Total Solar Irradiance Data Record
Accuracy and Consistency Improvements

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The Total Solar Irradiance Data Record

The graph shows the Total Solar Irradiance Database with data from various sensors including ERB, ACRIM I V1–8907, SOVA2, VIRGO V6–1102, ERBS V–0508, ACRIM II V3–0111, ACRIM III V–1009, NOAA9, NOAA10, and TIM V11–1107. The monthly sunspot number is also plotted against the years from 1980 to 2010.

TSI Data Record Improvements

G. Kopp, 18 Jul. 2011
What Are the Time Scales of TSI Variability?

- **0.1-0.3% over a few days**
  - Short duration causes negligible climate effect
- **0.1% over 11-year solar cycle**
  - Small but detectable effect on climate
- **0.05-0.3% over centuries (unknown)**
  - Direct effect on climate (Maunder Minimum and Europe’s Little Ice Age)
Climate-Quality Measurements Are Difficult

Solar Variability Exiting Maunder Minimum

Lean 2000

Wang 2005

Historical TSI Reconstructions

Wang et al (2005)
Topping et al (2007)
Lean (2000)
Steinhilber (2009)
Solar Cycle
Solar Variability Drives Measurement Requirements

Solar Rotation

TSIS/SIM

Solar Cycle

Solar Cycle Variability

Lean 2000

ACRIM & VIRGO (1000 ppm)

Leaner Minimum Variation

Wang 2005

Desired Sensitivity

SORCE/TIM (350 ppm)

Glory/TIM & TSIS/TIM (100 ppm)

100-yrs needed for MM detection

35-yrs needed for MM detection

10-yrs needed for MM detection
TSI Requirements To Address Climate Needs

- TIM Performance Requirements
  - Accuracy: 0.01% (1 σ)
  - Stability: 0.001%/yr (1 σ)
  - Noise: 0.001% (1 σ)
Glory Has Fixed This Problem – Without Even Flying

None of these instruments have been validated end-to-end for irradiance to desired accuracies
**TSI Radiometer Facility (TRF) Measures Irradiance**

The TRF

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

- Glory/TIM and PICARD/PREMOS are the first flight TSI instruments to be validated end-to-end
- First facility to measure *irradiance*  
  - at solar power levels  
  - in vacuum  
  - at desired accuracies
- NIST calibrations of L-1 cryo radiometer

Kopp *et al.*, SPIE 2007
Common Vacuum Beam Path

- The facility is designed to allow a TSI instrument or the cryogenic radiometer to sample exactly the same beam
  - Beam is not displaced, instruments are placed at the same location in a stationary beam
Common Vacuum Beam Path

• The facility is designed to allow a TSI instrument or the cryogenic radiometer to sample exactly the same beam
  – Beam is not displaced, instruments are placed at the same location in a stationary beam

Top-view of optical path: Cryogenic Radiometer in beam
Diffraction & Scatter Erroneously Increase Signal

All instruments except the TIM put primary aperture close to the cavity

NIST calculates this to be a 0.16% effect in the ACRIM instruments

Failure to correct for light diffracted into cavity erroneously increases signal

Failure to correct for light diffracted out of cavity erroneously decreases signal
**Diffraction & Scatter Erroneously Increase Signal**

All instruments except the TIM put primary aperture close to the cavity.

Expanding TRF beam from filling precision aperture while underfilling view-limiting aperture to overfilling view-limiting aperture causes increase in signal due to scatter and diffraction from front and interior sections of instrument.

Measured increases due to uncorrected scatter/diffraction are surprisingly large.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREMOS-1</td>
<td>0.10%</td>
</tr>
<tr>
<td>PREMOS-3</td>
<td>0.04%</td>
</tr>
<tr>
<td>VIRGO</td>
<td>0.15%</td>
</tr>
<tr>
<td>ACRIM-3</td>
<td>0.51%</td>
</tr>
</tbody>
</table>

Additional light allowed into instrument can scatter into cavity.

Majority of light is blocked before entering instrument.
**TRF Measurements Validating TSI Instruments**

- Currently performed on SORCE/TIM Witness, Glory/TIM, PICARD/PREMOS-1 and PREMOS-3, VIRGO-2, and ACRIM3
- Planned with EURECA/SOVA and SOVA-P
- Social aspects are even more impressive... see André Fehlmann’s thesis for updated values

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measured Optical Power Offset</th>
<th>Irradiance: Precision Aperture Overfilled</th>
<th>Irradiance: Entrance Aperture Overfilled</th>
<th>Difference Attributable To Scatter Error</th>
<th>Residual Irradiance Offset</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORCE/TIM ground</td>
<td>-0.035%</td>
<td>-0.035%</td>
<td>-0.035%</td>
<td>0.000%</td>
<td>0.000%</td>
<td>0.025%</td>
</tr>
<tr>
<td>Glory/TIM flight</td>
<td>-0.020%</td>
<td>-0.012%</td>
<td>-0.012%</td>
<td>0.000%</td>
<td>0.007%</td>
<td>0.020%</td>
</tr>
<tr>
<td>PREMOS-1 ground</td>
<td>-0.049%</td>
<td>-0.104%</td>
<td>-0.005%</td>
<td>0.098%</td>
<td>-0.055%</td>
<td>~0.038%</td>
</tr>
<tr>
<td>PREMOS-3 flight</td>
<td>0.631%</td>
<td>0.605%</td>
<td>0.642%</td>
<td>0.037%</td>
<td>-0.026%</td>
<td>~0.027%</td>
</tr>
<tr>
<td>VIRGO-2 ground</td>
<td>0.730%</td>
<td>0.743%</td>
<td>0.897%</td>
<td>0.154%</td>
<td>0.013%</td>
<td>~0.025%</td>
</tr>
<tr>
<td>ACRIM3 ground</td>
<td>0.021%</td>
<td>0.308%</td>
<td>0.534%</td>
<td>0.506%</td>
<td>0.007%</td>
<td>0.059%</td>
</tr>
</tbody>
</table>
... And PREMOS Data Are Recently Available

André Fehlmann’s talk addresses VIRGO
Value of TSI Measurements for Climate Science

TSI Measurements

1. Are the most stable solar irradiance measurements
   – Approaching stabilities necessary to detect climate-relevant solar variability
2. Provide >30 year solar irradiance record of entire radiative input to Earth’s climate system
Requirements of TSI Measurements for Climate Science

1. Improve absolute accuracy to 100 ppm. In the meanwhile,
2. Continue to rely on continuity and stabilities of <10 ppm/yr
3. Perform end-to-end ground irradiance validations against an SI-traceable reference (such as TRF)

![Image of solar irradiance and data graph]
How Good Are Resulting Composites?

- Trend detection between solar minima is currently marginal

10 ppm/yr stability

10 ppm/yr stability

10 ppm/yr stability
Desired Stabilities Not Yet Achieved

- There remain significant differences between existing instruments

NRL, SATIRE, SFO models
Desired Stabilities Not Yet Achieved

- There are significant differences between instrument data versions.
TIM Was Planned to Fly on Three Missions

- SORCE (SOlar Radiation and Climate Experiment)
  - Launched Jan. 2003
- Glory
  - Launch (failure) 4 March 2011
- JPSS/TSIS
  - Launch 2014 (?)

**SORCE**

**Glory/TIM**

**JPSS/TSIS**

**TIM**

**SIM**
TSI Record Currently Relies on Stability & Continuity

With launch failure of NASA’s Glory mission, TSI record continuity is currently at risk

TSI plots updated regularly at:
http://spot.colorado.edu/~koppg/TSI/