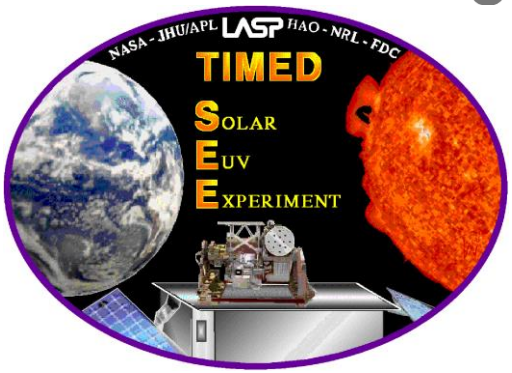
TIMED Solar EUV Experiment: Phase E Progress Report for 2009



Submitted for NASA Grant NNX07AB68G
by Tom Woods (SEE PI)
LASP / University of Colorado
1234 Innovation Drive
Boulder, CO 80303
Phone: 303-492-4224
E-mail: tom.woods@lasp.colorado.edu
Web: http://lasp.colorado.edu/see/

SEE Science Team

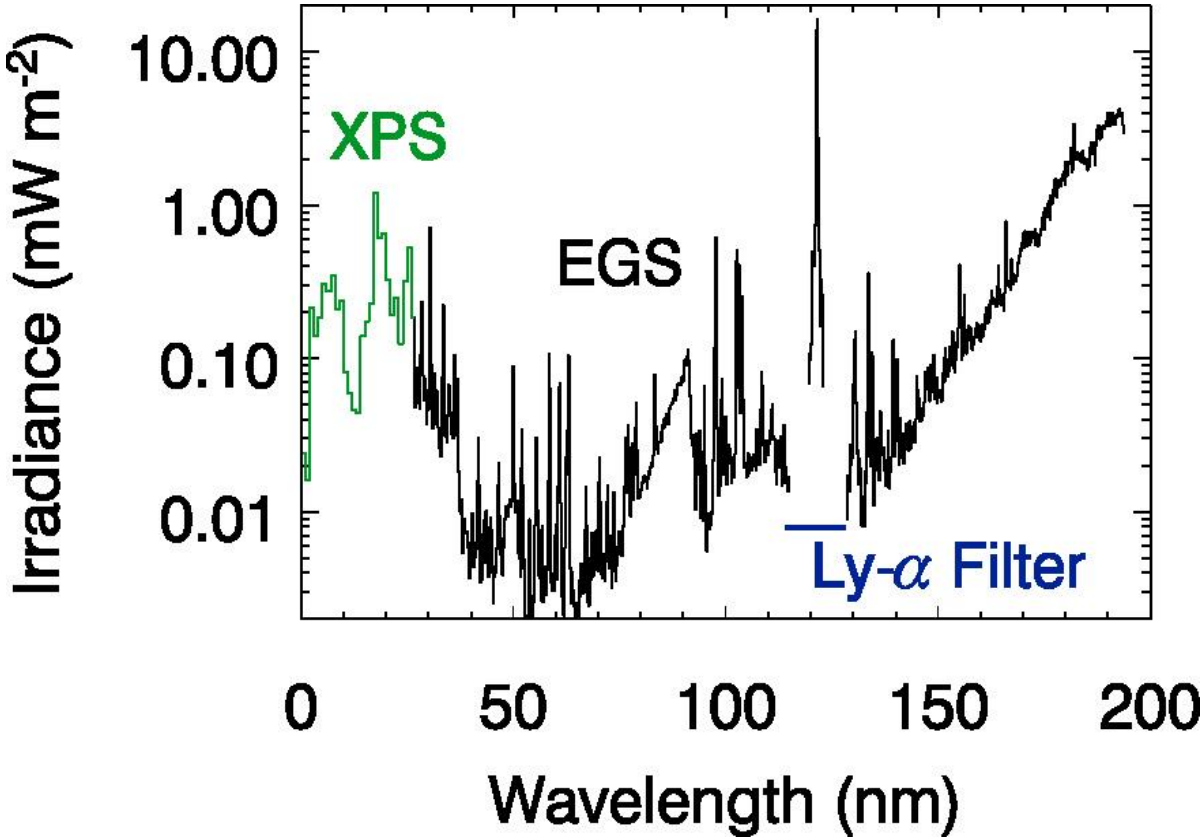
LASP/CU: Tom Woods (PI), Frank Eparvier, Don Woodraska
LASP Graduate Student: Michael Klapetzky
NASA/GSFC: Phil Chamberlin
HAO/NCAR: Stan Solomon, Ray Roble
NRL: Judith Lean
SET: Kent Tobiska
Virginia Tech: Scott Bailey

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 Data Products
- SEE Science Overview
- Summary of Recent SEE Science Results
- List of Recent SEE-related Talks & Papers
- Future Plans for SEE Team

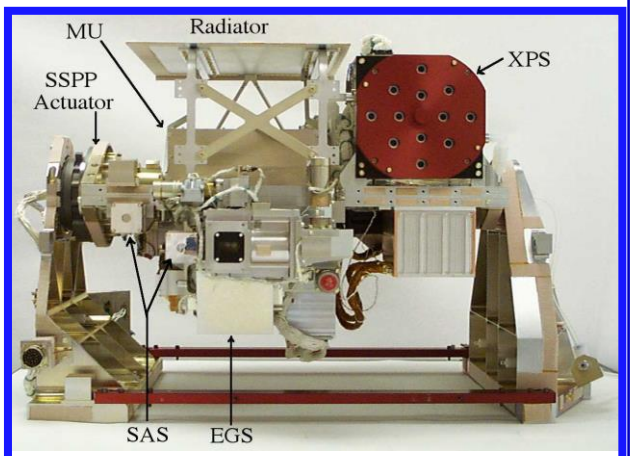
SEE Measures the Solar VUV Irradiance



XUV	EUV	FUV

EGS 27-194 nm with Δλ=0.4 nm

XPS 0.1-34 nm with Δλ=7-10 nm and Ly-α (121.6 nm) with Δλ=2 nm



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-α, 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 = EUV Grating Spectrograph
XPS = XUV Photometer System

Overview of SEE Operations
and
Status of SEE Instrument

Summary of SEE Flight Operations

- Planned Experiments (through Oct 20, 2009)
  - Number of normal solar experiments = 40,102
- Actual Experiments (through Oct 20, 2009)
  - Number of normal solar experiments = 39,023 (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

List of SEE Data Gaps - Very Few Gaps

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)

List of SEE Data Gaps - 2

Date	State	Sensor(s)	Science Data Affected
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

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 2002/205 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 Data Products

SEE Version 10 Data

- Version 10 released in September 2009
  - 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

http://lasp.colorado.edu/see/

- 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	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

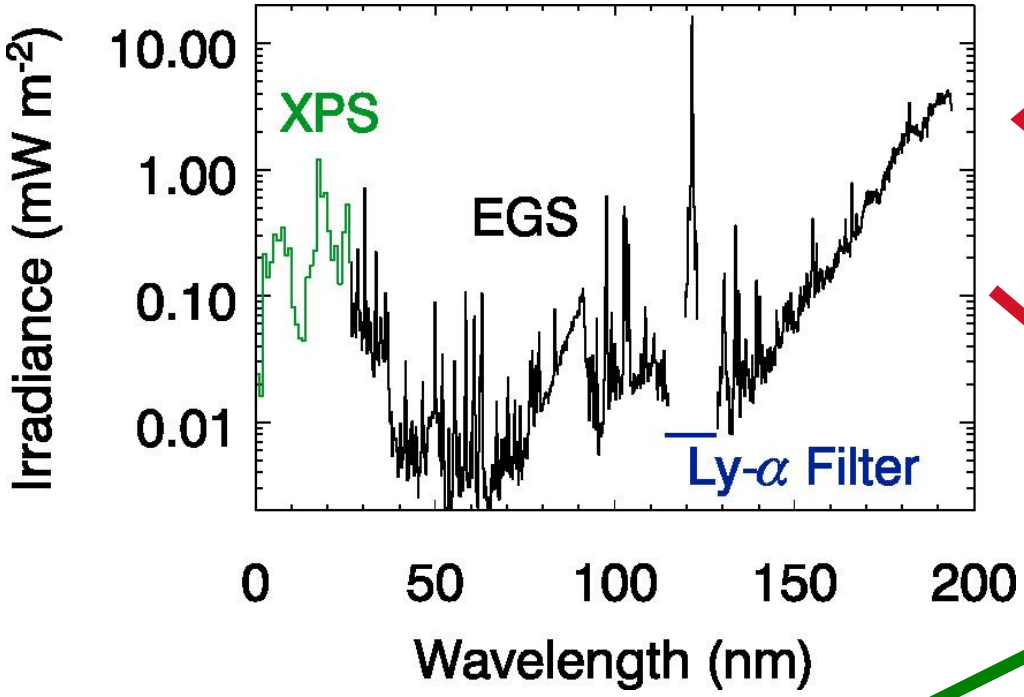
Future SEE Data Products

- 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 for delivery to archive center

SEE Science Overview

SEE Science Plans

Solar UV Irradiance Measurements



Obj. #1

Validations

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

Eparvier, Woods, Bailey, Rottman

Obj. #2

Solar UV Variability

Function of wavelength
Over time scales of minutes to years

All

Obj. #4

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. #3

Obj. #5

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

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 - 1

- **Objective 1: solar VUV spectral irradiance measurements**
  - Daily measurements since Jan. 22, 2002 with very few gaps
  - SEE solar EUV irradiance (version 9) and GUVI QEUV (0-45 nm) have less differences with recent improvements / calibrations for GUVI QEUV and for new XPS Level 4 algorithm for the 0.1-27 nm range [Woods, Meier, Lean]
  - New reference spectra for solar cycle minimum conditions as part of the international Whole Heliosphere Interval (WHI) campaign [Woods, Chamberlin]
- **Objective 2: solar variability**
  - Updated results on solar rotation and solar cycle variations [Woods et al.]
  - Updated results on flare variability as SEE has observed about 100 flares
    - New flare catalog on-line to make access to SEE's flare data quick and easy [Chamberlin, Woods]
- **Objective 3: model solar response in Earth's atmosphere**
  - Use of SEE solar data and FAST photoelectron data [Peterson, Richards]
  - Use of HAO TIME-GCM for atmospheric response to SEE's solar input Solomon, Roble, Qian, Lu]
  - Analysis of GUVI FUV airglow data during flare events [Strickland, Lean, Woods]
  - Satellite drag modeling / analysis indicating importance of solar EUV and FUV [Tobiska, Bowman, Solomon, Qian, Woodraska, Sutton, Forbes]

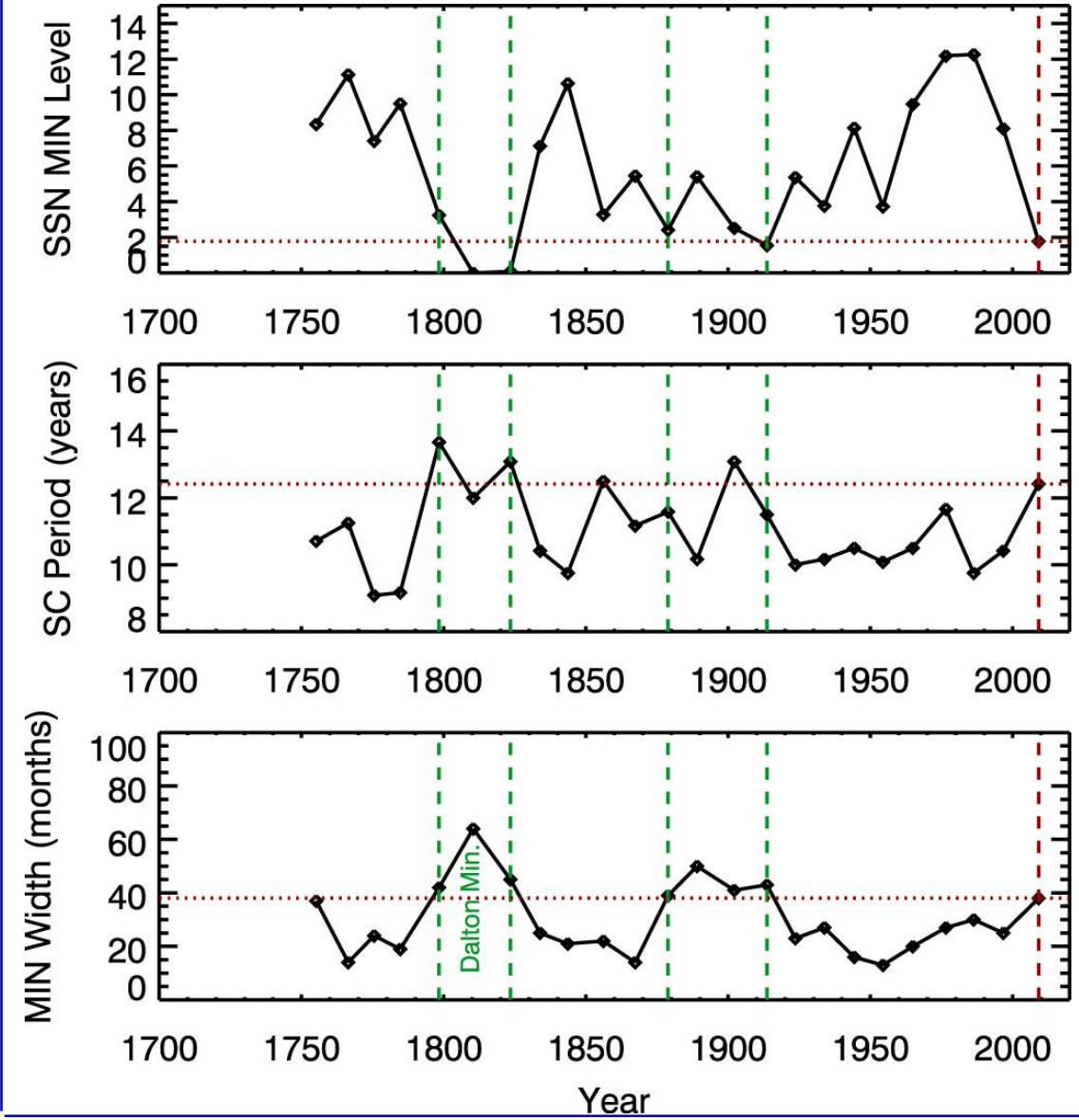
Summary of SEE Results - 2

- **Objective 4: solar irradiance modeling**
  - SOLAR2000 (S2K) model improvements [Tobiska]
  - NRLEUV model improvements [Lean, Warren]
  - HEUVAC model improvements [Richards]
  - 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**
  - New EGS Level 2B solar occultation data product released (version 9) [Eparvier]

Recent SEE Science Results

1. Solar reference spectra for solar cycle minimum
2. Thermosphere / ionosphere at solar cycle minimum
3. Photoelectrons variations over solar cycle
4. Atmospheric variations over solar cycle
5. Improvements for solar EUV irradiance models

This Current Solar Cycle Minimum (2007-2009) is Interesting

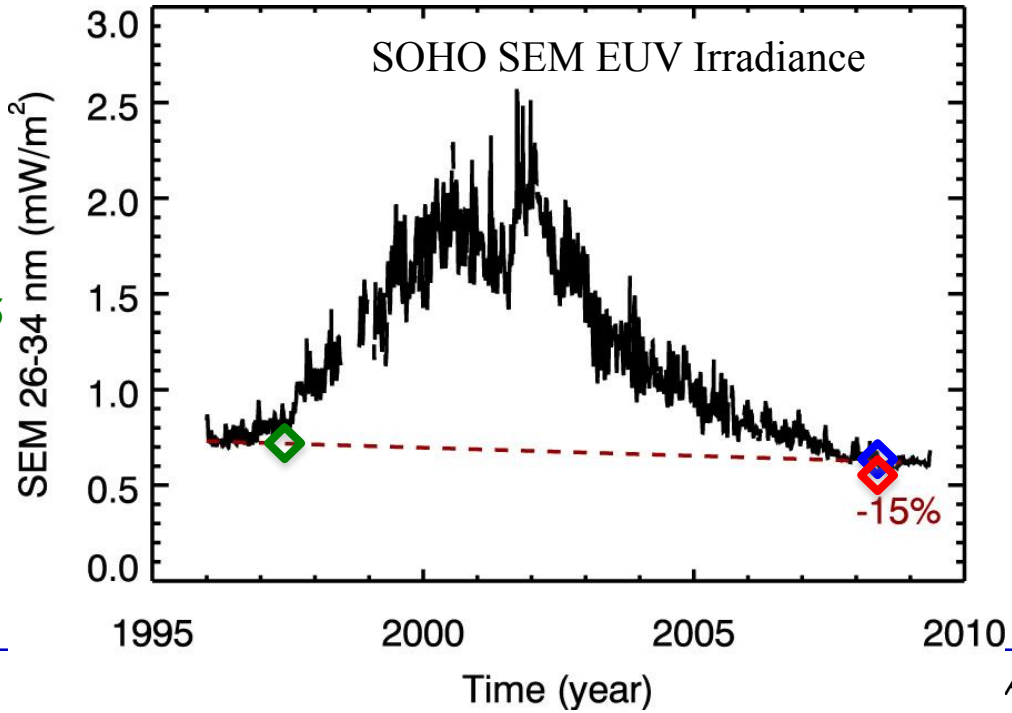


- SSN Minimum Level
  - Lowest since 1920s
  - (3 of 24 are lower)
- SC Period Length
  - Longest since 1900
  - (4 of 24 are longer)
- Minimum Duration
  - Widest since 1920s
  - (7 of 24 are wider)
- NOTE: This MIN is not completed yet, so expect width to go up !

Important to Establish Reference for This Minimum

- SOHO SEM band (26-34 nm) indicates 15% less in 2008 than in 1996 (from Leonid Didkovsky, 2009 SPD 18.07)
- Is this long-term trend real or instrument effect for SOHO SEM?
  - TIMED SEE and rocket results are consistent with the SEM measurements (uncertainty of ~20%)
  - Thermosphere and ionosphere indicate less density in 2008 than in 1996
  - Trend might be explained because there are more coronal holes in 2008

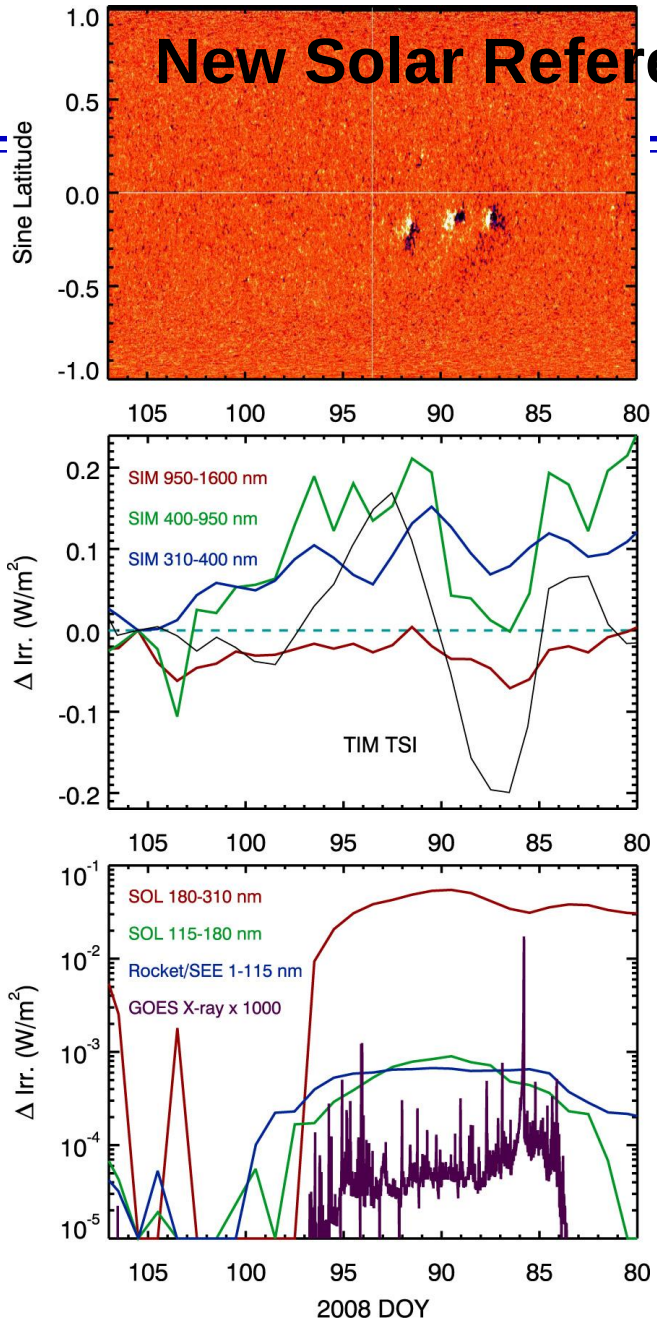
ATLAS-3 (rocket):
0.73 ± 0.15



TIMED SEE:
0.62 ± 0.15

WHI SIRS:
0.51 ± 0.08

New Solar Reference Spectra for Cycle Minimum

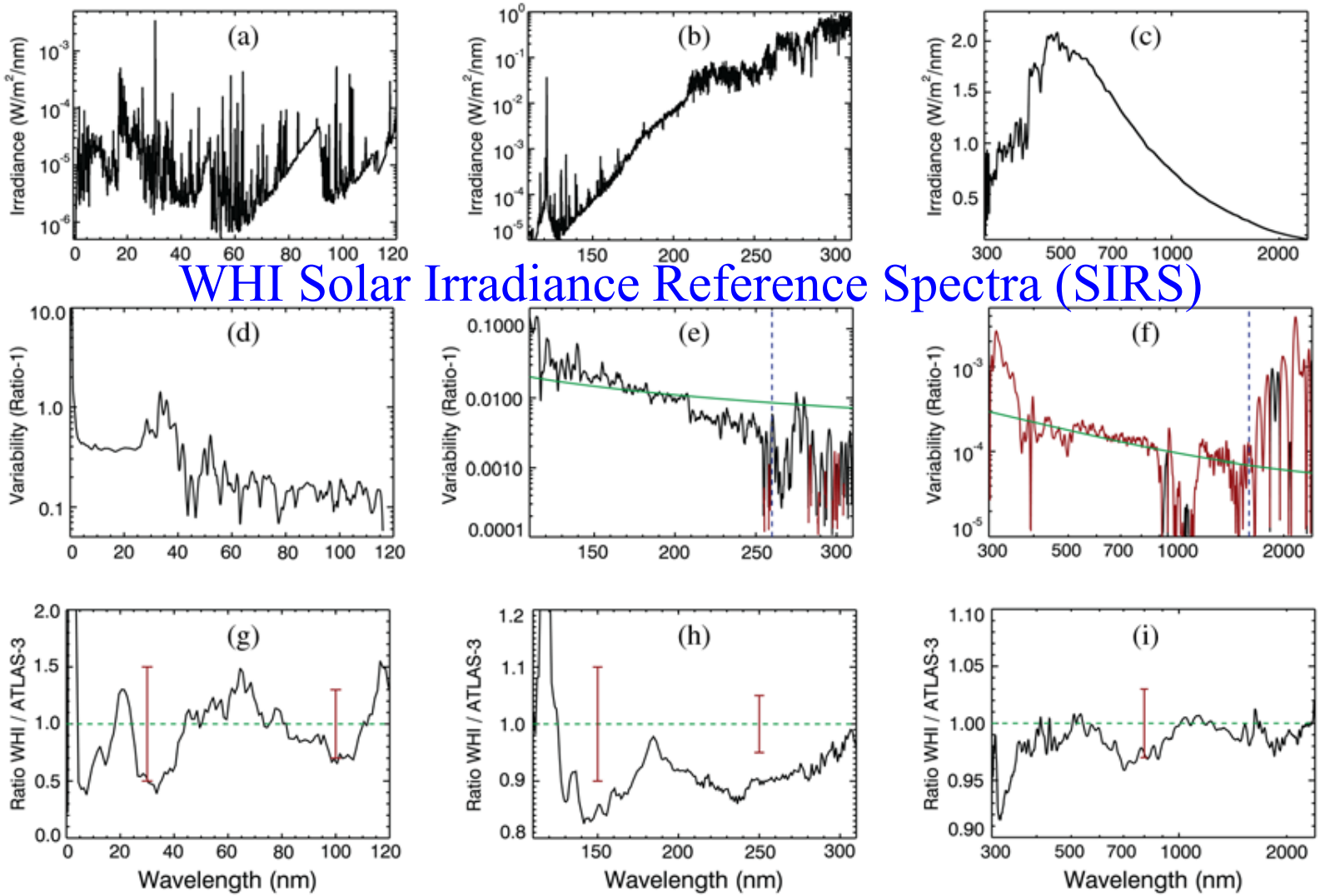


- Whole Heliosphere Interval (WHI) is an international coordinated observing and modeling effort to characterize the 3-dimensional interconnected solar-heliospheric-planetary system.

- WHI Period is March 20, 2008 to April 16, 2008
  - Solar Carrington Rotation 2068
  - Reference spectra established during this WHI period

From Tom Woods

WHI Solar Irradiance Reference Spectra (SIRS)

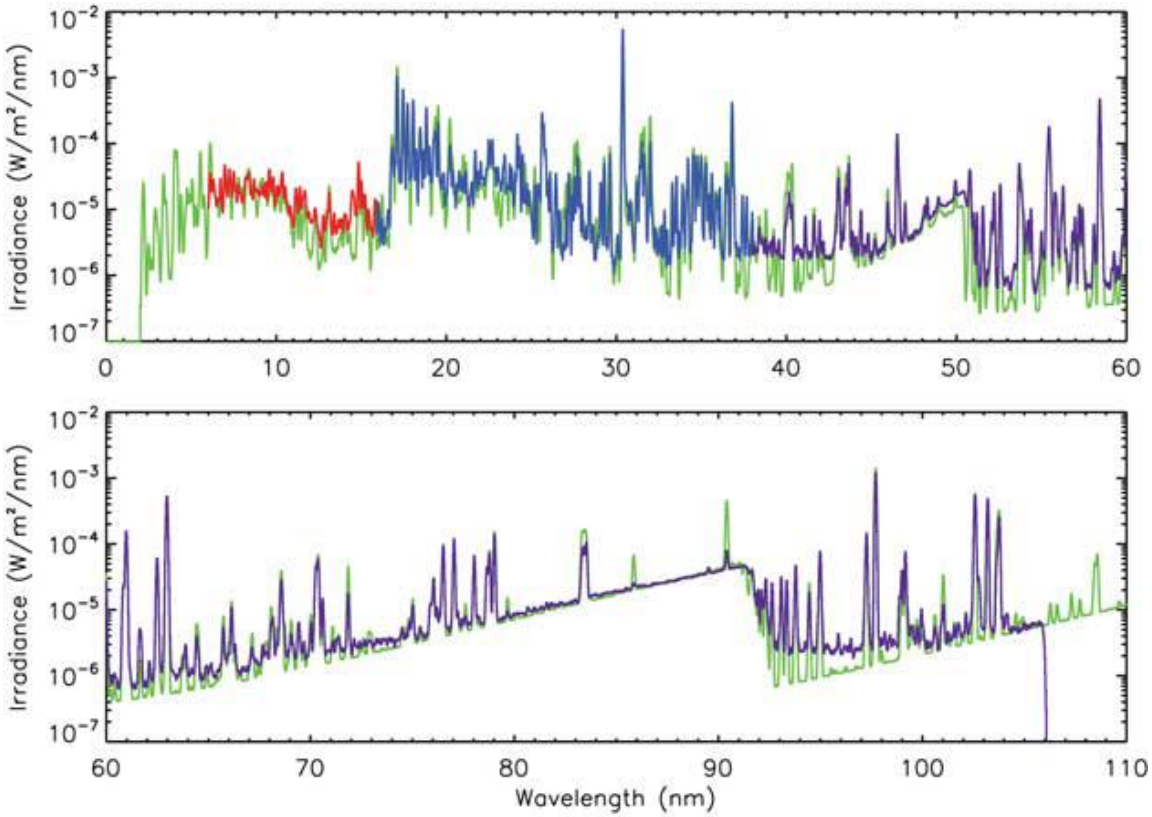


Panels (a)–(c) Solar Irradiance Reference Spectra (SIRS), (d)–(f) its variability, and (g)–(i) comparison to ATLAS-3 reference spectrum [Thuillier et al., 2004a, 2004b]. The results shortward of 116 nm are from the rocket EVE and TIMED SEE. The results between 116 and 310 nm are from SORCE SOLSTICE, and results from 310 to 2400 nm are from SORCE SIM. The variability shown in red are negative variations associated with sunspot blocking (darkening). The green solid lines are the derivatives of 5700 K Planck function with a change of temperature of 5 K (lower chromosphere) and 0.2 K (photosphere) in Panels (e) and (f), respectively. Most of the variability to the right of the dashed lines in Panels (e) and (f) are not statistically significant. The red error bars in Panels (g) – (i) are the comparison uncertainties that include both WHI SIRS and ATLAS-3 uncertainties.

From Tom Woods

TIMED SEE

New Higher Resolution Solar EUV Reference Spectrum



Measurements from the NASA 36.240 rocket flight from the three channels of EVE. MEGS A1 is given in red, MEGS A2 is given in blue, and MEGS B is shown in purple. The Warren [2005] reference spectrum is also shown for comparison in green.

From Phil Chamberlin

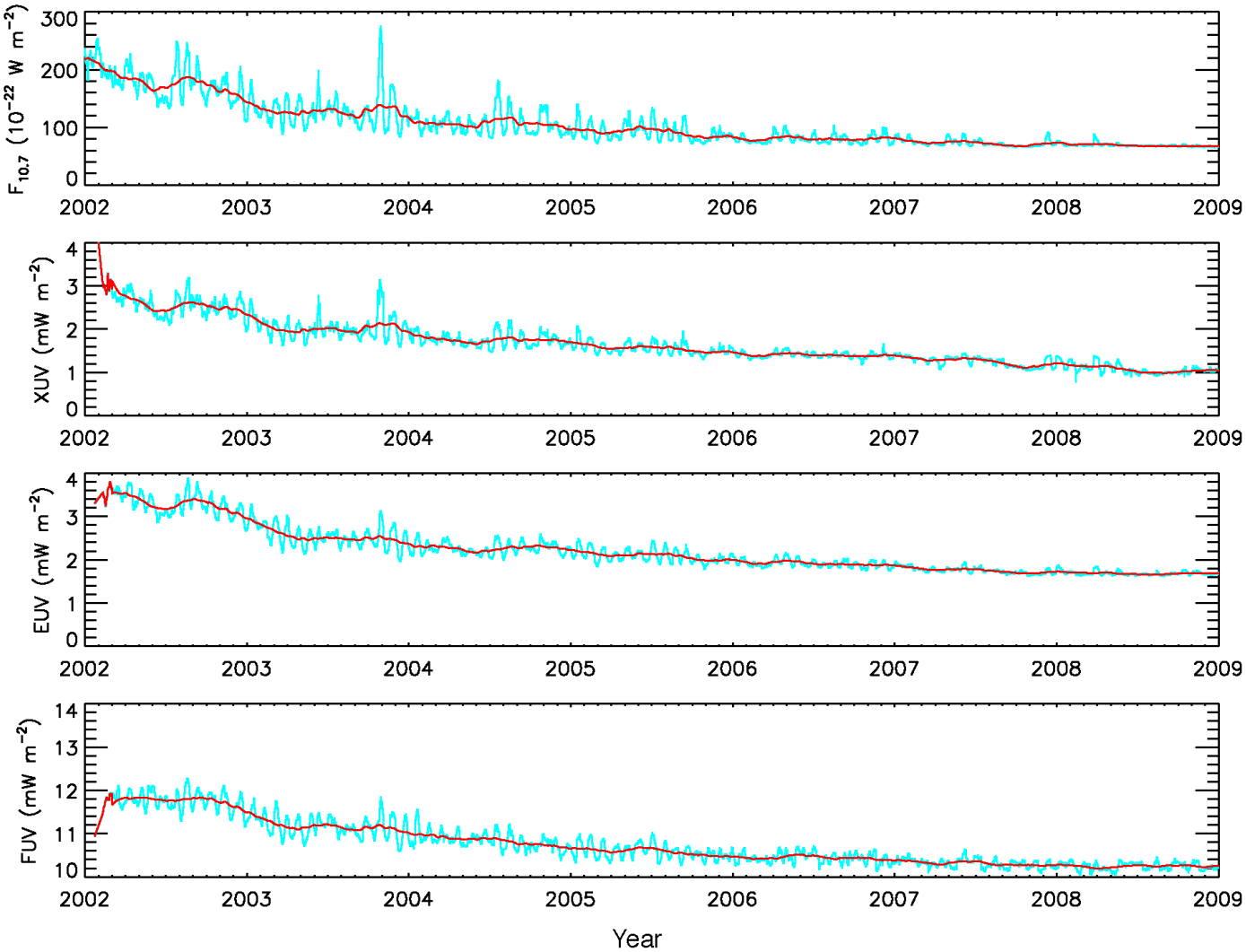
New Higher Resolution Solar EUV Reference Spectrum

The measurements taken during the rocket flight on 14 April 2008 provide the most accurate and highest spectral resolution solar EUV irradiance data taken during solar cycle minimum. There is also anticipated improvement in the measurement accuracy with the inclusion of the results from the post-flight calibration. Of course, there are the TIMED SEE daily observations throughout this period, but with less accuracy and less spectral resolution. Of particular importance is the rocket EVE spectral measurements shortward of 27 nm, which will be essential in validating the previous interpretations (modeling) of the broadband XPS measurements [e.g., Woods et al., 2008]. There are several rocket observations of the solar EUV irradiance during the previous solar cycles, but none of these had the spectral resolution and range of these MEGS measurements during the lowest minima in 1996 and 1985. The May 1997 rocket measurement [Woods et al., 2000] occurred during low solar activity (F10.7 of about 75) but not under minimum conditions.

This rocket result is also being used in the solar irradiance reference spectra being created for the Whole Heliosphere Interval (WHI) campaign during March–April 2008 [Woods et al., 2008].

From Phil Chamberlin

SEE Solar Irradiance Measurements During TIMED Mission

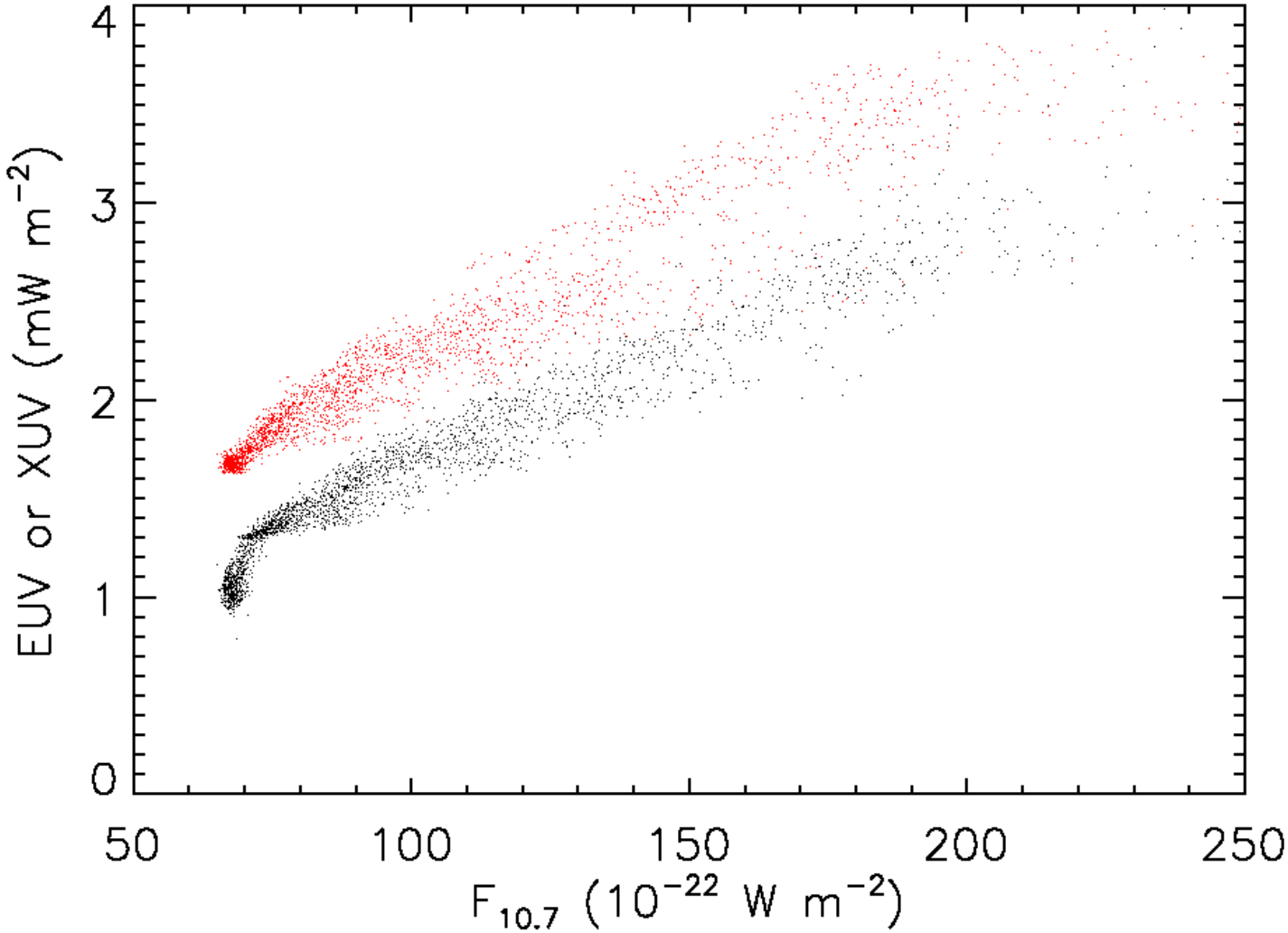


From Stan Solomon

TIMED SEE

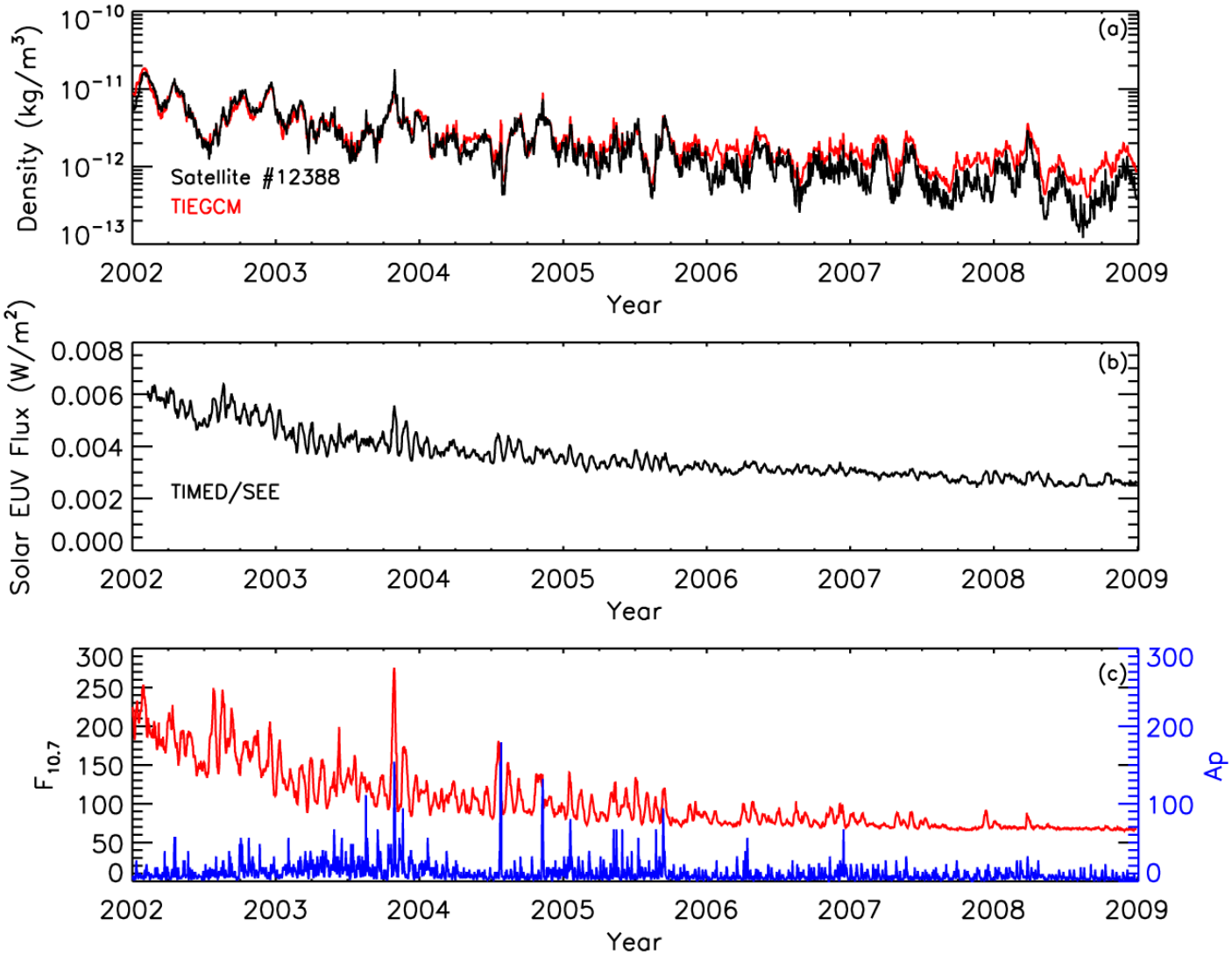
EUV and Soft X-ray Variability in SEE v. 10

F10.7 is flat during cycle minimum but XUV continues to decline in 2008-2009



From Stan Solomon

TIE-GCM Comparison Using New SEE Data

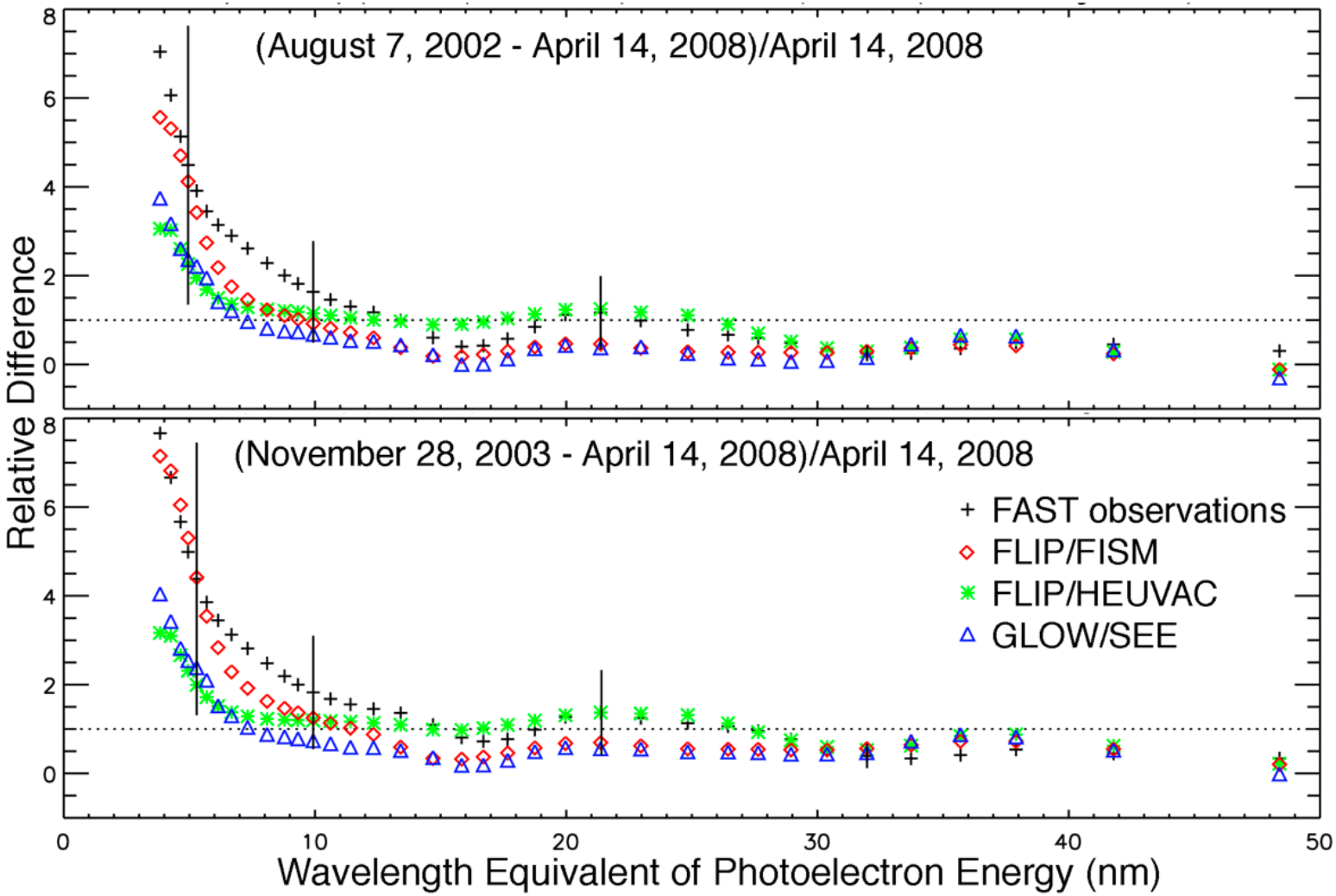


From Stan Solomon

TIMED SEE

Photoelectron Variability over Solar Cycle

FLIP/FISM (SEE-based irradiance model) shows good agreement with FAST photoelectrons variations

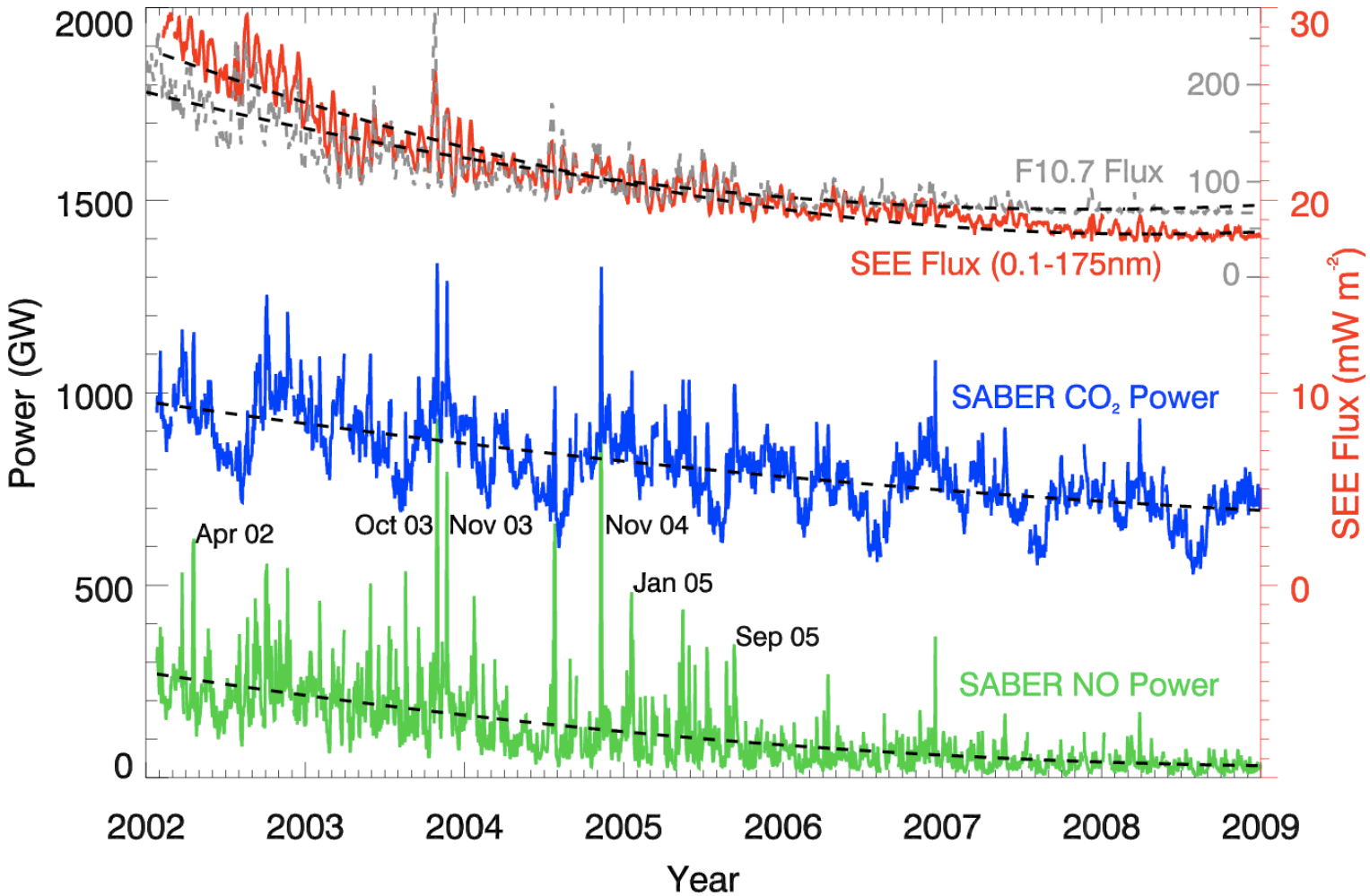


From Bill Peterson

TIMED SEE

CO_2 and NO Cooling Over Solar Cycle

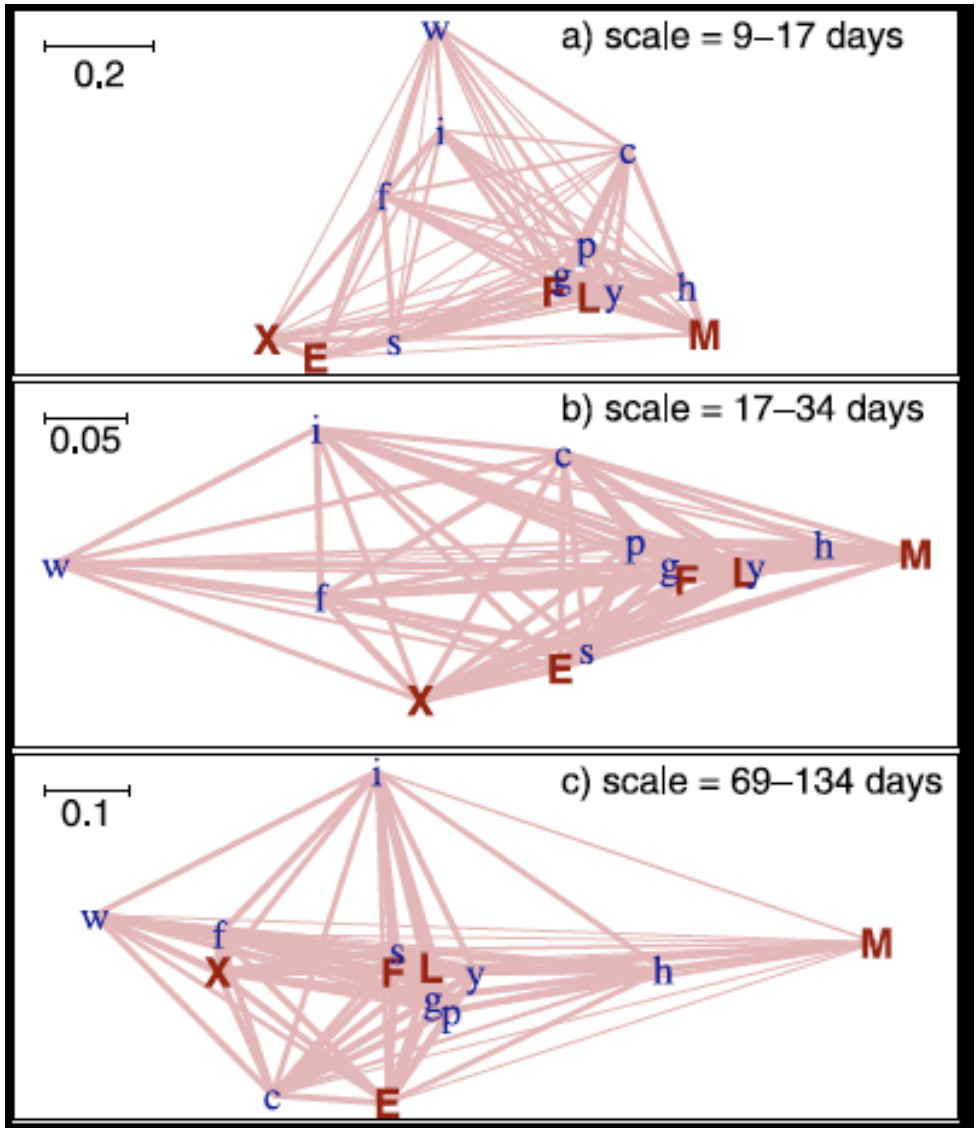
CO_2 and NO cooling trends are dominated by solar influence, seasonal effects, and also joule heating and auroral input for the NO variability near the poles.



From Gang Lu

TIMED SEE

Search for Best Proxies for EUV Variations



Correspondence maps for three characteristic scales. The distance between each pair of points corresponds to how well a proxy is related – closer is better.

Capitals designate 5 spectral bands: (X)UV, (E)UV, H I (L)yman-alpha, (F)UV and (M)UV.

The other characters correspond to proxies: (i)sn, (f)10.7, (s)10.7, M(g)II, (c)aK, M(p)SI, M(w)SI, L(y)man-alpha channel, (h)erzberg channel.

From Thierry Dudok de Wit

Improved Solar EUV Irradiance Models

- Updated solar irradiance models (using SEE Version 10 data)
  - FISM - Phil Chamberlin
    - 0-190 nm with 1-min cadence (flares)
    - Updated with latest SEE and SORCE latest data versions
    - FISM is now available from http://lasp.colorado.edu/lisird/
  - SIP (SOLAR2000) - Kent Tobiska
    - Updated with flare components
    - Updated with latest data versions
    - SIP is available from http://www.spacewx.com/solar2000.html
  - NRLSSI – Judith Lean
    - 120 nm – 100 microns solar spectral irradiance for 1950-2008
    - NRLSSI is now available from http://lasp.colorado.edu/lisird/
  - SRPM – Juan Fontenla
    - New effort to extend the SRPM spectral range down into EUV
    - SRPM will be available from http://lasp.colorado.edu/lisird/

Recent SEE-related Talks & Papers

Recent SEE Related Talks

- AGU, December 08, 2 talks
- Solar Validation Workshop, April 09, 3 talks
- EGU Meeting, April 09, 3 talks
- AGU, May 09, 2 talks
- SOHO-23 Workshop, September 09, 1 talk
- WHI-2 Workshop, November 09, 3 talks

Recent SEE Related Papers

- Chamberlin, P. C., T. N. Woods, D. A. Crotser, F. G. Eparvier, R. A. Hock, and D. L. Woodraska, New, Higher Resolution Solar Extreme Ultraviolet (EUV) Irradiance Results for Solar Cycle Minimum Conditions on April 14, 2008, *Geophys. Res. Lett.*, 36, L05102, doi: 10.1029/2008GL037145, 2009.
- 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.
- Rodgers, E. M., S. M. Bailey, H. P. Warren, T. N. Woods, and F. G. Eparvier, Nitric Oxide Density Enhancements due to Solar Flares, *Adv. Space Res.*, 43, in press, 2009.
- Dudok de Wit, T., M. Kretzchmar, J. Liensten, and T. Woods, Finding the best proxies for the solar UV irradiance, *Geophys. Res. Lett.*, 36, 10107, doi: 10.1029/2009GL037825, 2009.
- Peterson, W. K., E. N. Stavros, P. G. Richards, P. C. Chamberlin, T. N. Woods, S. M. Bailey, and S. C. Solomon, Photoelectrons as a tool to evaluate spectral variations in solar EUV irradiance over solar cycle time scales, *J. Geophys. Res.*, 114, A10304, doi:10.1029/2009JA014362, 2009.
- Woods, T. N. and P. C. Chamberlin, Comparison of solar soft X-ray irradiance from broadband photometers to a high spectral resolution rocket observation, *Adv. Space Res.*, 43, 349-354, 2009.
- Del Zanna, G., V. Andretta, P. C. Chamberlin, T. N. Woods, and W. T. Thompson, The EUV spectrum of the Sun: SOHO CDS NIS radiometeric calibration, *Astron. & Astrophys.*, submitted, 2009.
- Lean, J. L. and T. N. Woods, Solar Total and Spectral Irradiance Measurements and Models: A Users Guide, in Evolving Solar Physics and the Climates of Earth and Space, ed. K. Schrijver and G. Siscoe, Cambridge Univ. Press, submitted, 2009.
- Lu, G., M. G. Mlynczak, T. Woods, and R. G. Roble, On the relationship of Joule heating and nitric oxide radiative cooling in the thermosphere, *J. Geophys. Res.,* in press, 2009.
- Tobiska, W.K., Operational Space Weather Entering a New Era, *Space Weather*, 7, S10003, doi: 10.1029/2009SW000510, 2009.
- Tobiska, W.K., Space Weather Management, *AIAA 2009-1494*, 2009.
- Peterson, W. K., P. C. Chamberlin, T. N. Woods, and P. G. Richards, Temporal and spectral variations of the photoelectron flux and solar irradiance during an X class solar flare, *Geophys. Res. Lett.,* 35, L12102, doi: 10.1029/2008GL033746, 2008.
- Tobiska, W. K., International Standards Will Enhance Space Weather Management, *Space Weather*, 6, S06001, doi: 10.1029/2008SW000410, 2008.

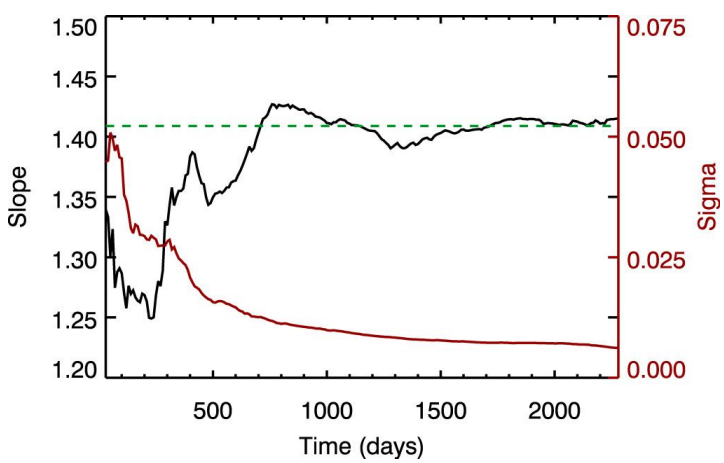
Conclusions and Future Plans

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
  - Extreme flare periods are April 2002, July 2002, May-June 2003, Oct.-Nov. 2003, July 2004, Jan. 2005, Sept. 2005, and Dec. 2006
  - Large flares vary as much as 11-year solar cycle variations
  - New flare models have been developed with SEE observations
- More than 90 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
  - Extended TIMED mission would observe solar cycle rising activity, perhaps starting in 2010

SEE Plans for 2010

- Daily mission operations and data processing for SEE to overlap with SDO EVE
  - As funds permit (might be last year of funding for TIMED SEE)
- Overlap with NASA Solar Dynamics Observatory (SDO) mission
  - EUV Variability Experiment (EVE) on SDO will provide 0.1-105 nm solar EUV irradiance with 0.1 nm spectral resolution
  - SDO's launch is planned for February 3, 2010. EVE's first undeflight calibration rocket is planned for May 2010 (also benefits calibration for TIMED SEE)
  - After adequate overlap with EVE to continue the solar EUV time series, then SEE will be turned off and final SEE data product will be produced
  - Final SEE product will be version 11



SEE-EVE overlap needs to be for at least 1 year to provide accurate continuation of the solar EUV time series.

Plot shows how uncertainty (sigma) of combining 2 solar data sets decreases with longer overlap time.