Solar Spectral Irradiance Measurements from the TSIS-1 SIM: Data continuity and comparisons to other records

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Continuous Solar Spectral Irradiance (SSI) Record covers < 2 decades

Total Solar Irradiance (TSI) Composite covers 4 decades
TSIS SSI Data Completeness & Exposure

Wavelengths Covered by Level 3 SSI Data (24HR Means) --- 518 Spectra Reported Over 653 Days

- B/A Duty cycle:
  - Planned: 11.2%
  - Actual: 11.8%

- C/B Duty cycle:
  - Planned: 12.5%
  - Actual: 13.2%

~80% daily scan completeness

http://lasp.colorado.edu/home/tsis/data/ssi-data
Final full ESR spectrum calibration of irradiance tied to NIST-traceable cryogenic radiometer
Spectral Stability Corrections

SIM Ch. C scan

240 nm

280 nm

350 nm

675 nm
TSIS SIM Overlap Comparison

**TSIS-1 SIM vs. SORCE**

- 200 nm to 240 nm
- 240 nm to 310 nm
- 310 nm to 500 nm
- 500 nm to 700 nm
- 700 nm to 1800 nm

Relative Change to first 81-days of TSIS SIM [%]

**TSIS-1 SIM vs. Models**

- 200 nm to 300 nm
- 300 nm to 400 nm
- 400 nm to 700 nm
- 700 nm to 1800 nm

Relative Change to first 81-days of TSIS SIM [%]
Comparison of the TSIS TIM TSI daily averages with the Integrated (200 – 2400 nm) Integ. TSIS SIM daily values.

- A constant offset of 51.6 W/m² is added to account for the ~4% of spectral irradiance not measured by SIM (wavelengths < 200 nm and > 2400 nm)

✓ Stability agreement better than 100 ppm (<0.01%) over the whole mission to date.
April 1-21, 2019 sunspot passage resulted in 0.03% decrease in TSI.

Future model improvements can be obtained by the superior TSIS SIM precision over previous SSI measurements.
Two Channel prism spectrometer (200 – 2800 nm)
Absolute ESR and fast Photodiode detectors

CSIM 6U CubeSat Implementation
Solar Spectral Irradiance (SSI) measurements by TSIS-1 SIM and CSIM during solar minimum period will result in a newly established SSI reference spectrum for Earth Science applications.

Obtained first ever on-orbit full SSI absolute validation. Both TSIS-1 SIM and CSIM have calibration tied to NIST-Standards.

Found excellent absolute SSI agreement between the CSIM spectrum compared to the TSIS-1 SIM spectrum.

**Absolute Mean differences:**
- 300 – 2400 nm: 0.44 ± 0.70 %

**SSI Weighted offsets:**
- 300 – 2400 nm: 0.56 ± 0.49 %

Solar Reference Spectrum

Reference Solar Irradiance Spectra and CSIM Compared to TSIS SIM

CSIM ESR Channel total uncertainty tied to cryogenic radiometer in SRF

- TSIS SIM
- TSIS SIM goal accuracy requirement
- TSIS SIM threshold accuracy requirement

Relative Percent Difference [%] from TSIS SIM

Wavelength [nm]

- ATLAS3 [Thullier et al., 2004]
- SOLID SSI (2008 Average) [Haberreiter et al., 2017]
- LASP WHI [Woods et al., 2009]
- NRLSSI2 Reference Spectrum [Coddington et al., 2016]
- SAO [Chance et al., 2010]
- SOLAR ISS [Metah et al., 2018]
- CSIM Flight Demonstration

Uncertainty [%]

Wavelength [nm]
CSIM and TSIS Daily Spectra Comparison

Three weeks of continuous SSI observations (21 daily spectra).
All spectra (CSIM and TSIS) plotted on their native irradiance scale
NO scaling or offsets applied
Three weeks of continuous SSI observations (21 daily spectra).
All spectra (CSIM and TSIS) plotted on their native irradiance scale
NO scaling or offsets applied
Every 2 weeks we obtain a full CSIM ESR spectrum

- Ch. A & B deg. corrections
- Photodiode A/W calibration

Still refining S/C pointing corrections and prism temperature (index of refraction) corrections.
CSIM Spectral Time Series (UV)
CSIM Spectral Time Series (Vis-IR)

0.05% Irradiance [W/m^2]

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Irradiance Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>1.7720 to 1.7740</td>
</tr>
<tr>
<td>750</td>
<td>1.6104 to 1.6114</td>
</tr>
<tr>
<td>1000</td>
<td>0.7256 to 0.7258</td>
</tr>
<tr>
<td>1618</td>
<td>0.2354 to 0.2356</td>
</tr>
</tbody>
</table>

% Change from last value:

- 0.05% for all wavelengths
CSIM pointing offsets are larger than expected

- The BCT pointing stability is poor, less stability in the azimuth direction (dispersion direction, most unfavorable)
  - In early September, we completed a BCT star tracker calibration scan to reset the FSS to star tracker pointing. This initially cured the offset in Azimuth, but then drifted back
  - Continue to monitor the trends over the next several months to verify the stability.
  - Noise in pointing stability data appears to have noise "spikes" common to the diode data.

CSIM temperature stability excellent

- Orbit to orbit stability ~0.2°C
- Mission stability shows no trends
Future of Solar Irradiance Continuity?

Proposed

- SORCE
  - EOM Feb 2020
  - TCTE (TSI only)
- TSIS-1 Prime Mission
- TSIS-1 Extension
- TSIS-2 Build
- TSIS-2 Prime Mission
- CSIM-FD Build
- CSIM-FD Prime Mission
- CTIM-FD Build
- CTIM-FD Prime Mission
- C-TSIS Build
- C-TSIS Prime Mission
- TSIS-3 Build
- TSIS-3 Prime Mission

• Demonstration that CSIM and CTIM can fully meet TSIS requirements in accuracy, stability, and reporting
  – Provide a 6 month overlap with TSIS-2
• Upgrade CSIM to a 3 channel instrument
• CTIM 1 Detector head (4 channels)
• Extend LASP 6U CubeSat design to 12U
• Improve parts reliability (Screening, Rad. Testing)
• Selectively move from CubeSat-class project engineering and production processes towards Class-D like project requirements (EEE parts, QA, SE, CM)
• Demonstrate regular and reliable mission operations, data capture, processing through improving automation and efficiencies from CSIM and CTIM lessons learned
BACK UP SLIDES
Average and std. dev. of derived rate from all temporally common SIM A/B spectral comparisons (spectral distribution similar to SORCE, but magnitude much smaller)