TIMED Solar EUV Experiment: Phase E Progress Report for 2010

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.
# Report Outline

- SEE Instrument Operations and Instrument Status
- SEE End of Mission Plan
- SEE Data Products
- SEE Science Overview and Recent Results
- List of Recent SEE-related Talks & Papers
- Conclusions and Future Plans for SEE
SEE Measures the Solar VUV Irradiance

**EGS** = EUV Grating Spectrograph
Rowland-circle grating spectrograph with 64x1024 CODACON (MCP-based) detector

**XPS** = XUV Photometer System
Set of 12 Si photodiodes - 8 for XUV, 1 for Ly-\(\alpha\), and 3 for window calibrations

**FUV** = Far UltraViolet: 115-200 nm
**EUV** = Extreme UltraViolet: 30-115 nm
**XUV** = X-ray UltraViolet: 0-30 nm

**EGS** 27-194 nm with \(\Delta \lambda = 0.4\) nm

**XPS** 0.1-34 nm with \(\Delta \lambda = 7-10\) nm and Ly-\(\alpha\) (121.6 nm) with \(\Delta \lambda = 2\) nm
Overview of SEE Operations
and
Status of SEE Instrument
Summary of SEE Flight Operations

♦ Planned Experiments (through Oct 3, 2010)
  • Number of normal solar experiments = 44,981

♦ Actual Experiments (through Oct 3, 2010)
  • Number of normal solar experiments = 43,811 (97%)

♦ Calibration rockets provide degradation rates for SEE
  • NASA 36.192 launched on Feb. 8, 2002, complete success
    - Rocket results incorporated into Version 6 data
  • NASA 36.205 launched on Aug. 12, 2003, complete success
    - Rocket results incorporated into Version 7 data
  • NASA 36.217 launched on Oct. 15, 2004, complete success
    - Rocket results incorporated into Version 8 data
  • NASA 36.233 launched on Oct. 28, 2006
    - Partial success (only 0.1-36 nm and 121.6 nm irradiance measured)
  • NASA 36.240 launched on April 14, 2008, complete success
    - Rocket results incorporated into Version 10 data
  • NASA 36.258 (SDO EVE rocket) launched on May 3, 2010, complete success
    - Rocket results consistent with Version 10; no update to SEE degradation trend
List of SEE Data Gaps - **Very Few Gaps**

<table>
<thead>
<tr>
<th>Date</th>
<th>State</th>
<th>Sensor(s)</th>
<th>Science Data Affected</th>
</tr>
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<tbody>
<tr>
<td>March 1, 2002</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Part day</td>
</tr>
<tr>
<td>March 2, 2002</td>
<td>Safe Mode</td>
<td>Both</td>
<td>All day</td>
</tr>
<tr>
<td>March 4, 2002</td>
<td>Ground SW Anomaly</td>
<td>EGS</td>
<td>All day</td>
</tr>
<tr>
<td>March 5, 2002</td>
<td>Ground SW Anomaly</td>
<td>EGS</td>
<td>Part day</td>
</tr>
<tr>
<td>March 19, 2002</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Part day</td>
</tr>
<tr>
<td>March 29, 2002</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Part day</td>
</tr>
<tr>
<td>July 24 - 30, 2002</td>
<td>XPS Filter Wheel Anomaly</td>
<td>XPS</td>
<td>All days</td>
</tr>
<tr>
<td>Nov. 18-19, 2002</td>
<td>Leonid Safing</td>
<td>Both</td>
<td>Part day</td>
</tr>
</tbody>
</table>
| Sept. 16 - 21, 2004| TIMED Flight Software Load        | Both      | Sept. 16,21: Part day
|                   |                                   |           | Sept. 17-20: All 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) |
## List of SEE Data Gaps - 2

<table>
<thead>
<tr>
<th>Date</th>
<th>State</th>
<th>Sensor(s)</th>
<th>Science Data Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug. 16-18, 2006</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Partial day on 16th All day on 17th Partial day on 18th</td>
</tr>
<tr>
<td>July 25-26, 2007</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Partial day</td>
</tr>
<tr>
<td>Nov. 19, 2007</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Partial day</td>
</tr>
<tr>
<td>Jan. 8-15, 2008</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Partial day on the 8th All day from 9-15</td>
</tr>
<tr>
<td>May 24-25, 2008</td>
<td>Safe Mode</td>
<td>Both</td>
<td>Partial day on 24th All day on the 25th</td>
</tr>
<tr>
<td>July 7, 2008</td>
<td>Planning Anomaly</td>
<td>Both</td>
<td>Partial day</td>
</tr>
<tr>
<td>June 14-23</td>
<td>Safe Mode</td>
<td>Both</td>
<td>All days from 14-18 Partial day on the 23th</td>
</tr>
<tr>
<td>Dec. 2-3, 2009</td>
<td>Safe Mode</td>
<td>Both</td>
<td>All day on the 2nd Partial day on 3rd</td>
</tr>
</tbody>
</table>
Status of SEE Instruments

No recent changes for SEE

♦ EUV Grating Spectrograph (EGS) - fully functional
  • The EUV ($\lambda < 115$ nm) has degradation mostly at the bright lines on the CODACON (MCP-based) detector, but it is being tracked with on-board redundant channel and flat-field detector lamp weekly experiments
  • The FUV (115-195 nm) has small recovery rate that is corrected using UARS, SORCE, and XPS comparisons

♦ XUV Photometer System (XPS) - 3 channels functional
  • Fully functional until 2002/2005 when there was a filter wheel anomaly (filter wheel stuck in position 6)
  • Three channels providing solar measurements
  • No spectral gaps in the XUV though because of new XPS Level 4 algorithm

♦ Microprocessor Unit (MU) - fully functional
♦ SEE Solar Pointing Platform (SSPP) - fully functional
Potential Life Issues for SEE

- **EGS (grating spectrograph)**
  - MCP-based detector has significant degradation at a few wavelengths (~5% of spectral range). Accuracy already degraded at those wavelengths. Degradation has slowed down with time, but still expect this degradation to continue during extended mission.
  - No degradation or anomalies for HV supply or slit changer mechanism; expect them to perform well for several more years

- **XPS (set of photometers)**
  - None: filter wheel mechanism is not used anymore
  - Lower priority than EGS as have SORCE XPS

- **SSPP (pointing platform)**
  - No degradation or anomalies for SSPP; expect it to perform well for several more years
SEE End of Mission Plan
SEE End of Mission Plan

♦ Overlap with SDO EVE
  • SDO EVE normal operations began May 1, 2010
    - EVE measurements are from 0.1-105 nm and at 121.6 nm
  • SDO EVE calibration rockets: May 3, 2010 and Feb. 22, 2011
  • Prefer 1-year overlap of SEE with EVE, but have limited funds left

♦ SEE turn-off plan
  • Continue normal SEE operations until March 1, 2011 so can overlap with SDO EVE second calibration rocket (Feb 22)
  • Perform special SEE calibrations for a month (March 2011)
    - Daily EGS calibration channel measurements, flatfield images, solar images
  • Move SSPP to 190° and turn off SEE on April 1, 2011

♦ SEE final data product will be version 11 (Oct. 2011 deadline)
  • Evaluate and update degradation trend over full mission
  • Evaluate and update EGS calibration in the 27-40 nm range
  • Evaluate and update XPS spectral model (7-40 nm) with EVE spectra
  • Evaluate and update EGS spectral model (114-129 nm) with SOLSTICE
SEE Data Products
SEE Version 10 Data

- Version 10 initially released in September 2009 and daily updates provided with 4-day latency
  - EGS revisions
    - Vastly improved FOV correction now uses long-term information
      - Corrects small daily jumps
    - Smaller degradation bins help with heavily degraded regions
    - Improved Gain correction now possible because of the better FOV algorithm
    - Updated FUV degradation rates from comparison to SORCE
    - Included updated EUV degradation rates using latest cal rocket (Apr 2008)
  - XPS revisions
    - Updated radiometric calibrations and updated XUV degradation rates
    - Improved empirical Gain correction
- **LASP Interactive Solar Irradiance Datacenter (LISIRD)**
  - Relatively new data center at LASP for its solar irradiance data products
    - SME, UARS SOLSTICE, TIMED SEE, SORCE, rocket experiments
    - Future missions: Glory TIM, SDO EVE
  - http://lasp.colorado.edu/LISIRD/
Summary of SEE Data Products

- Download data for individual days or merged set for the full mission
- Download IDL read / plot code
- Plot / browse data (ION script interface)

### Data Product

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

http://lasp.colorado.edu/see/
Future SEE Data Products

- No new SEE data products are planned
- Future SEE data versions
  - Version 11 (after end of operations)
    - Expected final release will include overlap measurements with SDO-EVE and rocket underflights
    - Final clean-up of production processing code
    - Prepare products and code for delivery to TIMED archive center
SEE Science Overview and Recent Results
SEE Science Plans

Solar UV Irradiance Measurements

- XPS
- EGS
- Ly-α Filter

Irradiance (mW m⁻²)

Wavelength (nm)

Validations
Internal Calibrations, Underflight Calibrations
SOHO, SNOE, UARS, SORCE

Obj. #1

Solar UV Variability
Function of wavelength
Over time scales of minutes to years

Obj. #2

Study Earth’s Response
Photoelectron analysis with FAST data and using the glow model
Atmospheric response studies using HAO’s TIM-GCM

Solomon, Roble, Bailey, Eparvier

Obj. #3

Modeling Solar Variation
Study variations related to active region evolution derived from solar images
Improve the NRLEUV, SOLAR2000, and SunRise solar irradiance models

Lean, Tobiska, Chamberlin, Woods

Obj. #4

Obj. #5

SEE Annual Report  Nov. 2010 - 17
Overview of SEE Science Objectives

1. Accurately and precisely determine the time-dependent solar vacuum ultraviolet (VUV: below 200 nm) spectral irradiance.

2. Study solar VUV variability (27-day rotations, solar cycle changes) and its sources.

3. Study the solar-terrestrial relationships utilizing atmospheric models, primarily the TIME-GCM at HAO/NCAR.

4. Improve proxy models of the solar VUV irradiance.

5. Determine the thermospheric neutral densities ($O_2$, $N_2$ and $O$) from solar occultations.
Summary of SEE Results

- **Objective 1: solar VUV spectral irradiance measurements**
  - Daily measurements since Jan. 22, 2002 with very few gaps
  - Additional analysis / validation for SEE results over full TIMED mission [Eparvier, Lean, Woods]

- **Objective 2: solar variability**
  - Updated results on solar rotation and solar cycle variations [Lean, Woods, Tobiska]
  - Updated results on flare variability as SEE for space weather research [Tobiska, Chamberlin]
    - Flare catalog on-line to make access to SEE’s flare data quick and easy

- **Objective 3: model solar response in Earth’s atmosphere**
  - Use of HAO TIME-GCM for atmospheric response to SEE’s solar input [Solomon, Qian, Lu]
  - Use of SEE solar data and FAST photoelectron data [Peterson, Richards]
  - Comparison of GUVI FUV airglow data with SEE results [Meier, Lean, Woods]

- **Objective 4: solar irradiance modeling**
  - SOLAR2000 (S2K) model improvements [Tobiska]
  - NRLEUV model improvements [Lean, Warren]
  - Flare Irradiance Spectral Model (FISM) improvements [Chamberlin]
    - SEE data used to parameterize FISM - daily components and 1-min flare components

- **Objective 5: atmospheric density from solar occultations**
  - EGS Level 2B solar occultation data product [Eparvier]
SEE observations start at solar cycle maximum in 2002, include the cycle minimum in 2008-2009, and detect the rise of new cycle 24.

Paper Figure 1. Time series of daily values of a) total EUV irradiance (0-120 nm) measured by SEE are compared with b) the Mg II index and c) the F10.7 index of solar activity for the duration of the TIMED mission. The arrows indicate times of rocket under flight calibrations of the SEE instrument.
NRLEUV irradiance model compares well to SEE observations at some wavelengths.

NRLSSI 2C and 3C models developed using the SEE measurements.

Paper Figure 3. Shown are all daily solar EUV spectra in 1 nm bins measured by SEE and estimated by a) the NRLSSI 2C proxy model and b) the NRLEUV model during the TIMED mission from 2002 to 2009.
**Paper Figure 5.** Estimates of the solar cycle amplitudes of the EUV spectral irradiance in 1 nm bins observed by SEE and modeled by NRLSSI and NRLEUV are compared in a) as percentage increases from solar cycle minimum to maximum ((max-min)/min×100) at the two times indicated by the grey vertical lines in Figure 4. The same changes are shown in b) in energy units.

SEE measured solar cycle variability is larger than NRLEUV and NRLSSI 2C estimated variability at most wavelengths.
Present, Past and Future Variations in Solar Extreme Ultraviolet Irradiance


SEE solar cycle minimum results agree reasonably well with model estimates derived from quiet Sun radiance observations.

Paper Figure 8. The solar EUV spectral irradiance in 1 nm bins observed by SEE during solar activity minimum in August 2008 is compared in a) with the spectrum of the quiet Sun (i.e., absent magnetic activity) obtained from the NRLEUV and NRLEUV2 models. Ratios of the NRLEUV and NRLEUV2 quiet sun spectra to the SEE solar minimum spectrum are shown in b). The thick broad lines in b) are the ratios in 10 nm bins.
Latest versions of GUVI and SEE data agree better than ever.

Paper Figure 9. Estimates of $QEUV$, the solar EUV energy $< 45$ nm, measured directly by SEE (one 3-minute measurement per orbit) and derived from GUVI measurements of the FUV dayglow (orbit-averaged from sub-second measurements wherever there is dayglow along the orbit) are compared in a) as daily means for the duration of the TIMED mission. In b) and c) orbital averages are compared during 2003, when solar activity was relatively high, and in d) and e) during 2005, when solar activity levels were more moderate. The comparisons during the two 180-day periods shown in b) and d) illustrate the details of rotational modulation and the comparisons during the two 25-day periods shown in c) and e) illustrate higher resolution temporal detail and flare irradiance variations superimposed on the overall rotational modulation.
Paper Figure 10. Reconstruction of daily total solar EUV irradiance (0-120 nm) with the 2C and 3C models from 1950 to 2010 are shown in a). Scenarios for annually averaged EUV irradiance changes since the Maunder Minimum derived using the 2C and 3C models are shown in b) and c). The reconstructions that incorporate background irradiance changes inferred from Wang et al. [2005], shown by the black lines in b) and c), are the basis for the numerical values listed in Table 1 for the Maunder Minimum.
Forecasting the future solar EUV irradiance level is now more accurate.

Paper Figure 12. Root-mean-square errors of the EUV irradiance changes forecast for 1 to 10 days ahead, obtained as averages of the forecast changes made over the period 2002 to 2009 using a third order autoregressive process, are compared with errors of analogous forecasts made using climatology and persistence. Approximate percentage errors of the forecasts are shown on the right ordinate.
Solar EUV 26-34 nm irradiance is 15% ± 6% lower in 2008 than in 1996.

Paper Figure 1. Solar EUV variation in the 26–34 nm band over solar cycle 23 measured by the SEM detector on the SOHO spacecraft. Black dots: daily average values. Blue line: 81-day centered mean (with data gaps interpolated). Estimated uncertainty is 6%. Also plotted, with estimated uncertainties, are irradiance measurements integrated over the same band from the ATLAS-3 calibration rocket on 15 May 1997 (orange), the SDO/EVE EUV SpectroPhotometer (ESP) prototype (cyan) and the SDO/EVE Multiple EUV Grating Spectrograph (MEGS) prototype (magenta) on a rocket on 14 April 2008, and the TIMED/SEE 2008 annual average (green). The decrease in SEM irradiance from 1996 to 2008 is ~15%.
Paper Figure 3. (a) Global mean thermospheric density at 400 km altitude, obtained from satellite orbital parameters over four solar cycles. Blue: 81-day centered running mean. Black: annual average. Green dotted lines: envelope of expected decrease due to increasing CO$_2$ levels, in the range of 2% to 5% per decade, starting with the 1976 annual average (see text). (b) Global mean thermospheric density annual average plotted as a function of the 26–34 nm solar EUV irradiance annual average measured by the SEM for the ascending (red) and descending (blue) phases of solar cycle 23.

Thermospheric density at 400 km is 28% lower in 2008 than in 1996. Of this, 2-5% appears to be due to higher greenhouse CO$_2$ concentration.
Anomously low solar EUV irradiance and thermospheric density during solar minimum


TIM-GCM model results confirm that lower thermospheric density is consistent with lower solar EUV irradiance in 2008-2009.

Paper Figure 4. Thermospheric temperature and density modeled by the NCAR TIE-GCM on day-of-year 227 using the spectra shown in Figure 2. (a, b) Model temperature and density at 400 km for 1996. (c, d) Model temperature and density for 2008. (e, f) Global average temperature and density as a function of altitude for 1996 and 2008. Black line: 1996. Red line: 2008 with both decreased solar EUV and increased CO₂. (g, h) Global average temperature change from 1996 to 2008, and density ratio for 2008 divided by 1996, as a function of altitude. Black line: 1996. Blue line: 2008 with only solar EUV decrease. Red line: 2008 with both decreased solar EUV and increased CO₂.
Recent SEE-related Talks & Papers
## Recent SEE Related Talks

- AGU, December 2009, 3 talks
- Boulder Solar Day, March 2010, 1 talk
- AAS / SPD, May 2010, 2 talks
- Aspen Global Change Institute (AGCI Workshop), June 2010, 1 talk
- COSPAR, July 2010, 4 talks
Recent SEE Related Papers


Conclusions and Future Plans
Summary of SEE Observations

- TIMED SEE has been very successful in obtaining new, accurate measurements of the solar EUV irradiance
  - SEE data available from http://lasp.colorado.edu/see/
- More than 100 flares have been observed by SEE
  - Large flares vary as much as 11-year solar cycle variations
  - New flare models have been developed with SEE observations
- More than 120 solar rotations have been observed by SEE
  - Variability of 5-70% observed (wavelength dependent)
- TIMED mission has observed solar maximum and minimum activity during solar cycle 23 and the start of cycle 24 in 2009
SEE Plans for 2011

- Plan to terminate the SEE operations in April 2011
  - Deactivate SEE after calibration rocket flight planned for Feb. 22, 2011
  - See slide 11 for more details
- Produce final data product for SEE by October 2011
  - Final SEE product will be version 11
  - See slide 11 for more details