SORCE/TSIS Overlap Analysis

Absolute Scale Comparison, Stability Estimates, and Cycle 23/24/25 Record Construction

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SIST - Study Goals

1. Based on the high-quality SI traceable calibrations adapted for the TSIS SIM instrument, produce a Solar Cycle 24 (SC24) solar minimum spectrum analogous to the WHI SC23 minimum spectrum. Recalibrate the SORCE instruments and refine the absolute scale of the SC23 observations based on the low uncertainty of the pre-flight calibration, common instrument configuration, and concurrent observations between TSIS and SORCE SIM/SOLSTICE.

2. With >1.5 year of overlap between SORCE and TSIS, conduct an in-depth analysis of the stability of these instruments to determine their long-term relative drift.

3. Produce a unified SC23-24 full spectral irradiance data set with derived observational uncertainties and estimates of drift that will span the 2003-2019 time period.
TSIS on the ISS

Visibility / Obstruction Map
SORCE SIM Absolute Scale Correction – Justification

• SORCE SIM never had a full end-to-end ground calibration before launch. Absolute irradiances were adjusted to the best solar reference spectra available at the time: ATLAS-3 from the SOLSPEC instrument (Harder et al., Sol Phys. 2010)

• TSIS SIM was launched with an absolute scale calibration traceable to NIST standards with an overall uncertainty of ~0.1-0.3% - about a factor of 10x improvement over available calibration capabilities at the time of the SORCE preflight calibration (2001-2003)

• SORCE/TSIS overlap period started in March of 2018 and will continue in until SORCE decommissioning in February of 2020
  - On-orbit overlap period occurs during an extended and very quiescent Solar Cycle 24 minimum period
Instrument design/operation improvement in TSIS

• Lessons learned from SORCE and applied to TSIS
• Advanced high vacuum / ultra clean instrument chamber design to limit hydrocarbon contamination of prism glass – leading cause of degradation in satellite-borne spectrometers.
• Three spectrometer redundancy instead of 2 allows for improved corrections for both the daily working channel and the monthly correction channel.
• Instrument operations follow strict non-varying rates of solar exposure.
• Significantly improved low-noise performance of the ESR and the focal plane photodiodes.
  • reduced capacitance of the ESR bolometer greatly improves open-loop gain thereby improving detector sensitivity.
  • TSIS SIM photodiodes employ ~20 bit ADC compared to ~13 bit ADC’s on SORCE – a factor of 128
• Improved stray light rejections and off-axis pointing corrections
Two main sources of instrument degradation

1. Photodiodes degrade in space with high energy particles bombardment
   - Electrical Substitution Radiometer (ESR) is radiation hard and is used as reference measurement

2. Solar UV radiation polymerize hydrocarbons on the surface of the prism reducing its transmission
   - Prism degradation is expected to be directly related to amount of solar exposure
   - Separate channels take measurements at different cadence
   - SORCE has 2 identical channels, TSIS has 3 (channel-C exposed every 6 months for very slow degradation)
TSIS SIM Uncorrected Irradiance at 268.0nm vs Cumulative Solar Exposure

TSIS Data from quiet Sun period 2018-03-14 to 2019-12-26
Degradation model assumes the prism degradation is a function of the Cumulative Solar Exposure:
Channels A, B and C should follow the same trend
SORCE Uncorrected Irradiance show a clear difference in trends over the mission (Solar Cycle variations are folded in the data plotted below).

TSIS Data from quiet Sun period
2018-03-14 to 2019-12-26
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TSIS Data from quiet Sun period
2018-03-14 to 2019-12-26
TSIS SIM & SORCE SIM Uncorrected Irradiance at 268.0nm vs Cumulative Solar Exposure

Over the first 10 days of cumulative solar exposure, the trends appear similar ...

A longer TSIS dataset will better show the trends between all 3 channels ...
TSIS Corrected Irradiances

Plots show representative UV to near IR wavelengths and the results of the SIM A degradation corrections based on SIM channel B & C stability corrections.

Right axis on each plot shows the relative level of change (in %) between corrected and uncorrected irradiances.

As of **TSIS Mission Day 740** (Dec. 23, 2019), SIM A had ~69 days of cumulative solar exposure. The degradation is the following (SORCE-SIMA is in red for SD=563 with 69 days of exposure):

- 239 nm – 4% (23%)
- 280 nm – 3% (19%)
- 348 nm – 2% (6%)
- 676 nm – 0.2% (0.34%)
- 703 nm – 0.15% (0.29%)
- 965 nm – < 0.05% (0.19%)

The final corrected irradiances are shown in **Yellow**.
SORCE/TSIS on TSIS First Light (2018-03-14)

- Uncorrected scattered light in SORCE is believed to cause effect at 227nm and 280nm
- General slope is attributed to cumulative errors in the degradation correction
**SORCE/TSIS Overlap Analysis**

**TSIS SIM vs SORCE SIM**

**SORCE/TSIS on TSIS First Light (2018-03-14)**
- SORCE overestimates the IR > 1000 nm (as does ATLAS3)
- Next SORCE data release will fold in TSIS absolute measurements on First Light
TSIS & SORCE Temperatures

- Since Day-Only-Operations, SORCE SIM temperatures fluctuates significantly.
- Small residual temperature effects can be seen in the SORCE data
TSIS SIM vs SORCE SIM & TSI

SORCE, TSIS Integrated SSI vs TSI

- SORCE SIM Integrated 240-1600nm (+146.83)
- SORCE TIM
- TSIS SIM Integrated 240-1600nm (+154.35)
- TSIS TIM

SORCE 1-σ / TSIS 1-σ = 3.7
185 ppm 49 ppm

185 ppm 49 ppm
SSI Reference Spectra

\[ \int_{200}^{2400} E(\lambda) \, d\lambda = 96\% \text{ TSI} \]

### Table: SSI Reference Spectra

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>205-2390 (W/m²)</th>
<th>+ 52 (W/m²)*</th>
<th>TIM TSI (W/m²)</th>
<th>Diff (W/m²)</th>
<th>% Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS3</td>
<td>1333</td>
<td>1386</td>
<td>1361</td>
<td>+ 25</td>
<td>+ 1.81</td>
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<tr>
<td>SIRS-WHI</td>
<td>1323</td>
<td>1375</td>
<td>1361</td>
<td>+ 14</td>
<td>+ 1.02</td>
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<tr>
<td>SOLAR-ISS</td>
<td>1321</td>
<td>1373</td>
<td>1361</td>
<td>+ 12</td>
<td>+ 0.87</td>
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<tr>
<td>TSIS SIM</td>
<td><strong>1307.6</strong></td>
<td><strong>1359.6</strong></td>
<td><strong>1360.6</strong></td>
<td><strong>- 1</strong></td>
<td><strong>- 0.08</strong></td>
</tr>
</tbody>
</table>

*Integrated SSI contribution outside 205-2390 nm (±0.1% variability uncertainty)