Solar Spectral Irradiance Variability in Cycle 24: Model Predictions and OMI Observations

S. Marchenko\textsuperscript{1}, M. DeLand\textsuperscript{1}, J. Lean\textsuperscript{2}

\textsuperscript{1} SSAI and NASA/GSFC, USA
\textsuperscript{2} Naval Research Laboratory, USA

Aura STM, 2016
Climate change - known major forcing factors (no ranking…):

- solar
- volcanoes
- aerosols (+ clouds)
- green house gases
- ozone.

“…most of the global warming in the 1st half of the 20th century was natural in origin, and much of this can be attributed to solar forcing.”


… and then the green-house gases took over …

Both the total energy input and its spectral distribution are important for climate studies.
<table>
<thead>
<tr>
<th>Solar-cycles changes ((\sim11) yrs)</th>
<th>Short-term ((\sim)monthly/weekly) changes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Solar Irradiance</strong></td>
<td></td>
</tr>
<tr>
<td>(1360.54 \pm 0.36) (\text{W/m}^2) (G. Kopp, 2016, priv.comm)</td>
<td>(~0.10-0.15%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Solar Spectral Irradiance (SSI)</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>at ~ 100 nm</td>
<td>(~100%)</td>
</tr>
<tr>
<td>at ~ 250 nm</td>
<td>(~1-10%)</td>
</tr>
<tr>
<td>at &gt; 400 nm</td>
<td>(&lt;0.1% (?))</td>
</tr>
<tr>
<td></td>
<td>comparable or [much] below</td>
</tr>
<tr>
<td></td>
<td>? it depends…</td>
</tr>
</tbody>
</table>

The climate-study wish list:

regular (~weekly, at least), long-term (>10 years) spectrally resolved (to \(\Delta\lambda<1-10\) nm) solar observations in ~100 nm - 2 \(\mu\)m range, accurate (long-term!) to

\(~1\% - 0.1\%\) (MUV-NUV)

\(~0.01\%\) (Vis-NIR)

... good luck with that ...
The Cycle-24 hardware (data in public domain, UV-Vis range):

**SORCE (SOLSTICE & SIM**, since Jan. 2003); multiple/day observations; 115-2400 nm, variable spectral resolution, 0.1-24.6 nm; planned long-term accuracy ~0.2%; achieved accuracy ~1-2%.

**GOME-2 A** (since Oct. 2006); daily solar observations; 240-790 nm range with 0.3-0.5nm resolution; high degradation, uncertain to >~ 1%.

**OMI** (since Jul. 2004); daily solar observations; 265-500 nm, 0.4-0.6 nm resolution; **long-term degradation (y2007-current)** characterized to ~0.2%.

The software:

**NRLSSI2** (Coddington et al., BAMS, 2016) – the purely empirical class Naval Research Laboratory Solar Spectral Irradiance; **an operational NOAA (USA) Solar Irradiance Climate Data record**

**SATIRE-S** (Yeo et al., JGRA, 120, 2015) – a representative of the semi-empirical class Spectral And Total Irradiance REconstruction for the Satellite era
Bremen MgII composite index

OMI MgII index, 280 nm

Bremen composite (M. Weber): http://www.iup.uni-bremen.de/gome/gomemgii.html
OMI’s annual degradation: irradiances

Normalized daily SSI changes from OMI data (relative to yy2007-2009 reference)

<table>
<thead>
<tr>
<th>Date, JD - 2450000</th>
<th>Wavelength, nm</th>
<th>Relative change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7540 (May 30, 2016)</td>
<td>308</td>
<td>0.90%</td>
</tr>
<tr>
<td></td>
<td>316</td>
<td>0.35%</td>
</tr>
<tr>
<td></td>
<td>336</td>
<td>-0.20%</td>
</tr>
<tr>
<td>4102 (Jan 01, 2007)</td>
<td>358</td>
<td>-0.20%</td>
</tr>
</tbody>
</table>
Normalized daily SSI changes (relative to yy2007-2009 reference)

- Wavelength, nm
- Relative change, %
- Time, JD-2450000

Solar min., Jan. 2009, our 'reference'
Solar max., Jan. 2015

Scaled MgII index

312.131 nm
344.227 nm

Relative change, %

Time, JD-2450000

Normalized daily SSI changes (relative to yy2007-2009 reference)
Normalized short-term (~weekly) SSI changes from yy2012-2013
Normalized long-term (yy2012-2014 vs. yy2007-2009) SSI changes
The normalized and binned OMI fluxes and the models

- 265-345 nm
- 345-425 nm
- 425-500 nm

Irrad. difference, %

Year range: 2007-2015

OMI, SORCE SIM, NRLSSI2, SATIRE-S
Short-term (~weeks) SSI variability:

OMI, SORCE, GOME-2 and NRLSSI2 [mostly] agree to ~1-2 σ (~0.1-0.2%); problems with strong spectral lines in SATIRE-S.

Long-term (~solar cycle) changes:

- OMI agrees with the model output at ~1-2 σ level (~0.2-0.4)%;

- SORCE data cannot be reconciled with model predictions in the 290-340 nm range.

If OMI lasts through the Cycle 24-25 minimum (at least 3 years on; ideally, ~5 years), then we may be able to improve long-term accuracy of the SSI measurements to ~0.05% - 0.10%, thus

- providing a unique long-term SSI record;
- enabling further model refinements in the UV-Vis region.
Backup
'c' = 'continuum'

'\lambda'  = spectral line/blend

Irrad. difference, %

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
<th>2013</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>267.5 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>313.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>442.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>280.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>340.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>471.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>285.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>393.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500.0 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

265-345 nm

OMI
SORCE SIM
NRLSSI2
SATIRE-S

'I' = spectral line/blend