Solar Spectral Irradiance: Users, Applications, Models

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Motivation
- atmospheric, surface and ocean transmission, reflection, scattering and absorption are all wavelength dependent
- solar radiative forcing is spatially and altitudinally dependent

Users and Applications
- inputs for model simulations of present and past climate and atmospheric processes and variability

Spectral Irradiance Variability Model
- wavelength-dependent sunspot and facular influences

SORCE Irradiance Observations
- SIM and SOLSTICE → TIM (thanks to Jerry H. for sending SIM data)
- comparison with models
Global Heat Flows

Kiehl and Trenberth, 1997

SUN (255 K) + GHG (33 K) = 288 K
Incoming Solar Radiation

341.5 Wm$^{-2}$

$= \frac{1366}{4}$

SOHO: 1996 →
ACRIMSAT: 1999 →
SORCE: 2003 →
Solar Radiative Processes Depend on Geography and Altitude

- **UV radiation** ($\lambda < 315$ nm)
  - $20$ Wm$^{-2}$

- **near UV, VIS, IR Radiation** ($\lambda > 315$ nm)
  - $1346$ Wm$^{-2}$

- **Ozone**
- **Cloud cover**

**Graphical Representation**
- **Stratosphere**
- **Unit optical depth**

**Legend**
- **Sun**
- **Wavelength (nm)**
- **Altitude (km)**

**Additional Information**

- **Sun**
- **Near UV, VIS, IR Radiation**
- **Ozone**
- **Cloud cover**
<table>
<thead>
<tr>
<th>User Application</th>
<th>Wavelength Range Number of Bins</th>
<th>Time Period Cadence</th>
</tr>
</thead>
<tbody>
<tr>
<td>David Rind NASA/GISS GCM simulations</td>
<td>117-100,000 nm 190 bins</td>
<td>1880-2005 monthly</td>
</tr>
<tr>
<td>V. Ramaswamy NOAA/GFDL GCM simulations</td>
<td>202-100,000 nm 18 bins</td>
<td>1976-2004 monthly</td>
</tr>
<tr>
<td>David Lary NASA/GSFC AutoChem</td>
<td>121-850 nm 203 bins</td>
<td>1976-2005 daily</td>
</tr>
<tr>
<td>Kunihiko Kodera MRI, Tskuba, Japan Strat.-climate model</td>
<td>116-735 nm 171 bins</td>
<td>1882-2000 monthly</td>
</tr>
<tr>
<td>Don Wuebbles Univ. Illinois Strat. model</td>
<td>120-735 nm 134 bins</td>
<td>1975-2000 monthly</td>
</tr>
</tbody>
</table>
Climate Models

Hansen et al., JGR, 2002

117-100,000 nm
190 bands
Atmospheric Chemistry Modeling and Assimilation: AutoChem CDACentral

- Heterogeneous Chemistry
  - On sulfate aerosols
  - On carbonaceous aerosols
- Chemical Mechanisms
  - Hydrocarbon oxidation
  - Speculative processes
- Chemical Data Assimilation
  - Methodology
  - Instrument/Model Validation

AutoChem Applications

Solar Flux Data
Albedo Data
Box Model
Box Model Control File
Box Model Source Code

121-859 nm
203 bands
Solar Irradiance Variability Models: Total

- faculae

- sunspots

Solar Spectral Irradiance Variability Model

Solar Spectral Irradiance

10^4
10^2
10^0
10^-2
10^-4
10^-6

mW m^-2 nm^-1

Wavelength (nm)

Solar Spectral Irradiance Variability: 11-year Cycle

model: 1 nm bins
120-100,000 nm
daily since 1947
monthly since 1882
yearly since 1610

UV radiation varies more than visible radiation because UV faculae are brighter

Faculae

Sunspots

magnetic fields have different effects on radiation at different wavelengths

Lean, 2000; Lean et al., 2005
Flux transport simulations suggest that accumulated total magnetic flux produces a smaller facular contribution to secular irradiance change than in previous reconstructions.

Since the Maunder Minimum:
- total irradiance increase = 1.1 Wm$^{-2}$
- climate forcing = 0.2 Wm$^{-2}$
- surface temperature increase = 0.1-0.2°C ($\kappa = 0.5$-1°C per Wm$^{-2}$)

Lean et al., Sol. Phys., 2005
## Solar Irradiance Validation: Total

<table>
<thead>
<tr>
<th>TSI Record</th>
<th>Mean Value (W m⁻²)</th>
<th>Standard Deviation (W m⁻²)</th>
<th>Ratio to TIM</th>
<th>Correlation with TIM</th>
<th>Slope (W m⁻² per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIM</td>
<td>1360.98</td>
<td>0.579</td>
<td>1</td>
<td>1</td>
<td>-0.182 (0.013%)</td>
</tr>
<tr>
<td>PMOD</td>
<td>1365.76</td>
<td>0.573</td>
<td>1.00351</td>
<td>0.9964</td>
<td>-0.134 (0.010%)</td>
</tr>
<tr>
<td>ACRIM</td>
<td>1366.09</td>
<td>0.582</td>
<td>1.00375</td>
<td>0.9829</td>
<td>-0.261 (0.019%)</td>
</tr>
<tr>
<td>SARR</td>
<td>1366.73</td>
<td>0.577</td>
<td>1.00423</td>
<td>0.9967</td>
<td>-0.191 (0.014%)</td>
</tr>
<tr>
<td>Model</td>
<td>1365.95</td>
<td>0.479</td>
<td>1.00365</td>
<td>0.9634</td>
<td>-0.069 (0.005%)</td>
</tr>
</tbody>
</table>

Irradiance variability model derived from multiple regression of sunspot and facular indices with the PMOD composite underestimates the TSI variance observed by SORCE/TIM

Lean et al., Solar Phys., 2005
Solar Spectral Irradiance Validation: UV/Vis/IR

17 OCT 03 - 30 OCT 03

<table>
<thead>
<tr>
<th>Spectral Band (nm)</th>
<th>200-300</th>
<th>315-400</th>
<th>400-700</th>
<th>700-1000</th>
<th>1000-1600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Rotation</td>
<td>0.9990</td>
<td>0.9959</td>
<td>0.9965</td>
<td>0.9979</td>
<td>0.9980</td>
</tr>
<tr>
<td>30 Oct 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Rotation</td>
<td>0.9993</td>
<td>0.9956</td>
<td>0.9967</td>
<td>0.9975</td>
<td>0.9982</td>
</tr>
<tr>
<td>17 Oct 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Cycle</td>
<td>1.013</td>
<td>1.002</td>
<td>1.0008</td>
<td>1.0004</td>
<td>1.00025</td>
</tr>
<tr>
<td>1989/1986</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Variance is increased in irradiance variability model derived from multiple regression of sunspot and facular indices with TIM data, relative to model derived from PMOD composite.
Comparison of PMOD and TIM Models

Facular Brightening

Sunspot Darkening

PMOD Irradiance Composite
TIM Model
PMOD Model
TIM Data

Wm^-2

1362.00
1361.75
1361.50
1361.25
1361.00
1360.75
1360.50

### New UV/Vis/IR Spectral Irradiance Variability Model

<table>
<thead>
<tr>
<th>Current Model</th>
<th>New Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference (quiet Sun) spectrum from UARS/SOLSTICE and SOLSPEC</td>
<td>reference (quiet Sun) spectrum consistent with SIM and SOLSTICE</td>
</tr>
<tr>
<td>wavelength-dependent sunspot and facular contrasts are consistent with rotational modulation measured by UARS SOLSTICE ($\lambda &lt; 400$ nm) and from Unruh theoretical model ($\lambda &gt; 400$ nm)</td>
<td>wavelength-dependent sunspot and facular contrasts are consistent with rotational modulation measured by SIM and SOLSTICE ($\lambda &lt; 1600$ nm) and from Unruh theoretical model ($\lambda &gt; 1600$ nm)</td>
</tr>
<tr>
<td>integral of sunspot blocking and facular brightening match the bolometric (total) values derived from the multiple regression of PMOD composite data - <em>bolometric sunspot contrast 0.36</em></td>
<td>integral of sunspot blocking and facular brightening match the bolometric (total) values derived from the multiple regression of TIM data - <em>bolometric sunspot contrast 0.43</em></td>
</tr>
</tbody>
</table>
SORCE vs. Modeled Variability

SORCE
Lean (2000)
new model

200.0–210.0 nm

750.0–760.0 nm

350.0–355.0 nm

850.0–860.0 nm

500.0–505.0 nm

950.0–960.0 nm

650.0–660.0 nm

1500.0–1550.0 nm

mW m^{-2} nm^{-1}

2004.0 2004.5 2005.0 2005.5 2006.0
SORCE solar irradiance spectra are helping answer the Sun-climate questions:

- how and why does solar irradiance vary?
- what are the mechanisms of irradiance variability?
- are long-term changes occurring in addition to the 11-year cycle?
- how and why does climate respond to wavelength-dependent irradiance variations?
- are solar-induced surface temperature changes limited to 0.1-0.2°C?
- what are the roles of land, atmosphere and oceans in direct surface heating?
- what are the indirect effects of radiative and dynamical vertical atmospheric couplings?
- does solar forcing induce mode amplification (ENSO, QBO), stochastic resonance, frequency modulation, triggering altered stability states (AO, AAO)?
- mechanisms for significant hydrological cycle responses?
Construction of a Solar Spectral Irradiance Variability Model from SORCE data

SOLSTICE B V5 (115.5 -179.5 nm)
SOLSTICE A V5 (180.5 – 309.5 nm)
SIM V9 UV (201.5 – 306.5 nm)
SIM V9 VIS1 (310.5 – 955.5 nm)
SIM V9 VIS2 (338.5 – 1071.5 nm)
SIM V9 IR (849.5 – 1664.5 nm)
1 nm grid (on 0.5 nm centers) from 115 to 1600 nm
daily mean time series from April 2004 – 2006 $F(\lambda,t)$
bolometric sunspot and faculae time series from TIM TSI model, $P_s(t)$ $P_f(t)$
All time series smoothed twice with ±40-day squarewave
- detrended by converting to fractional changes
$F_d=(F(\lambda,t)- F_s(\lambda,t))/ F_a(\lambda)$
Multiple linear regression performed for detrended spectral irradiance time series at each $\lambda$
$F_d=a_0(\lambda)+ a_1(\lambda)\times P_f(t)+a_2 (\lambda)\times P_s(t)$
Irradiance model calculated from proxies by
$F_m(\lambda,t)=(a_0(\lambda)+ a_1(\lambda)\times (P_f(t)-P_f)+a_2 (\lambda)\times (P_s(t)-P_s)/P_s)\times F_a(\lambda,t)+F_a(\lambda,t)$