Solar and Anthropogenic Climate Signals

Volcanic aerosols

El Nino

La Nina

Omitting solar forcing →

.. poorer tracking of centennial variations

.. higher sensitivity to GHGs

Greenhouse gases

Industrial aerosols

from Judith Lean, NRL

GISS Land+Ocean Global Temperature

Temperature Anomaly (K)


model: ENSO+VOL, r = 0.48

model: SUN+ANTH, r = 0.70

Volcanic aerosols

CO2

Tropospheric aerosols

1860 1880 1900 1920 1940 1960 1980 2000

Climate Forcing (W m^-2)

http://data.giss.nasa.gov/

GISS Land+Ocean Global Temperature monthly means

http://data.giss.nasa.gov/
None of these instruments is calibrated end-to-end for irradiance.
TSI Record Has Relied on Continuity

Total Solar Irradiance Missions

- NIMBUS7/ERB
- SMM/ACRIM I
- ERBS/ERBE
- NOAA9
- NOAA10
- UARS/ACRIM II
- EUREKA/SOVA2
- SOHO/VIRGO
- ACRIM4/ACRIM III
- SOHO/ACRIM III
- SORCE/TIM
- PICARD/SOVAP
- Glory/TIM
- NPOESS-C2/TIM
- NPOESS-C5/TIM

Total Solar Irradiance Composite

ERB
ACRIM I V1-B9
ACRIM II V3-0110
ACRIM III D811
VIRGO V6-0702
TIM V7-0706

Average Monthly Sunspot Number

Year
Monthly Sunspot Number
0 50 100 150 200 250

Greg Kopp, p. 4
Solar Total Irradiance Measurement Summary

- Continuous and overlapping measurements are critical in maintaining a long term data record.
  - Critical for climate
  - Useful for inputs to solar and atmospheric models
- NIMBUS7 ERB (1978 - 1993)
- UARS ACRIM II (1991 - 2001)
- SOHO VIRGO (1996 - )
- ACRIMSat ACRIM III (1999 - )
- SORCE TIM (2003 - )
- PICARD PMO6 & SOVAP (2008 - )
- Glory TIM (2008 - )
- NPOESS TIM (2013 - )
Composites Rely on Continuity and Stability

Two primary TSI composites differ by 40 ppm/yr caused by 2 years of marginal quality data – not even a gap!
Future Needs: TSI – Accuracy and Stability

- Performance Requirements
  - Accuracy 0.01% (1 σ)
  - Stability 0.001%/yr (1 σ)
  - Noise 0.001% (1 σ)
Stability Has Been Achieved by Duty Cycling Radiometers

TIM Cavity B Degradation

(B−A) Relative Variation
Cavity B Est. Degradation

B−A Initial Offset = 246.62 ppm
Net Degradation to Date = 121.22 ppm
Ultimate Degradation = 142.58 ppm
Degradation Time = 605.79 days
RSS Differences = 8.724 ppm
TSI Instrument Uncertainties – With Diffraction Correction

1295 ppm diffraction correction applied to ACRIMs
200 ppm diffraction correction applied to ERBE

Correction not yet approved or applied by ACRIM or ERBE Teams
Instrument Uncertainties Determined at the Component Level

**SORCE/TIM**

<table>
<thead>
<tr>
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<td>Measurement Repeatability (Noise)</td>
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<td>Uncertainty due to Sampling</td>
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<tr>
<td><strong>Total RSS</strong></td>
<td><strong>206</strong></td>
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</tr>
</tbody>
</table>

**VIRGO/PMO**

Uncertainty of the PMO6V WRR/SI traceability @ 1400W/m2

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>u</th>
<th>c</th>
<th>(u*c)^2</th>
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<tr>
<td>Pclosed</td>
<td>45 mW</td>
<td>0.0000045</td>
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<td>CR</td>
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<td>7.00E-05</td>
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<tr>
<td>CSt</td>
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<td>2.84105</td>
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<td>Uncertainty abs</td>
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<td>1.6855 W/m2</td>
<td></td>
<td></td>
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<tr>
<td>Uncertainty rel</td>
<td></td>
<td>1685.5 ppm</td>
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<tr>
<td>95% Uncertainty</td>
<td></td>
<td>3371.1 ppm</td>
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**VIRGO/DIARAD L**

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<tr>
<th>Component</th>
<th>Relative</th>
<th>W/m2</th>
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<tbody>
<tr>
<td>Area</td>
<td>0.000425</td>
<td>0.58</td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>0.000130</td>
<td>0.18</td>
</tr>
<tr>
<td>Electrical Power</td>
<td>0.000150</td>
<td>0.20</td>
</tr>
<tr>
<td>Cavity absorption</td>
<td>0.000030</td>
<td>0.04</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>0.000735</strong></td>
<td><strong>1.00</strong></td>
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<tr>
<td>RSS</td>
<td>0.000470</td>
<td>0.64</td>
</tr>
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</table>

17 July 2007

Solar Irradiance Calibrations

Greg Kopp, p. 10
Ground Calibration Improvements Lower Glory Uncertainties

- Glory/TIM has lower uncertainties than SORCE/TIM because of improved ground calibrations

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Note dominant uncertainties are optical, and affect all solar radiometers

Largest calibration improvement
TIM Requires “Subtle” Corrections

- Aperture knowledge accuracy
  \[
  \frac{\Delta A}{A} = \frac{2\pi r \cdot \Delta r}{\pi r^2} = 10^{-4} \quad (100 \ \text{ppm}) \quad \Rightarrow \quad \Delta r = 200 \ \text{nm}
  \]

- Doppler correction due to S/C orbit velocity
  \[
  2\frac{v}{c} = 2 \cdot \frac{8 \times 10^5 \ \text{cm/s}}{3 \times 10^{10} \ \text{cm/s}} \approx 5 \times 10^{-5} \quad \Rightarrow \quad \pm 50 \ \text{ppm}
  \]

- Thermal (mid-IR) background
  \[
  \sigma T^4 \cdot \text{Cone Entrance Area} = 8 \times 10^5 \ \text{ergs} \quad \Rightarrow \quad 1.2 \times 10^6 \ \text{ppm}
  \]
  - Need “chopping,” or phase sensitive detection

Instrument is characterized rather than calibrated

for 100 ppm absolute standard uncertainty
Address Applied Power: Trap Diode Power Comparison

- This was a recommendation from the 2005 TSI Accuracy Workshop
- NIST and LASP performed optical power comparisons between a trap diode transfer standard and a ground-based TIM
  - Applying solar power levels with the TIM in vacuum
  - NPL has done similar power comparisons before

This is an optical power measurement, not irradiance
Current Glory/TIM Optical Power Measurements

- Compare radiometer consistency within instrument
  - Preliminary results are consistent with ±0.01% accuracy
- Compare Glory/TIM to SORCE Witness
  - Measures optical power only, not irradiance
  - SORCE Witness compared to trap diode at NIST in Nov. 2006
TSI Radiometer Facility Measures *Irradiance*

- No flight TSI instrument has been calibrated end-to-end
- First facility to measure irradiance
  - at desired accuracies
  - at solar power levels
  - in vacuum

See TRF poster
TSI Radiometer Facility Measures *Irradiance*

The TRF will:

1. Improve the calibration accuracy of future TSI instruments,
2. Establish a new ground-based radiometric irradiance standard, and
3. Provide a means of comparing existing ground-based TSI instruments against this standard under flight-like operating conditions.

*Intended to achieve ~100 ppm accuracy*

See TRF poster
Solar Variability Depends on Wavelength

SORCE and TIMED provide the first ever daily measurements of solar spectrum variations throughout the X-ray, UV, visible, and NIR
Also Need Solar Spectral Irradiance Inputs

Near UV, visible, near infrared radiation affect surface and ocean processes

Chemistry Climate Models Need SSI
GISS GCM [Rind et al., 2004; Shindell et al., 2006]
NCAR WACCM [Marsh et al., 2007]
HAMMONIA [Schmidt and Brasseur, 2006]
CMAM [Beagley et al., 1997]

Solar Spectral Irradiance

Chemistry Climate Models Need SSI
GISS GCM [Rind et al., 2004; Shindell et al., 2006]
NCAR WACCM [Marsh et al., 2007]
HAMMONIA [Schmidt and Brasseur, 2006]
CMAM [Beagley et al., 1997]
Atmospheric Heating Rates Depend on Spectral Irradiances
SORCE and TIMED Measure Irradiance Across Spectrum

- Solar irradiance measurements since March 2003
- Nearly complete solar spectral coverage
Solar Spectral Irradiance Measurement Summary

- GOES XRS (1975 - )
- POES SBUV (1985 - )
- SME (1981 - 1990)
- GOME (1995 - )
- SOHO SEM (1996 - )
- SOHO VIRGO SPM (1996 - )
- TIMED (2001 - 2008)
- SORCE (2003 - 2009)
- GOES EUVS (2006 - )
- SDO EVE (2008 - 2013+)
- NPOESS SIM (2013 - )
The SIM Acquires Daily Solar Spectra

- This is the best calibrated solar spectral irradiance instrument acquiring regular spectra
  - 310 - 2400 nm
  - 2% accuracy
NIST SIRCUS Calibrations Will Improve Future SIMs

- Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) tests on SORCE/SIM radiometer alone improved efficiency knowledge
- \(~0.1\%\) accuracy possible with such end-to-end calibrations

![Diagram showing SIRCUS calibration results]
Validate Earth Viewing Instruments From Accurate Solar?

- Cross-calibrating Earth viewing instruments off solar irradiance instruments provides on-orbit calibration or independent validation.

Pointing system allows hyperspectral imagers to view the Earth or the Sun for calibrations.

Solar Irradiance Calibrations: Conclusions

- **Calibration accuracies**
  - TSI
    - Progress is being made toward 0.01% absolute accuracy
    - Ground-based calibration facilities provide baseline for future instruments
    - Desired stability has been achieved
  - SSI
    - 0.1% likely achievable with NIST SIRCUS calibrations
    - 300 - 2400 nm

- **Solar Irradiance Uses**
  - Total solar irradiance used for climate sensitivity studies by extending 30-year data record and understanding solar variability
  - Solar spectral irradiance measurements needed to model Earth’s atmospheric response and solar variability
  - Absolute accuracy of radiative balance