Progress towards a high-resolution, high-accuracy solar reference spectrum based on TSIS-1 SIM

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Outline

• Motivation
  • new, high-accuracy TSIS-1 SIM
  • Comparisons of TSIS-1 SIM to CSIM
  • Comparisons of TSIS-1 SIM to other common solar reference spectra

• Developing a high-resolution, high-accuracy solar reference spectrum
  • Methodology
  • Available high-resolution solar irradiance datasets
  • Example of re-calibrating a high-resolution dataset to TSIS-1 absolute scale

• Next steps
Motivation

• Knowledge of solar spectral irradiance (SSI) magnitude and variability is important for:
  • attribution of climate forcing,
  • solar irradiance variability modeling,
  • radiative transfer modeling,
  • conversion of measured satellite reflectance to radiance,
  • satellite calibration and on-orbit stability tracking
  • and much more.

• TSIS-1 SIM is designed, characterized, calibrated and validated to quantify and track SSI variability.
  • TSIS-1 SIM absolute accuracy performance is 0.41% (uv) and 0.24% (vis/nir)
  • Pre-TSIS SSI absolute accuracy is 2-8%
Detector-based calibration is key to high accuracy

- TSIS-1 SIM is the first, solar-viewing spectroradiometer using an electrical substitution radiometer that traces its accuracy to a primary detector-based standard.
  - detector-based radiometry allows for \(~5x\) improvement in accuracy (~0.05% unc) versus blackbody sources (~0.25% unc.) [H. Yoon, Calcon, 2013]

- For radiometric calibration, you can build a more accurate detector than a source (lamps, blackbodies, etc.).
  - LASP built the Spectral Radiometer Facility

\[
\mathcal{E}_\lambda (\lambda_s) = \frac{P_D(\lambda_s)}{A \cdot \Delta \lambda(\lambda_s)} \quad \text{units: } \frac{W}{m^2 \cdot \text{nm}}
\]

\(P_D\) is the optical power directly measured by the SIM ESR
CSIM and TSIS-1 SIM Difference

• The Compact SIM (CSIM) technology demonstration mission (launched early 2019) shows on-orbit agreement to TSIS-1 SIM to 1%.
### Reference Solar Irradiance Spectra and CSIM Compared to TSIS SIM

#### Ultraviolet

<table>
<thead>
<tr>
<th>Name</th>
<th>Accuracy</th>
<th>Spectral Resolution</th>
<th>Spectral Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS 3</td>
<td>2-4%</td>
<td>0.25 nm - 0.5 nm</td>
<td>0.5 nm - 2400 nm</td>
</tr>
<tr>
<td>LASP WHI</td>
<td>2-3%</td>
<td>0.1 nm &lt; 310 nm</td>
<td>0.5 nm - 2400 nm</td>
</tr>
<tr>
<td>SOLAR-ISS, v1.1</td>
<td>1.26% (mean)</td>
<td>0.6 nm – 9.5 nm</td>
<td>265 nm – 3000 nm</td>
</tr>
<tr>
<td>NRLSSII2</td>
<td>LASP WHI &amp; ATLAS 3</td>
<td>0.1 nm &lt; 300 nm</td>
<td>115 nm – 2400 nm (obs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 nm; 300-1000 nm</td>
<td>2400 nm - 100,000 nm (theory)</td>
</tr>
<tr>
<td>IRSPERAD</td>
<td>1%</td>
<td>10 nm</td>
<td>600 nm – 2300 nm; discrete bands</td>
</tr>
<tr>
<td>CSIM</td>
<td>&lt;1% 300-2000 nm</td>
<td>Variable</td>
<td>200-2800 nm</td>
</tr>
</tbody>
</table>

*All datasets except CSIM and IRSPERAD have been convolved to TSIS SIM resolution.*

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### TSIS-1 SIM sets a new standard for SSI accuracy.

*TSIS-1 SIM sets a new standard for SSI accuracy.*

*All datasets except CSIM and IRSPERAD have been convolved to TSIS SIM resolution.*
Developing a high-accuracy, high-resolution reference

• Methodology to re-calibrate a high-resolution dataset to the lower resolution TSIS-1 SIM scale
  • Spectral ratio method [e.g. Dobber et al. 2008; Kang et al., 2017]
  • Scaling factor = the ratio of the TSIS-1 SIM to the high-resolution spectrum convolved to the TSIS-1 SIM spectral resolution
  • Convolution requires good knowledge of TSIS-1 SIM instrument line shape (ILS)

TSIS SIM ILS measured at 42 wavelengths UV – NIR: 206-2700 nm
A high fidelity instrument model is used to reproduce the ILS across the spectrum
TSIS SIM ILS’s are publicly available: [http://lasp.colorado.edu/home/tsis/data/ssi-data/](http://lasp.colorado.edu/home/tsis/data/ssi-data/)
Which high-resolution data set to use? So many choices!
*All datasets have been convolved to TSIS SIM resolution.

<table>
<thead>
<tr>
<th>Name</th>
<th>High Resolution Dataset(s)</th>
<th>“Radiometric” Dataset</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAO2010</td>
<td>AFGL and KPNO</td>
<td>ATLAS 3 &gt; 305 nm</td>
<td>5-30% &lt; 305 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5% &gt; 305 nm</td>
</tr>
<tr>
<td>QASUME/FTS</td>
<td>QASUME/FTS and KPNO</td>
<td>QASUME</td>
<td>4% at 300 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2% 310-500 nm</td>
</tr>
<tr>
<td>KNMI</td>
<td>AFGL and KPNO</td>
<td>SUSIM/UARS &lt; 410 nm</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCIAMACHY balloon val &gt; 400 nm</td>
<td></td>
</tr>
</tbody>
</table>

Let’s ‘re-calibrate’ this one...
Re-calibrating SAO2010 to TSIS-1 SIM

TSIS-1 SIM

SAO2010
SAO2010 - convolved

Ratio = scaling factor used to calibrate high-res dataset
Next Steps

• Produce the high-resolution reference spectrum at TSIS-1 SIM irradiance scale:
  • 200-2800 nm (extended from 2400 nm with CSIM; pending conclusion of CSIM analysis)
  • ~0.001 nm spectral resolution and 0.00025 nm sampling.
  • K. Chance, R. Kurucz, and M. Kang to advise on high resolution datasets
  • Report to GSICS in March, 2020.
  • Finalize analysis and report at IRS in July, 2020.

• Our Sun is a variable star
  • TSIS-1 SIM launched near to solar minimum (“first light” spectrum)
  • The ‘WHPI campaigns’ will define the “Quiet” Sun period, based on irradiance and solar activity metrics

• Define uncertainties, wavelength-dependent, with contributions from:
  • TSIS-1 SIM accuracy
  • The small offset needed to scale (reduce) CSIM to TSIS-1 SIM at 2400 nm.
  • A metric of how well the re-calibrating of the high-resolution data to TSIS SIM scale can be performed
  • Uncertainties in wavelength scale (propagated into irradiance)
  • Others sources?