TSIS Solar Spectral Irradiance Measurements

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Solar irradiance is the dominant external source of energy to Earth's atmosphere. Knowledge of solar spectral irradiance (SSI) variability is critical for understanding Earth's atmospheric response to solar forcing. Since early 2018, the Spectral Irradiance Monitor (SIM) instrument on the Total and Spectral Solar Irradiance Sensor (TSIS) mission has observed smaller changes in SSI than previously measured and at unprecedented low uncertainty (< 0.3%) over the majority of the spectrum, traceable to *Système Internationale (SI)* reference standards. TSIS-1 observations provide necessary validation for solar irradiance variability models that prescribe solar forcing at decadal to millennial timescales for climate models.

THE SPACE-BASED SSI RECORD

Space-based measurements of SSI at ultraviolet wavelengths began in 1978 [1] but it was not until the NASA Solar Radiation and Climate Experiment (SORCE) in 2003 that daily, calibrated measurements were made over nearly the entire spectrum, including the visible and near-infrared. The SORCE SSI measurements were crucial in evaluating and improving models on solar rotation (~ 27 days) timescales at most ultraviolet and visible wavelengths, but lacked the stability to quantify the quasi 11-year solar cycle impacts at all wavelengths [2]. Building a long-term SSI climate data record requires continuous instrument calibration in which measurement uncertainties are characterized, and maintained, against SI standards.

THE TSIS SIM INSTRUMENT

The TSIS-1 SIM, covering 200-2400 nm or approximately 96% of the total solar irradiance (TSI), is designed, characterized, calibrated and validated to meet the measurement requirements to quantify and track SSI variability for the climate record [3]. TSIS SIM achieves and maintains this detector-based calibration with an electrical substitution radiometer (ESR). The ESR radiometry is established pre-launch to better than 0.3% across most of the spectrum (Fig. 1) against an absolute cryogenic radiometer traceable to the NIST Primary Optical Watt Radiometer [4]. The ESR calibration is maintained over time by correcting on-orbit degradation using three independent SIM channels that are operated at different solar exposure rates. In early 2019, the Compact SIM (CSIM) technology demonstration mission [5] under the NASA In-Space Validation of Earth Science Technologies program was launched and demonstrated on-orbit agreement to TSIS-1 SIM to 1% (Fig. 2).

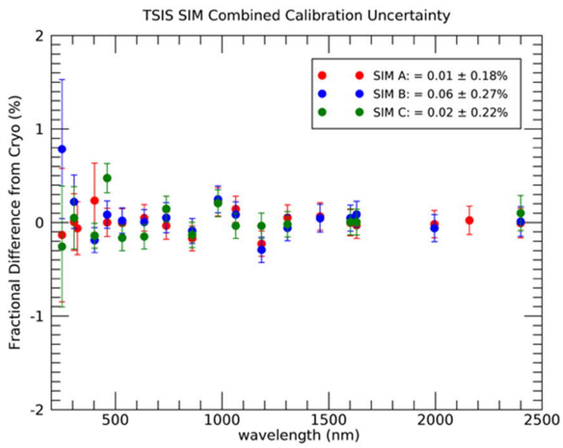

Figure 1. The final pre-launch spectral calibration and k=1 uncertainties of all three TSIS SIM channels against the absolute cryogenic radiometer irradiance values.

A TSIS SIM REFERENCE SPECTRUM

Solar reference spectra are utilized for varying purposes in atmospheric science and climate model applications. Solar spectra are used to convert measured satellite reflectances to radiances and as top of atmosphere boundary conditions in radiative transfer models for remote sensing applications and renewable energy research. Additionally, some instruments use the Sun for monitoring the stability of their radiometric calibration. Even instruments that assess the stability of their radiometric calibration relative to the Moon rely on a solar reference spectrum.

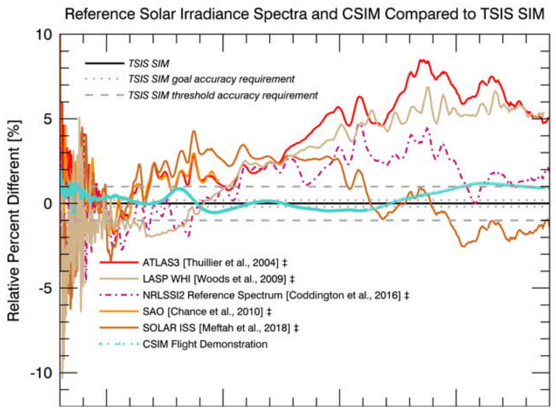

Figure 2. The relative % difference between TSIS SIM and several well-established SSI reference spectra as well as the CSIM flight demonstration mission.

The literature provides a variety of solar reference spectra for these applications [6-10]. A direct comparison of these spectra to TSIS SIM shows differences of as much as 10% in the ultraviolet and up to 8% in the near-infrared (Fig. 2), motivating the need for a new solar reference at the TSIS SIM scale. We are in the progress of developing a new reference spectrum at native TSIS-1 SIM resolution in addition to a higher resolution spectrum using independent, high-resolution solar line data.

DAILY SOLAR VARIABILITY

Even though the Sun is currently in a minimum-activity state, there was a small sunspot occurrence in April and May 2019. The improvements in measurement precision for TSIS-1 SIM relative to concurrent measurements by SORCE SIM are

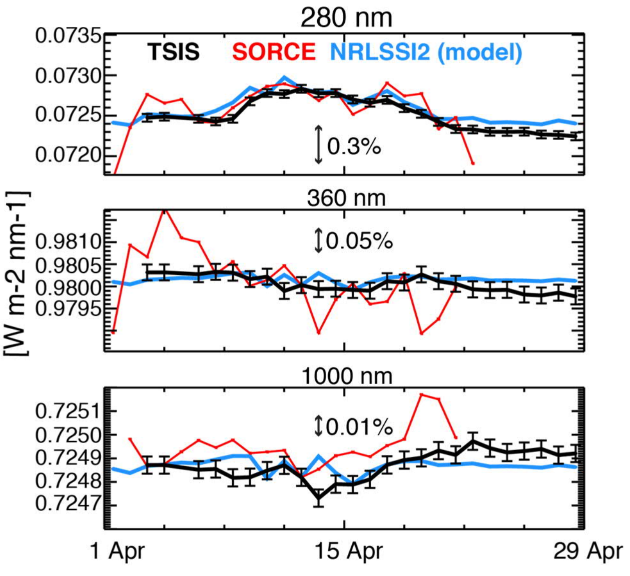

Figure 3. Short-term SSI variability during a sunspot passage in April, 2019 as measured by TSIS SIM (black) and SORCE (red) and estimated by NRLSSI2 (blue).

evident in the passage of this sunspot (Fig. 3). TSIS-1 SIM is resolving 0.01% solar variability at near-infrared wavelengths.

The TSIS-1 SIM precision is helping to improve and validate solar variability models such as version 2 of the Naval Research Laboratory (NRL) SSI model (NRLSSI2) [8]. This model assumes the primary sources of solar irradiance variability are bright faculae and dark sunspots on the Sun's surface and estimates the wavelength-dependent irradiance modulations from multiple linear regression of proxy indices of sunspots and faculae with SORCE SSI observations on short time scales. Development has already begun on a new version of this model to adopt TSIS-1 SIM observations for the absolute scale and in the fidelity at which solar activity is correlated with irradiance, especially between 300-400 nm and longward of 900 nm [11].

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