SORCE SSI Workshop Summary

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Over 30 scientists and calibration specialists gathered at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, for the first *Solar Spectral Irradiance (SSI) Variations Workshop*, Feb. 28-March 1, 2012. The purpose of the workshop was to address the interesting and conflicting differences for the reported SSI variations during the Solar Radiation and Climate Experiment (SORCE) Mission and other missions. The SORCE science team, in collaboration with NIST and NASA Goddard Space Flight Center (GSFC) met with other SSI instrument teams and calibration experts to examine these discrepancies by focusing on issues primarily related to understanding degradation trends that affect the measurement of solar cycle variations in irradiance. The agenda included:

- Reviewing various SSI instrument observations, capabilities, and their estimated irradiance uncertainties
- Discussing how each instrument team analyzed the spectral data to separate out instrument effects (*e.g.* degradation) from intrinsic solar variations
- Discussion to gain a better understanding of the SSI differences and refinement of their uncertainties
- Planning future methods to identify the significant differences (new studies, new calibrations, etc.) and refine uncertainties

A summary of this workshop, including PDF versions of many of the presentations, is available at: *http://lasp.colorado.edu/sorce/workshops/index.htm*.

The first day began with a keynote presentation about the challenges in understanding the SSI solar cycle variability by **Gary Rottman** [Laboratory for Atmospheric and Space Physics (LASP), University of Colorado (CU)], the original SORCE Principal Investigator. He cautioned that observing the sun in space is a very hostile environment for any optical instrument. The responsivity of all instruments change with time and exposure, and this degradation presents the greatest obstacle to determining solar variability. For this workshop, it was critical that participants examine the methods used to perform long-term degradation corrections. The techniques used for correcting on-orbit irradiance vary from instrument to instrument, so an analysis of how these corrections are performed and an uncertainty estimate of those corrections are necessary. Figure 1 shows the importance of this problem. The top panel shows how the solar spectrum is 'filtered' from the top of the atmosphere, through the atmosphere to the surface, showing that solar variability is significant throughout the entire spectrum. The lower panel indicates one model estimate of the solar variability based on total solar irradiance (TSI) measurements in the visible/infrared (VIS/IR) and Upper Atmosphere Research Satellite (UARS) ultraviolet (UV) measurements. The UARS instruments provide a standard uncertainty of about

1 % in the 200 nm to 400 nm range. However, to measure the variability in the visible and near-infrared spectral range requires uncertainty due to degradation corrections more than an order of magnitude smaller than in the UV. To understand the degradation corrections, a measurement equation approach is necessary to define the irradiance corrections and to evaluate the uncertainties in the observations. This approach is also needed to evaluate where potential systematic uncertainties arise in the measurements.

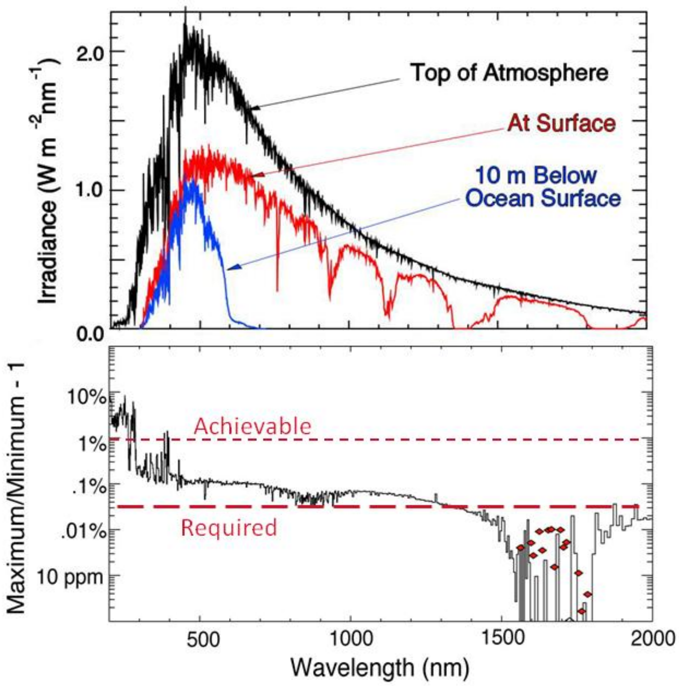

Figure 1a. Solar radiation is captured in different wavelength regions throughout the Earth's atmosphere.

Figure 1b. Model results are based on total solar irradiance (TSI) and UV observations adapted from Solanki and Unruh (1998).

Image credit: G. Rottman, LASP, CU.

Various international SSI instrument teams, including SORCE SOLSTICE (SOLar-Stellar Irradiance Comparison Experiment) and UARS SOLSTICE (**Marty Snow, Bill McClintock,** and **Tom Woods** [CU/LASP]); UARS Atmospheric Laboratory for Applications and Science Solar UV Spectral Irradiance Monitor (ATLAS SUSIM) (**Linton Floyd** and **Jeff Morrill** [Naval Research Laboratory, Washington DC]); Solar Backscatter UV Instrument (SBUV) (**Matt DeLand** [Science Systems and Applications Inc.]); ATLAS SOLar SPECtrum (SOLSPEC) (**Gérard Thuillier** [Laboratoire Atmospheres, Milieux, Observations Spatiales (LATMOS-CNRS]); Solar and Heliospheric Observatory / Variability of solar Irradiance and Gravity Oscillations (SoHO VIRGO) (**Christoph Wehrli** [Physikalisch-Meteorologisches Observatorium (PMOD)—Davos, Switzerland]); SORCE Spectral Irradiance Monitor (SIM) (**Jerry Harder** and **Juan Fontenla** [CU/LASP]); and PICARD PREcision Monitoring Sensor (PREMOS) (**Gäel Cessateur** [PMOD]), each had an opportunity to explain how their instrument adheres to a measurement equation and to explain additional contributions and/or omissions.

Figure 2 summarizes the long-term trends in the current SSI data sets. In the UV discussion, the SOLSTICE team announced that the (most recent) Version 11 data from SORCE SOLSTICE is improved relative to the previous version, but there are still 1% to 2% variations that appear to be instrumental rather than of solar origin. The SOLSTICE team plans to do further analysis of the sun-star field-of-view (FOV) degradation correction and of the transfer between the two channels needed for the mid-UV (MUV) spectral range. Each of these corrections currently has an uncertainty of 1 % to 2 % (*k*=1).

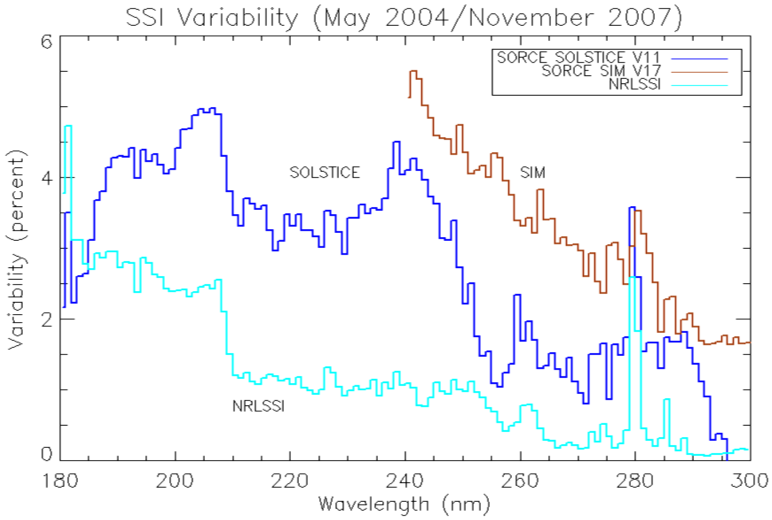

Figure 2. Solar variability in the middle ultraviolet as currently reported by the two SORCE spectrometers (SOLSTICE in blue, SIM in brown). For comparison, the variability predicted by the NRLSSI model (Lean, 2000; Lean et al., 2005) is shown in cyan. The variability is estimated by taking ratio of the average irradiance in each 1 nm bin for the month of May 2004 to the average for the month of November 2007. Image credit: M. Snow, LASP, CU.

During the visible-near IR discussion, there was some detailed discussion about the SIM degradation correction, based on the assumption that both SIM channels have the same degradation rate as function of exposure time. There are only two channels in SIM, and both are degrading. In contrast, SUSIM had several channels, enabling it to more precisely measure degradation rates as a function of exposure time relative to a set of onboard calibration lamps. There was general agreement that it would have been better if SIM had had more channels, enabling it to check this assumption (as SUSIM was able to do for its lamps), and the next generation SIM being built for the Total and Spectral Solar Irradiance Sensor (TSIS) mission will have a third channel. SORCE SIM clearly has superior measurement precision than any other NUV-VIS-NIR instrument for wavelength >300 nm, but uncertainties for its long-term trend could be larger than the solar cycle variation. This will be studied during the rising phase of solar cycle 24 with the reversal of irradiance trends as seen in Figures 3 and 4.

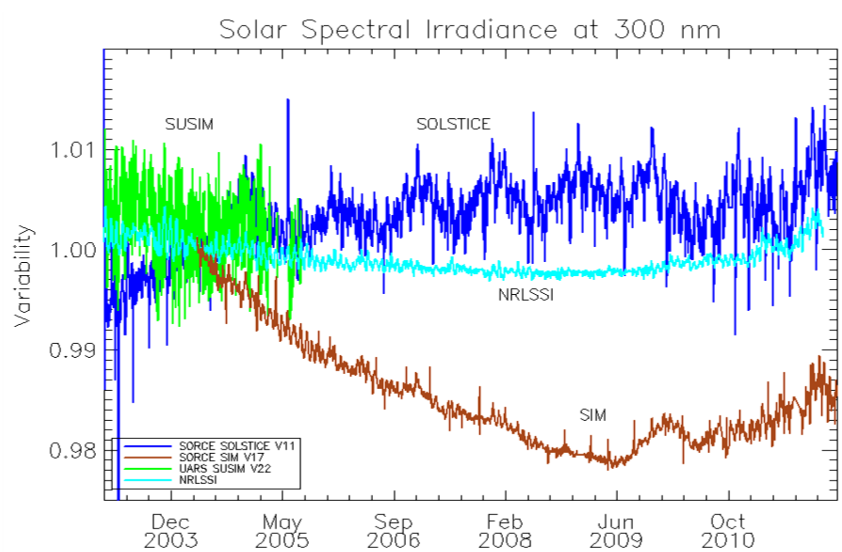

Figure 3. Time series comparing observations at 300 nm for the two SORCE instruments (SOLSTICE and SIM) and UARS SUSIM. The NRLSSI curve shows results from a model with inputs based on past observations and is plotted for comparison. In each case, the time series was normalized to be unity in May 2004. Based on observations from the previous solar cycle, the variability shown by the NRLSSI model is what was expected by many scientists for the current solar cycle. The trend shown by the SOLSTICE dataset is consistent with the NRLSSI model at this wavelength given the estimated uncertainty in the SOLSTICE degradation correction (see text). Estimated uncertainty in the SIM degradation correction from the intercomparison of its two channels is ±0.3 % (*k*=1). The trend shown by the SIM dataset is well in excess of the variability predicted by the NRLSSI model at this wavelength. Image credit: M. Snow, LASP, CU.

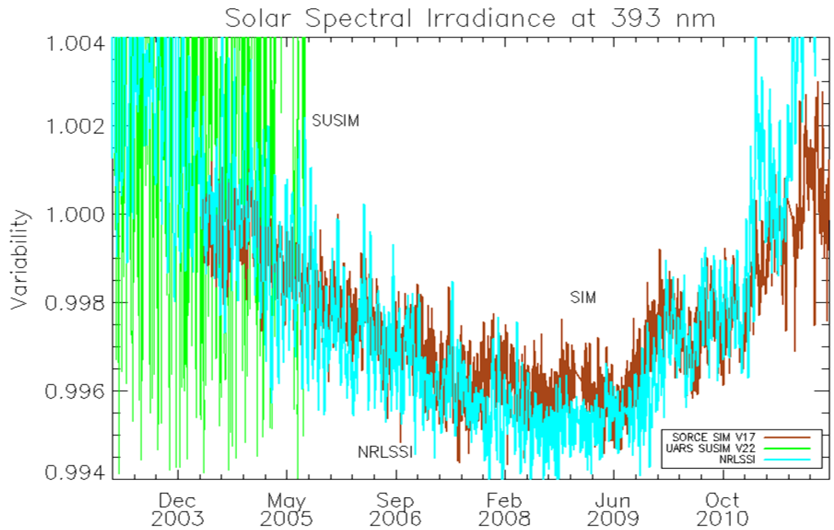

Figure 4. Time series comparing observations at 393 nm for SORCE SIM and UARS SUSIM. This wavelength includes the variability from singly ionized calcium. As in Fig. 3, the datasets are normalized to May 2004. Image credit: M. Snow, LASP, CU.

NIST experts led discussions on the second day by reviewing laboratory studies characterizing material damage and analysis of degradation mechanisms for space flight missions. They offered an independent perspective on root causes of degradation in SSI instruments beginning with an understanding that degradation rate is dependent on exposure rate, materials, pressure, and temperature. The greatest degradation is caused by photons with wavelengths shorter than 200 nm, but degradation mechanisms can still be effective at longer UV wavelengths.

Uwe Arp [NIST] addressed capabilities of the NIST Synchrotron Ultraviolet Radiation Facility (SURF III) for the calibration of SSI throughout the UV, visible, and infrared spectral ranges. **Shannon Hill** [NIST] discussed issues related to the degradation of optical materials with exposure to intense vacuum UV (VUV) radiation, and **Ping Shaw** [NIST] focused on detector degradation, sharing new results on Si photodiode degradation in the ultraviolet that he has been studying at SURF. Shaw concluded that some Si photodiodes are more stable than others, most degradation is caused by wavelengths shorter than 400 nm and is related to surface degradation effects. His research also shows that photodiodes can recover about half of their sensitivity loss after the exposure (period of months), and a degradation function needs to have both fast and slow decay components as related to exposure rate.

Allan Smith [NIST] discussed the calibration capabilities of NIST's Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) facility for SSI instruments in the visible to infrared range. **Joannie Chin** [NIST] concluded the NIST segment by discussing their capabilities regarding polymer-based degradation. She explained that although everything under the sun degrades, ground-based in-atmosphere degradation of materials may not be directly applicable for space (in-vacuum) degradation effects. **Erik Richard** [CU/LASP] concluded the session by sharing his radiation testing experience for the TSIS SIM instrument.

NASA contamination experts, **David Hughes** [GSFC] and **Therese Errigo** [GSFC], shared their knowledge of degradation and contamination effects and offered suggestions on how space flight instruments might be designed for reduced degradation and how scientists might better understand the contamination. Options included having vents towards the anti-sun side and/or extending out past any radiator plate, providing a means to warm-up optics and detectors during flight, flying a cold trap / cold plate near sensitive optics, and flying a Thermoelectric Quartz Crystal Microbalance (TQCM) to monitor contamination deposition rate real-time during flight.

Attendees compared the SSI observations from all instruments represented at the workshop at all of the different wavelengths. Each instrument had its own unique challenges regarding calibration and degradation. The key instrument degradation trend challenges include:

1. Degradation trends are complicated: multiple drivers, multiple parameters, different time scales, etc.
2. Most instrument calibration channels have different trend relationships with exposure time than its daily channel.
3. Laboratory measurements indicate that photodiodes can have significant recovery (up to 50 %) after being exposed to intense levels of UV radiation if they are kept unexposed for a period of time after the UV exposure.
4. Carbon deposition degradation rate has many dependences (pressure, temperature, contamination materials, etc.), so the "same" optics can have different trends. Elapsed time, in addition to exposure time, is potentially important due to the recovery mentioned above.
5. Solar spectral changes during solar cycle (SC) can enhance degradation (i.e. 1-minute of SC max exposure is not the same as 1-minute of SC min exposure).

The workshop concluded with a discussion of action items required to move forward on this complicated issue. These included:

- Improving SOLSTICE, SIM, and PREMOS temperature corrections
- Making SORCE SIM 2003 data available for SUSIM comparisons
- Applying SUSIM reference channel data results as comparison data for the SBUV instruments on board the National Oceanic and Atmospheric Adminstration-16 (NOAA-16) and NOAA-17 satellites
- Studying degradation models in more detail (although this might be too unique to each instrument to develop common functions that can be shared with others)
- Studying contamination degradation versus wavelength of exposure
- Exploring how continuous versus intermittent exposure (use) affect degradation rate
  - Possible in-flight experiment for SIM?
  - Laboratory measurements of SIM-like optics and SUSIM-like lamps?
- Initiating a comparative study of SORCE and ISS SOLSPEC irradiance on specific days since the start of the SOLSPEC record in 2007
- Comparing SORCE and VIRGO/PREMOS photometers in more detail
- Studying validation of TSIS SIM laboratory calibration with a NIST 0.1% uncertainty lamp (or other source)
- Planning a second SSI Variations Workshop to follow-up

This fall there will be a small one-day follow-up *SSI Validation Workshop* to continue the discussions from the first Workshop, re-visit the progress on the Action Items, and compare instrument data sets.

References:

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Solanki, S. K. and Y. C. Unruh, *Astronomy and Astrophysics,* **329,** 747, 1998.