17 Years of Highlights from the SORCE/TIM

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Total Irradiance Monitor (TIM) Instrument Overview

- Total Irradiance Monitor (TIM)
- Vacuum Door
- Shutter
- Precision Aperture
- Light Baffles
- Radiometer
- Vacuum Shell
- Detector Head Board
- Heat Sink

Four Radiometers
Track Degradation

SORCE Science Meeting
Tucson, AZ 27-31 Jan. 2020
Highlights from the SORCE/TIM
**TIM Innovations Enable Accuracies & Stabilities**

The Total Irradiance Monitor, first launched on NASA’s SORCE mission in 2003, introduced several measurement innovations

- Precision aperture at **front** of instrument
- **Nickel Phosphorus** cavity interiors demonstrate best inherent, on-orbit stability of any TSI instrument
- **Phase sensitive detection** of servo system and applied in signal analysis
  - Reduces sensitivity to out-of-band noise
  - Servo gain and non-equivalence only need to be known at shutter fundamental
- **Feedforward** maintains cavity thermal stability, improving servo response
- **Thermal contributions** are measured and modeled
- **Pulse width modulation** of precision DC voltage reference applies power linearly
- Digital servo system uses PID control
- Digital control of shutters

*from (almost) every talk I give*
Evolution of the TSI Record

Total Solar Irradiance Data Record

- ER8
- ACRIM1 V1–8907
- SOVA2
- ERBS V–0508
- NOAA9
- ACRIM2 V1405–0102
- NOAA10

Monthly Sunspot Number

Year

1980
1990
2000
2010

Sunspot Number

1000 ppm

G. Kopp, 19 Nov. 2014
Evolution of the TSI Record

[Graph showing the evolution of the Total Solar Irradiance (TSI) record over time, with labels for different instruments and solar activity cycles.]
Evolution of the TSI Record

Greg’s Rule #1:
Consistency is comforting;
but agreement is not accuracy.

Life was pretty good!
Evolution of the TSI Record

...until SORCE launched in Jan. 2003
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.

Additional light allowed into instrument can scatter into cavity

Majority of light is blocked before entering 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>VIRGO2</td>
<td>0.15%</td>
</tr>
<tr>
<td>ACRIM-3</td>
<td>0.51%</td>
</tr>
<tr>
<td>SOVAR</td>
<td>0.20%</td>
</tr>
</tbody>
</table>

This affects the World Radiometric Reference too

Fehlmann et al., Metrologia, 2012 report the WRR measures TSI 0.34% higher than the true SI scale.

Kopp and Lean, GRL, 2011
Evolution of the TSI Record

ACRIM3 adjustments applied Apr. 2011
Evolution of the TSI Record

PREMOS data released Aug. 2011
Evolution of the TSI Record

TCTE data released Mar. 2014
Evolution of the TSI Record

VIRGO adjustments applied Oct. 2014
Evolution of the TSI Record

VIRGO refinements applied Nov. 2014
Evolution of the TSI Record

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3 TIM Missions Currently On-Orbit

Total Irradiance Monitor (TIM)
Status of Current TSI Instruments
Measurements from Current TIM Instruments
SORCE/TIM Observed the Largest Short-Term TSI Decrease Recorded
28 Oct. 2003 X17 SORCE Flare Observations

Perspective
Net flare energy is <0.008% of what the Sun emitted in that ~40-min. time range.

Woods et al., GRL 31, L10802, 2004
Two Venus Transit Measurements by SORCE/TIM

Venus transits occur in pairs 8 years apart separated by either 105.5 or 121.5 years.
Venus Transit Detections

2004 Venus Transit

2012 Venus Transit

SORCE/TIM TSI - V.18

[Graphs showing light intensity changes during Venus transits]
Mercury Transit “Observations”

Plots available at http://spot.colorado.edu/~koppg/TSI
What Are the TSI Trends?

Comparisons to SORCE/TIM

VIRGO Offset Relative to TIM
Offset = -172 +/- 89 ppm  Slope = -18.7 ppm/yr

ACRIM3 Offset Relative to TIM
Offset = 209 +/- 135 ppm  Slope = -36.1 ppm/yr

NRLTSI2 Model Relative to TIM
Offset = -5 +/− 89 ppm  Slope = -3.6 ppm/yr

SATIRE-ST Model Relative to TIM
Offset = 51 +/− 89 ppm  Slope = -13.5 ppm/yr

SFO Model Relative to TIM
Offset = 13 +/− 94 ppm  Slope = -9.6 ppm/yr
The SORCE/TIM Has:

- Established a lower TSI value of 1361 W m\(^2\)
- Demonstrated better inherent stability than any other space-borne TSI instrument
- Shown lower noise than other contemporary TSI instruments
- Helped maintain measurement continuity of the TSI record
- Reported the first measurement of a solar flare in TSI
- Observed two Venus and four Mercury transits
- Recorded the largest short-term decrease ever measured in TSI
Value of TSI Measurements for Climate Science

1. Are the most stable solar-irradiance measurements
   - Achieve stabilities necessary to detect climate-relevant solar variability

2. Provide ~41-year solar-irradiance record of entire radiative input to Earth’s climate system