TOTAL SOLAR IRRADIANCE
PREMOS/PICARD and CLARA/NorSat-1

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with contributions by Gael Cessateur (PREMOS),
Benjamin Walter and Wolfgang Finsterle (CLARA)
and the PREMOS and CLAR teams

PMOD/WRC, Switzerland

Lake Arrowhead, CA, USA 20.3.2018-23.3.2018
Overview

• Introduction:
  Amplitude vs time scale of TSI variations and stability of long term trends

• New version PREMOS/PICARD data (27.7.2010-4.3.2014)
  • data version 1 (distributed version):
    linear correction of the sensitivity change
  • assessing the beginning to end-of-mission sensitivity change
    “ratios of ratios” (Ball et al. 2016, JSWSC 6, A32)
  • Data version 2:
    detector sensitivity change assessment by comparison to other space experiments

• What TSI accuracy do we need?
• News from CLARA/NorSat-1: 1st light 21.8.2017
• Conclusions
Conclusion: magnetic variability + granulation explains the solar TSI variability on all time scales from few minutes to months to …
Modelled solar variations

Conclusion:
magnetic variability +
granulation
→
explains all
time scales from
few minutes to 19 years!

Shapiro et al. 2017
Nature Astronomy 1, 612
Different instruments have different strengths

Shapiro et al. 2017
Nature Astronomy 1, 612
Long term TSI trend

Fig. from Fröhlich, JSWSC 6, A18 (2016)

Plotted are original TSI data with absolute values adjusted to overlap, RELATIVE to the PMOD-composite.
Diverging TSI trends

4 TSI space experiments:
- PREMOS data version 1 (2010-2014)
- TIM (launched 2003)
- ACRIM III (2000-2013)
- DIARAD/IRMB … relative to VIRGO (launched 1995)

Conclusion:
comparing instruments allows to estimate the order of magnitude of the long-term stability:

TSI-trend after 2003 is of the order of

≈ 200 ppm / 10 years

PREMOS/PICARD can be used to assess whether TIM or VIRGO was likely to be more stable
PREMOS/PICARD (27.7.2010-4.3.2014)

PREMOS instruments:

Total Solar Irradiance
- 2 PMO6-type absolute radiometers

Spectral Solar Irradiance
- 12 filter radiometers @ 6 wavelengths

Filter Radiometers

Total Solar Irradiance

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Absolute calibration

PREMOS is the first SI-traceable calibrated radiometer in space

First Light on 27. July 2010

PREMOS(TRF)/PICARD 1360.9 ± 0.4 W/m²
TIM/SORCE (V17) 1361.0 W/m²

TIM and PREMOS are consistent!

Schmutz et al. 2013, AIP 1531, 624, doi: 10.1063/1.4804847 (in 2013, TIM V13 was at 1361.3 W/m²)
Basics of sensitivity corrections of radiometers

Standard tool to correct for inflight degradation:
→ two or more radiometers (PREMOS has 2):
   \( A \) – exposed operationally
   \( B \) – exposed rarely for calibration only

**Hypothesis:** \( B \) has the *same* sensitivity change as \( A \) as a function of the exposure time

Until 3. February 2014:

\( A \) total exposure: 600 days
\( B \) total exposure: 3.75 days

→ Sensitivity change is evaluated from the measured \( A \) to \( B \) ratio
Sensitivity change of $\mathcal{A}$ relative to $\mathcal{B}$

$\mathcal{B}$ total exposure: 3.75 days

$\mathcal{A}$ total exposure: 600 days

Special events listed in chronological order:
1. Night mode
2. Night mode
3. Heater modification (high noise)
4. Longer integration time & night mode
5. Switched to $B$ as nominal instrument
6. Switch off abnormal shutter ASIC
7. Save mode (anomaly, freezing?)
8. Premos off: anomalous current
9. Premos off: anomalous current
10. PGCU off
11. MNO Procedure nr2
12. Normal control setup, mode PREMOS off
13. Uploading LVDPS PICO 20.4, switch on PGCU
14. Anomalies
15. Night mode after anomalies on 5th & 6th June 2012
16. Uploading patch #9 LVDSP PICO 20.3 PREMOS in night mode
17. No HK data after single event upset 18.11.12 thus switch off 5–8.12.12

Exposure time PREMOS A [days]

Measured ratio

Fit

Total exposure: 3.75 days

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Ratios \( A \) to \( B \)

Begin of operation in 2010

- \((6\text{-hr av.})\) PREMOS\(\text{-} A : \) TIM \(= 421 \text{ ppm} \) \(\Delta\)
- \((1\text{-hr av.})\) PREMOS\(\text{-} A : \) VIRGO \(= 425 \text{ ppm} \) \(\triangleleft\)
- PREMOS\(\text{-} A : \) PREMOS\(\text{-} B \) \(\bigcirc\)
- \((1\text{-hr av.})\) PREMOS\(\text{-} B : \) DIARAD \(= 4600 \text{ ppm} \) \(\bullet\)
- \((1\text{-hr av.})\) PREMOS\(\text{-} A : \) DIARAD \(= 350 \text{ ppm} \) \(\bigcirc\)
- (heater on; \(6\text{-hr av.})\) PREMOS\(\text{-} A : \) DIARAD \(= 350 \text{ ppm} \) \(\bigcirc\)
- \((1\text{-hr av.})\) PREMOS\(\text{-} A : \) PMO6\(\text{-} V \) \(= 900 \text{ ppm} \) \(\bigcirc\)

Heater on
Heater off

Exp. \(= 3.75 \text{ days} \)
Ratios $A$ to $B$ compared to $A$ to DIARAD and $A$ to PMO6-V

Begin of operation in 2010

![Graph showing ratios over exposure days]

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Correct sensitivity change of $B$ with a linear increase:

- Exposure time $B$ until end of operation of $A$: 3.75 days
- Exposure time $B$ until end of operation: 13.5 days

Schmutz et al. 2013: 81.7 ppm per exposure day
During the last two weeks of PREMOS operation head $B$ was switched to the operational instrument to evaluate $B$ sensitivity change relative to DIARAD, PMO6-V, or TIM instruments …
Ratios $A$ to $B$ compared to $A$ to DIARAD and $A$ to PMO6-V

![Graph showing ratios over exposure time]

(6-hr av.) PREMOS-A : TIM = 421 ppm
(1-hr av.) PREMOS-A : VIRGO = 425 ppm
PREMOS-A : PREMOS-B
(1-hr av.) PREMOS-B : DIARAD = 4600 ppm
(1-hr av.) PREMOS-A : DIARAD = 350 ppm
(heater on; 6-hr av.) PREMOS-A : DIARAD = 350 ppm
(1-hr av.) PREMOS-A : PMO6-V = 960 ppm

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Hypothesis is verified:

\[ B \text{ (in 2014 starting at } t_E=3.75 \text{ days) had the same sensitivity change as } A \text{ (in 2010) as a function of the exposure time.} \]

\[ \rightarrow \] Use the measured \( A:B \) ratios in 2010 to correct for the sensitivity changes of head \( B \) from 2010 to 2014.
PREMOS calib. V1 versus TIM

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Amplitude vs time scale of TSI variations and Stability of long term trends

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What TSI accuracy do we need?

News from CLARA/NorSat-1 (1st light 21.8.2017)

Conclusions
Ball et al. 2016, JSWSC 6, A32

Use the measured $A:B$ ratios in 2010 to correct for the sensitivity change of head $B$ in 2014:

1) Determine the accumulated exposure time $t_E$ of head $A$ for the measured $A:B$ ratios 1, 2, .., 6, …

2) Determine the dates of head $B$ when it has accumulated the corresponding dose

3) Use “ratios of ratios”, e.g. ratio-4/ratio-1, to correct for the sensitivity change of head $B$ in 2014 relative to the date when B had accumulated the same exposure time as A in 2010 for ratio-1
Ratios $A$ to $B$

Begin of operation in 2010

Until 4. Feb 2014 $B$ had 3.75 days of exposure
TIM minus VIRGO

Reference: October 31, 2011
Feb./March 2014

Date (yyyy/mm): 2010/07, 2011/07, 2012/07, 2013/07, 2014/07

TSI, Wm$^{-2}$

$\Delta$TSI, Wm$^{-2}$
Using ratios \( A \) to \( B \): Step 3
Conclusions by Ball et al. (2016)

PREMOS $B$ “ratios of ratios” sensitivity correction has an uncertainty
October 2011 to February 2014 ratio: $\pm 0.02 \, \text{Wm}^{-2}$ (over 2.3 yr)
$\rightarrow$ 6 ppm per year

PREMOS $B$ agrees with TIM
$\rightarrow$ TIM stability confirmed to $\leq 6$ ppm/yr

PREMOS $B$ disagrees with PMOD composite (version 2016!)
Difference: 0.12 Wm$^{-2}$ or 90 ppm after 2.3 years
$\rightarrow$ PMOD-composite stability approximately $\geq 38$ ppm/yr
(not clear: systematic or random ?)

PMOD-composite cycle-cycle minima uncertainty:
11 yr x 38 ppm/yr = 418 ppm $\rightarrow$ 0.6 Wm$^{-2}$!
Is there an observed TSI-trend?

Conclusion:
minimum-to-minimum trends of TSI composites are not significant!

\[ \pm 0.6 \, \text{Wm}^{-2} \]

from Fröhlich (2016, PMOD/WRC website)
Overview (repeat)

- Amplitude vs time scale of TSI variations and Stability of long term trends
- New version PREMOS/PICARD data (27.7.2010-4.3.2014)
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- Conclusions
PREMOS-A to <instrument>
21-Jul – 26-Sep 2010

\[ y = -1.373222E-08x^5 + 4.671338E-07x^4 - 5.353597E-06x^3 + 1.564982E-05x^2 + 9.261267E-05x + 1.000000E+00 \]
PREMOS-Å to <instrument>
21-Jul – 26-Sep 2010
PREMOS-\(B\) to VIRGO

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Overview (repeat)xs

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Reconstructed temperature in Kyoto and Edo bay (Tokyo)

March temperatures derived from the date of cherry blossom

Aono & Kazui (2008); Aono (2015)
Reconstructed temperature in Kyoto and Edo bay (Tokyo)

… compared to the reconstruction of Egorova et al. (2018, in press) which is an updated version of Shapiro et al. (20011)
Conclusion:

We do not need to worry that the observed TSI composite is not more stable than a a few ppm/10 yr

If the Sun has an influence on climate then its TSI variations have to be much much larger than observed up to now!
Overview

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A new generation of the Davos space radiometers:

**CLARA = Compact Light weight Radiometer**
- Mass: 2.21 kg
- Dimension: 12.8 x 15.8 x 13.8 cm
- Average power consumption: 4.5 W

→ suitable for Micro- / Nanosatellites
Precision apertures in front!
CLARA Innovations

Innovation 1:
- Radiometer box and control unit in different boxes. The radiometer unit is thermally fully isolated.

Innovation 2:
- Digital controller
  → measurement frequency
    30 sec
    (15 s open – 15 s closed)
    (PMO6V 120 sec)
Innovation-3:

- Three cavity design for degradation tracking and redundancy
- New Cavity and heatsink design to minimize size and weight of the instrument
CLARA/NorSat-1
Calibration at TSI Radiometer Facility (TRF) in Boulder, Colorado

<table>
<thead>
<tr>
<th>Characterization Item</th>
<th>Value</th>
<th>σ</th>
<th>Value</th>
<th>σ</th>
<th>Value</th>
<th>σ</th>
<th>Value</th>
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<th>Value</th>
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<tbody>
<tr>
<td>Absorptivity ($C_{abs}$)</td>
<td>1.002056</td>
<td>288</td>
<td>1.002198</td>
<td>308</td>
<td>1.002048</td>
<td>287</td>
<td>1.002225</td>
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<td>1.002372</td>
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<td>Diffraction ($C_{diff}$)</td>
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<td>Dark correction ($C_{dark}$)</td>
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<td>Heater voltage ($C_{H}$)</td>
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<td>0.999200</td>
<td>1600</td>
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<td>0.999200</td>
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<tr>
<td>Shunt voltage ($C_{S}$)</td>
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<td>1600</td>
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<td>Lead heating ($C_{L}$)</td>
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<td>1.001099</td>
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<td>Shutter delay issue</td>
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<td>–</td>
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<td>0.998600</td>
<td>700</td>
</tr>
</tbody>
</table>

| Calibration factor                     | 1.001902| 2282  | 1.001279| 2285  | 1.000551| 2387  | 1.003273| 2286  | 1.003555| 2289  | 1.001920| 2391  |
| Repeatability                          | –      | 236   | –      | 217   | –      | 258   | –      | –     | –      | –     | –      | –     |
| Scattered light                        | 0.999920| 40    | 0.999920| 40    | 0.999920| 40    | –      | –     | –      | –     | –      | –     |
| Aperture placement                     | 1.000650| 225   | 1.000650| 225   | 1.000650| 225   | –      | –     | –      | –     | –      | –     |
| TRF calibration uncertainty            | –      | 393   | –      | 393   | –      | 393   | –      | –     | –      | –     | –      | –     |
| CLARA/TRF ratio                        | 1.001693| 512   | 1.001221| 504   | 1.001409| 523   | 1.001693| 512   | 1.001221| 504   | 1.001409| 523   |

SI cryogenic laboratory scale calibration factor: 1.001577 ± 0.77 W m⁻² ≈ 576 ppm

Walter et al. 2017, *Metrologia* 54, 674
1st light TSI value cavity B

Channel B: uncertainty = ± 0.77 W m²

Mean 21+22.8.17: 1360.0 Wm⁻²

Daily averages of virgo
6h TIM value at orbit time
Comparison to composite and TIM
1st light TSI value cavity B

Channel B: uncertainty = ± 0.77 W m⁻²

Mean 21+22.8.17: 1360.0 Wm⁻²

21.8.17  1360.41
1359.84 W m⁻²  1360.14
08/21/17-14:25:30 14:35 14:40 14:45 14:50 14:55 time

22.8.17  1360.41
1360.18 W m⁻²  1360.15
08/22/17-18:00 18:10 18:20 time

28.9.17  1360.61
1360.46 W m⁻²  1360.51
09/28/17-19:20 19:30 19:40 time

Daily averages of virgo
6h TIM value at orbit time
Summary CLARA/NorSat-1

- Launched on 14.7.2017
- Preliminary 1\textsuperscript{st} light value of cavity B on 21./22.8.2017
  \[1360.0 \pm 0.77 \text{ W/m}^2\]
- Three cavity design should provide excellent long term stability of CLARA/NorSat-1 …
  … to be seen!
Conclusions

- TSI-composite has a problem 2013/2014 at the transition from the VIRGO-ACRIM-III-TIM-PREMOS to the VIRGO-TIM-TCTE period.

- Ball et al. (2016) assessment of the relative calibration of PREMOS/PICARD supports the TSI record of TIM and disagrees with VIRGO.

- PREMOS data vs2 confirms stability of TIM.

- TSI-composite may have a trend of the order of a few 100 ppm/10 yr for > 1996.

- This TSI record accuracy is sufficient for climate impact estimates.

- CLARA/NorSat-1 is a new operational radiometer to help establishing the long term stability of the TSI-composite.
Thank you for your attention!

NorSat-1

20.3.2018 Werner Schmutz
Correcting A using the corrected B channel