Overview of Measured SSI and Its Variability

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Presentation Outline

♦ The importance of an absolute solar spectrum and solar variability to the Earth climate problem.
♦ Brief introduction to the SORCE instruments
♦ Solar Variability: long term & short term variations
♦ Solar Variability and its impact on the Earth Atmosphere (a work in progress!)
♦ Conclusions, activities, and outlook
Spectral Irradiance Measurements Contribute to Key Climate Issues

- Response of climate to solar variability is highly wavelength dependent:
  - Direct surface heating at near-ultraviolet wavelengths and longer.
  - Indirect processes through absorption of UV in the stratosphere and radiative and dynamical coupling with the troposphere.

- Greatest *relative* variability occurs in the ultraviolet (indirect); greatest *absolute* variability occurs in mid visible (direct).

- Relative uncertainty in solar forcing is very large and must be reduced in order to separate natural from anthropogenic radiative forcing.

- Knowledge of TOA spectral distribution of solar radiation is crucial in interpreting the highly spectrally dependent radiative processes in the troposphere and at the surface.
SORCE Solar Irradiance Measurements

SORCE Instruments measure total solar irradiance and solar spectral irradiance in the 1 - 2000 nm wavelength range.
Total Irradiance Monitor (TIM)

Goals
◆ Measure TSI for >5 yrs
◆ Report 4 TSI measurements per day
◆ Absolute accuracy <100 ppm (1 σ)
◆ Relative accuracy 10 ppm/yr (1σ)
◆ Sensitivity 1 ppm (1 σ)

Major Advances
◆ Phase sensitive detection at the shutter fundamental frequency eliminates DC calibrations
◆ Nickel-Phosphide (NiP) black absorber provides high absorptivity and radiation stability
Solar Stellar Irradiance Comparison Experiment (SOLSTICE)

Science Objectives:

• Measure solar irradiance from 115 to 320 nm with 0.1 nm spectral resolution and 5% or better accuracy.

• Monitor solar irradiance variation with 0.5% per year accuracy during the SORCE mission.

• Establish the ratio of solar irradiance to the average flux from an ensemble of bright early-type stars with 0.5% accuracy for future studies of long-term solar variability.
Spectral Irradiance Monitor SIM

- Measure 2 absolute solar irradiance spectra per day
- Broad spectral coverage
  - 200-2400 nm
- High measurement accuracy
  - Achieving about 2% (±1σ)
- High measurement precision
  - SNR ≈500 @ 300 nm
  - SNR ≈20000 @ 800 nm
- High wavelength precision
  - 1.3 μm knowledge in the focal plane
  - (or δλ/λ < 150 ppm)
- In-flight re-calibration
  - Prism transmission calibration
  - Duty cycling 2 independent spectrometers

Total Solar Irradiance (TSI)

\[
TSI_{TIM} = \int_{\lambda=0}^{\lambda=\infty} E_{\lambda} \, d\lambda \approx 1362 \text{ Watts/m}^2
\]

Spectral Solar Irradiance (SSI)

\[
TSI_{SIM} = \int_{\lambda=200}^{\lambda=2400} E_{\lambda} \, d\lambda \approx 96\% \text{ of TSI}
\]
SIM Measures the Broadband Solar Spectrum

![Graph showing broadband solar spectrum measurements.](image)

**Irradiance (W m⁻² nm⁻¹)**

- **SIM**
- **Thuillier Composite**
- **SRPM**

**Brightness Temperature (K)**

**Wavelength (nm)**
Instrument Resolution

- SIM measures the irradiance weighted by the bandpass.
- Low resolution instruments respond to the density of lines, not to individual lines.
Solar FUV and MUV radiation is a primary source of energy for earth’s upper atmosphere.

FUV irradiance varies by ~ 10-100% but MUV irradiance varies by ~ 1-10% during an 11 year solar cycle.
**SIM Time Series at Fixed Wavelengths**

- **280 nm: Mg II**
  - Pseudo-continuum & cores of the Mg II lines.
  - 280 nm irradiance peaks when the plage area is the largest.
  - Flux is affected by active network.

- **656 nm: Hα**
  - Continuum contributions + Hα.
  - Almost identical in character to TSI.

- **1550 nm: H- Opacity**
  - Less sunspot contrast than TSI
  - Enhancement of IR brightness above TSI not present at visible wavelengths. (Fontenla et al., 2004)
SIM Partitions the TSI Into Discrete Bands as a Function of Time

• The character of the variability in integrated bands is a strong function of wavelength.

<table>
<thead>
<tr>
<th>SIM Wavelength Range (nm)</th>
<th>Irradiance (E) (W/m²)</th>
<th>~ΔE (W/m²)</th>
<th>ΔE/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-310</td>
<td>18.9</td>
<td>0.31</td>
<td>1.7x10⁻²</td>
</tr>
<tr>
<td>310-400</td>
<td>87.7</td>
<td>0.55</td>
<td>6.2x10⁻³</td>
</tr>
<tr>
<td>400-680</td>
<td>499.9</td>
<td>1.07</td>
<td>2.1x10⁻³</td>
</tr>
<tr>
<td>680-9500</td>
<td>294.0</td>
<td>0.49</td>
<td>1.7x10⁻³</td>
</tr>
<tr>
<td>950-1600</td>
<td>302.5</td>
<td>0.40</td>
<td>1.3x10⁻³</td>
</tr>
<tr>
<td>1600-2400</td>
<td>105.9</td>
<td>0.16</td>
<td>1.6x10⁻³</td>
</tr>
</tbody>
</table>
SSI and Climate

Spectral Irradiance Contributions to Key Climate Issues:

- Climate response to is highly wavelength dependent
  - Surface heating for wavelengths > 300 nm
  - Water absorption in near-infrared
  - UV absorption in the stratosphere and radiative and dynamical coupling with the troposphere.

- Uncertainty in solar forcing must be reduced to separate natural from anthropogenic radiative forcing.
- TOA spectral distribution of solar radiation needed to interpret spectrally dependent radiative processes in the atmosphere at the surface.
Incident (TOA) and Absorbed Irradiance Spectra

\[ F_{\text{abs}} = (1 - T)F_0 \]
Solar Cycle Variability in the UV

- UARS (cycle 22) & SORCE SOLSTICE (cycle 23) show very similar behavior
- Differences are under investigation
Longer Time Scale Solar Spectral Variability in VIS/IR

![Graph of Solar Irradiance Variability](image)

- **Red line**: Krivova et al. (2003) & Unruh et al. (in preparation)
- **Blue line**: SORCE SIM (v8 processing)

![Graph of Fractional Solar Variability](image)

**Wavelength (nm)**

- **Y-axis**: Solar Irradiance Variability (W m\(^{-2}\) nm\(^{-1}\))
- **Y-axis**: Fractional Solar Variability

**Source**: SORCE
27-Day Solar Rotation Variability in the UV

The amplitude of 27-day variability is strongly dependent on active region morphology.
Short Time Scale Solar Variability in the Vis/IR

Solar time variability is a function of wavelength.

- TSI constrains the magnitude of the variability, but not its spectral distribution.
- Solar surface features modulate spectral irradiance distribution.
- The Earth’s response to solar variability is wavelength dependent.
Solar Heating Rate Difference

11 Feb 2006 - 15 Jan 2005
SUNSPOT DOMINATED CASE
Solar Heating Rate Difference

11 Feb 2006 - 27 Oct 2004
PLAGE DOMINATED CASE
Conclusions, activities, and outlook

♦ The SORCE instruments TIM, SIM, and SOLSTICE provide a complete suite of instruments to accurately measure solar irradiance spectrum and its variability.

♦ Ongoing degradation analysis and validation will continue to improve the data quality.

♦ The data from these instruments can be tailored to meet the needs of the Earth climate community.