J. M., G. Lu, S. Bruinsma, S. Nerem, and X. Zhang, Thermosphere density variations due to the 15-24 April 2002 solar events from CHAMP/STAR accelerometer measurements, *J. Geophys. Res.,* 110, A12S27, doi: 10.1029/2004JA010856, 2005.

Sutton, E. K., J. M. Forbes, R. S. Nerem, and T. N. Woods, Neutral density response to the solar flares on October and November 2003, *Geophys. Res. Lett.*, 33, L22101, doi: 10.1029/2006GL027737, 2006.

Bowman, B. R., W. K. Tobiska, and F. A. Marcos, A New Empirical Thermospheric Density Model JB2006 Using New Solar Indices, *AIAA*, 2006-6166, 2006.

Woodraska, D. L., T. N. Woods, and F. G. Eparvier, Comparison of TIMED Satellite Drag with Solar EUV Experiment (SEE) Measurements, *Journal of Spacecraft and Rockets,* 44, 6, 1204-1209, doi: 10.2514/1.28639, 2007.

1.4. Understanding solar VUV variability and its sources

1.5. Improving proxy models of the solar VUV irradiance

These two SEE objectives are very much inter-related and are thus discussed in a single section. Once the solar VUV variability is better understood, then the models of the solar VUV irradiance can be improved. Five different proxy models of the solar EUV irradiance have been improved because of the SEE observations: NRLEUV, SOLAR2000, HEUVAC, FISM, and NRLSSI. Two of these models, SOLAR2000 and FISM, also include flare components, which had not existed in proxy models prior to the TIMED mission. These models and how they were improved with SEE data are described in detail in the following list of papers.

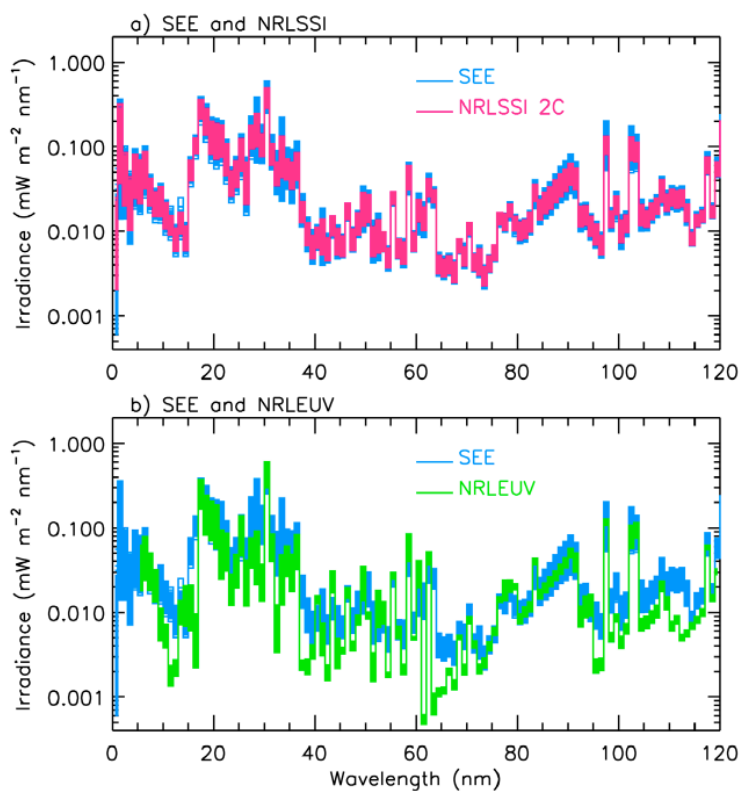

Figure 1.8. Comparison of NRLSSI model (Lean et al., 2011) and NRLEUV model (Warren et al., 2006) to SEE. The NRLSSI model shows improvement when 3 components of solar variability are included instead of just 2 components. (Figure 3 from Lean et al., 2011).

<u>Key papers about solar proxy models of the solar EUV irradiance:</u>

Warren, H., NRLEUV 2: a new model of solar EUV irradiance variability, *Adv. Space Res.*, 37, 2, p. 359-365, 2006.

Tobiska, W. K., and S. D. Bouwer, New developments in SOLAR2000 for space research and operations, *Adv. Space Res.*, 37, 2, p. 347-358, doi:10.1016/j.asr.2005.08.015, 2006.

Richards, P. G., T. N. Woods, and W. K. Peterson, HEUVAC: a new high resolution solar EUV proxy model, *Adv. Space Res.*, 37, 2, p. 315-322, 2006.

Chamberlin, P. C., T. N. Woods, and F. G. Eparvier, Flare Irradiance Spectral Model (FISM): Daily component algorithms and results, *Space Weather,* 5, 7, S07005, doi: 10.1029/2007SW000316, 2007.

Chamberlin, P. C., T. N. Woods, and F. G. Eparvier, Flare Irradiance Spectral Model (FISM): Daily component algorithms and results, *Space Weather,* 5, 7, S07005, doi: 10.1029/2007SW000316, 2007.

Dudok de Wit, T., M. Kretzchmar, J. Liensten, and T. Woods, Finding the best proxies for the solar UV irradiance, *Geophys. Res. Lett.* 36, doi: 10107, 10.1029/2009GL037825, 2009.

Lean, J. L., T. N. Woods, F. G. Eparvier, R. R. Meier, D. J. Strickland, J. T. Correira, and J. S. Evans, Solar extreme ultraviolet irradiance: Present, past and future, *J. Geophys. Res*., 116, A01102, doi: 10.1029/2010JA015901, 2011.

2. SEE Mission Operations and Data Processing System Overview

2.1. Summary of SEE mission operations

Through November 29, 2011, SEE successfully completed 49,801 normal solar experiments out of the 50,988 experiments planned. This is 97%, which meets the minimum NASA mission criteria. Throughout the entire mission SEE has consistently been well above the acceptable levels. As shown in Table 2.1, there have been very few observational gaps since TIMED normal operations began in January 2002. The SEE normal operations ended in April 2011, but SEE has remained on for overlapping measurements with the Solar Dynamics Observatory (SDO) EUV Variability Experiment (EVE) in 2010-2011. This extension is being operated with automatic operations and data processing (minimal funding), and so SEE could be permanently turned off if there are any new anomalies with SEE or the TIMED spacecraft.

Table 2.1. List of TIMED SEE Data Gaps. SEE Sensors are EGS and XPS.

Date	State	Sensor(s)	Science Data Affected
March 1, 2002	Safe Mode	Both	Part day
March 2, 2002	Safe Mode	Both	All day
March 4, 2002	Ground SW Anomaly	EGS	All day
March 5, 2002	Ground SW Anomaly	EGS	Part day
March 19, 2002	Safe Mode	Both	Part day
March 29, 2002	Safe Mode	Both	Part day
July 24 - 30, 2002	XPS Filter Wheel Anomaly	XPS	All days
Nov. 18-19, 2002	Leonid Safing	Both	Part day
Sept. 16 - 21, 2004	TIMED Flight Software Load	Both	Sept. 16,21: Part day Sept. 17-20: All day
Sept. 29 - Oct. 1, 2004	TIMED Flight Software Load	Both	Sept. 29, Oct. 1: Part day Sept. 30: All day
May 4, 2005	Lost data due to HK rate being at 5 sec (normally 15 sec)	Both	Part day (after SSR allocation reached)
Aug. 16-18, 2006	Safe Mode	Both	Partial day on 16th All day on 17th Partial day on 18th
July 25-26, 2007	Safe Mode	Both	Partial day
Nov. 19, 2007	Safe Mode	Both	Partial day
Jan. 8-15, 2008	Safe Mode	Both	Partial day on the 8th All day from 9-15
May 24-25, 2008	Safe Mode	Both	Partial day on 24th All day on the 25th
July 7, 2008	Planning Anomaly	Both	Partial day
June 14-23	Safe Mode	Both	All days from 14-18 Partial day on the 23th
Dec. 2-3, 2009	Safe Mode	Both	All day on the 2nd Partial day on 3rd
Nov. 27-28, 2011	Safe Mode	Both	Partial day on both days

2.2. Summary of SEE data products

The final TIMED SEE data product is Version 11 and it includes:

- Final clean-up of production processing code
- Delivery of final data products and code to the TIMED archive center at JHU/APL
- Improved spectral model (7-40 nm) based on SDO/EVE for wavelengths shorter than 27 nm
- Improved spectral model in the 114-129 nm range based on SORCE SOLSTICE
- Improved scattered light correction for EGS in the 27-40 nm range
- Revised EGS responsivity calibration in the 27-40 nm range based on new SDO/EVE results
- Improved degradation corrections for the calibration channel as related to change in operations in 2008-2009
- Evaluation of degradation trend over the full mission using all of the in-flight calibrations and the calibration rocket results (2002-2011)

All SEE data products are available from the SEE web site (http://lasp.colorado.edu/see), but the TIMED archive site will be the long-term residence for the SEE data products. The SEE data product types are listed in Table 2.2. Most research papers have used the SEE L3 and L3A products. The SEE version 11 products are expected to be released in January 2012.

The SEE Level 3 data product and Composite Lyman-alpha time series is also available on the LASP Interactive Solar Irradiance Datacenter (LISIRD) website – http://lasp.colorado.edu/LISIRD

Table 2.2. List of TIMED SEE Data Products

Data Product	Period	Description
SEE L2A SpWx	Orbit	8 solar indices (emissions/bands) for SpWx Ops
SEE L3	Day	1-nm spectrum from 0.5 nm to 194.5 nm, 38 emission lines, XPS 9 bands
SEE L3A	Orbit	Same as L3 but for orbit average (3-min avg)
EGS L2, L2A	D & O	0.1-nm spectrum from 27 nm to 195 nm
XPS L2, L2A	D & O	XPS 9 bands
XPS L4, L4A	D & O	0.1-nm spectral model from 0 to 40 nm
EGS L2B (Occ)	Orbit	Atmospheric transmission (single altitude)
Composite Ly-α	Day	H I Lyman-α irradiance from 1947 to present

2.3. Calibration rocket flights during the TIMED mission

In addition to the in-flight calibrations of redundant channels and flat-field lamp checks on a weekly basis, the TIMED SEE data also depend on underflight calibration rocket flights for understanding instrumental / degradation trends. Figure 2.1 shows the times of the LASP solar EUV irradiance rocket measurements, and Table 2.3 lists the dates for the calibration rockets during the TIMED mission.

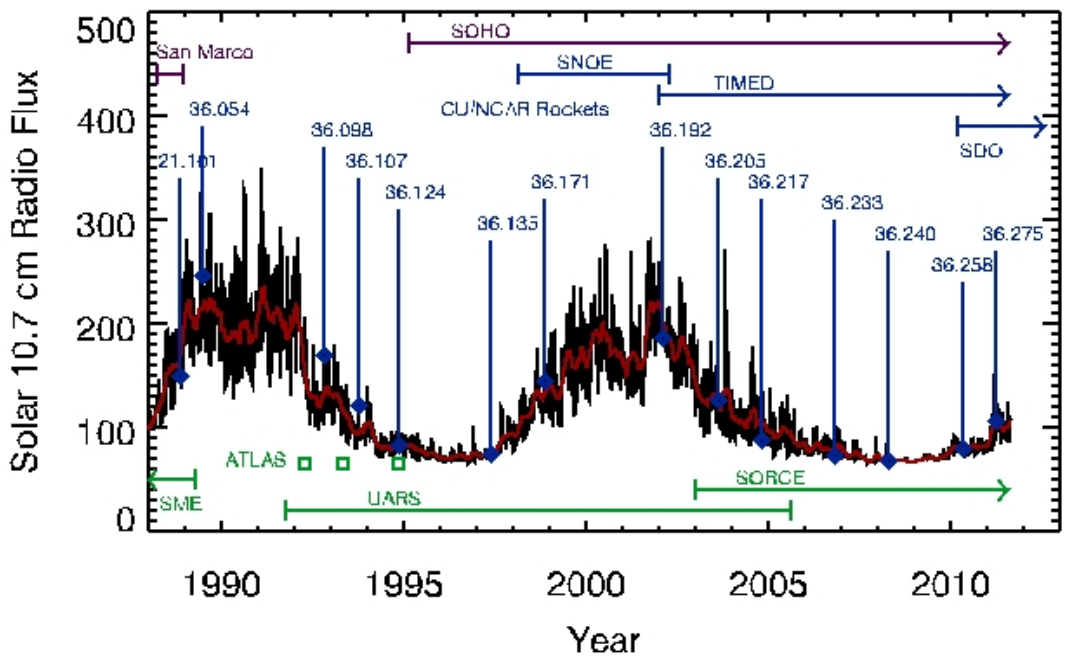

Figure 2.1. Times of the LASP rocket flights that measure the solar EUV irradiance.

Table 2.3. List of LASP Rocket Flights During the TIMED Mission.

Rocket Number	Launch Date / Time	Rocket Instruments
NASA 36.192	28-Feb-2002 / 18:41:00 UT	SEE EGS/XPS, Airglow, Ly-α Imager
NASA 36.205	12-Aug-2003 / 18:23:30 UT	SEE EGS/XPS, Airglow, Ly-α Imager
NASA 36.217	15-Oct-2004 / 17:23:34 UT	SEE EGS/XPS, Airglow, Ly-α Imager
NASA 36.233	28-Oct-2006 / 17:58:00 UT	SEE XPS, SDO EVE, Ly-α Imager
NASA 36.240	14-Apr-2008 / 16:58:00 UT	SEE XPS, SDO EVE
NASA 36.258	3-May-2010 / 18:32:00 UT	SEE XPS, SDO EVE, GOES-R XRS
NASA 36.275	23-Mar-2011 / 17:50:00 UT	SEE XPS, SDO EVE, GOES-R XRS

3. List of SEE Personnel and Students

The following is a list of the LASP professional staff and students who have worked on developing and operating the TIMED/SEE instrument. The list of the SEE Science Team members are listed on the report cover page.

3.1. TIMED SEE Professional Staff -- Univ. of Colorado, LASP

Mike Anfinson, SEE Program Manager
Paul Bay, SEE Mechanical Assembly
Karen Bryant, SEE Mission Operations Manager
Kip Denhalter, SEE Engineer
Ginger Drake, SEE Calibration Engineer
Francis Eparvier, SEE Project Scientist
Steve Ericksen, SEE Accountant
Vanessa George, SEE Management Assistant
Roger Gunderson, SEE Electrical Engineer
Caroline Himes, SEE Administration
Bonnie Hotard, SEE Administration
Jim Johnson, SEE Mechanical Assembly
Michelle Kelley, SEE Planning Software Engineer
Michael Klapetzky, SEE Rocket Engineer (was LASP graduate student)
Rick Kohnert, SEE Rocket System Engineer
Kraig Koski, SEE Mechanical Engineer
Mark Lankton, SEE Flight Software Engineer
George Lawrence, SEE Co-I – instrument / detector scientist
Jack Marshall, SEE Mechanical Assembly
Bill McClintock, SEE Science
Mike McGrath, LASP Engineering Director
Bill Peterson, SEE Collaborator – FAST Photoelectron Scientist
Heather Reed, SEE Mechanical Engineer Lead
Gary Rottman, SEE Co-I – solar variability
Patti Sicken, SEE Electrical Assembly
Steve Steg, SEE Mechanical Engineer
Gail Tate, SEE Flight Software and Test Engineer
Brian Templeman, SEE Data Processing Programmer
Greg Ucker, SEE System Engineer
Paul Weidmann, SEE Procurement
Jim Westfall, SEE Electrical Engineer
Neil White, SEE Electrical Engineer Lead
Oran R. White, SEE Co-I – solar variability
Don Woodraska, SEE Science Data Processing System Manager
Thomas Woods, SEE PI

3.2. TIMED SEE Students -- Univ. of Colorado, LASP

Jeff Cadieux, graduate (currently teaching in Japan)
Phillip Chamberlin, graduate (currently working at NASA GSFC)
Daniel Dexter, undergraduate (currently grad student at Univ. of Waterloo)
Rachel Hock, graduate (currently at LASP working on SDO/EVE flare research)
Ryan Keenan, undergraduate (currently grad student at Univ. of Wisconsin)
Matt Kelly, undergraduate
Sarah McNamara, undergraduate (currently grad student at Univ. of Colorado)
Will McNeill, undergraduate (currently working at LASP on SEE operations, Univ. of Colorado)
Andrew Poppe, undergraduate (currently at Space Sciences Lab, Univ. of California - Berkeley)
Erica Rodgers, graduate (currently working in Atchison, Kansas)
Erica Stavros, undergraduate (currently grad student at Univ. of Washington)
Edward Thiemann, undergraduate (currently at LASP working on GOES-R EXIS)
Angie Williams, undergraduate (currently working at ASI, Lockheed Martin contractor)

4. List of SEE-Related Publications

1. Qian, L., A. G. Burns, P. C. Chamberlin, and S. C. Solomon, Variability of the thermosphere and ionosphere response to solar flares, *J. Geophys. Res.*, 116, A10309, doi: 10.1029/2011JA016777, 2011.
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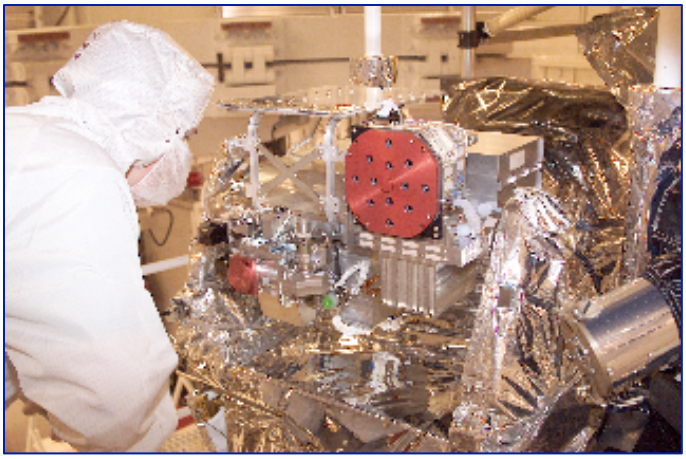

Tom Woods at the final inspection of the SEE instrument prior to launch.