AIP Conference Proceedings

Total solar irradiance measurements with PREMOS/PICARD

Werner Schmutz, André Fehlmann, Wolfgang Finsterle, Greg Kopp, and Gerard Thuillier

Citation: AIP Conf. Proc. **1531**, 624 (2013); doi: 10.1063/1.4804847
View online: http://dx.doi.org/10.1063/1.4804847
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1531&Issue=1
Published by the American Institute of Physics.

Total Solar Irradiance Measurements with PREMOS/PICARD

Werner Schmutz[a], André Fehlmann[a], Wolfgang Finsterle[a], Greg Kopp[b] and Gerard Thuillier[c]

[a]*Physikalich Meteorologisches Observatorium Davos and World Radiation Center, Dorfstrasse 33, 7260 Davos Dorf, Switzerland*
[b]*Laboratory for Atmospheric and Space Physics, 1234 Innovation Drive, Boulder, CO 80303-7814, USA*
[c]*LATMOS-CNRS, 11 boulevard d'Alembert, 78280 Guyancourt, France*

Abstract. PREMOS on the French satellite PICARD is the first spaceborne absolute radiometer measuring Total Solar Irradiance that has been irradiance-calibrated in vacuum with SI-traceability. The measurements of PREMOS at first light on July 27, 2010, yield a TSI value of 1360.9±0.4 W/m^2 (k=1). This value agrees with the absolute TSI value measured by TIM/SORCE for this date within their combined uncertainties, and it differs by more than ten sigma from the absolute value of other space experiments, e.g. VIRGO/SOHO. The PREMOS measurements thus establish SI-traceability to a solar constant value of 1361 W/m^2.

Keywords: Solar Irradiance, TSI, PREMOS, PICARD, Absolute radiometer, Space experiment.
PACS: 07.87.+v, 95.55.-n, 07.60.Dq, 96.60.Ub

INTRODUCTION

Prior to the launch of the PREMOS/PICARD experiment, the reported observed absolute Total Solar Irradiance (TSI) values measured in space relied on the precise characterization of instrument components. The only exception is the VIRGO/SOHO instrument that was compared to the World Radiometric Reference (WRR) in Davos prior to launch, and thus VIRGO is traceable to the SI scale for ground based solar irradiance. The launch and operation of the TIM/SORCE experiment in 2003 [1] brought conflicting observations, with TIM/SORCE being lower by more than 4 W/m^2 [2] (more than 10 standard deviations of the assessed uncertainties of TIM) from the readings of all other operational experiments at the time, namely the PMO6V instruments on VIRGO/SOHO, the DIARAD instruments on VIRGO/SOHO, and the ACRIM3/ACRIMSat. In 2005 a workshop dedicated to finding reasons for the offsets identified stray light as a possible source [3]. However, at that time no facility was available to test this assumption. In 2007 Kopp *et al*. [4] started operations of the Total solar irradiance Radiometer Facility (TRF) located at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado USA. The TRF compares TSI instruments measuring irradiance at typical solar 1.3 kW/m^2 levels to a cryogenic radiometer, which is traceable to the SI scale via NIST calibrations [4].

PREMOS is an experiment built to measure TSI and spectral solar irradiance in five pass bands from the French satellite PICARD [5], which was launched in June 2010. Here we report on the TSI measurements with PREMOS. The PREMOS radiometers were originally calibrated in optical power, as reported by Schmutz et al. [6]. A last-minute exchange of one of the two flight PREMOS TSI radiometers provided the opportunity to fly a flight spare instrument that had been calibrated for its irradiance response at the TRF [7].

METHODS

A detailed description of the PREMOS experimental set up at the TRF and a discussion of the uncertainty budget are given by Fehlmann *et al*. [8]. Figure 1 illustrates the results from one of four calibration runs, where the radiometer PREMOS 3 – which became PREMOS A in the operational PREMOS/PICARD experiment – and the cryogenic radiometer were alternately moved into the 11 mm diameter TRF optical beam. The final PREMOS-to-TRF calibration has an estimated relative standard uncertainty (k=1) of 330 parts per million.

Radiation Processes in the Atmosphere and Ocean (IRS2012)
AIP Conf. Proc. 1531, 624-627 (2013); doi: 10.1063/1.4804847

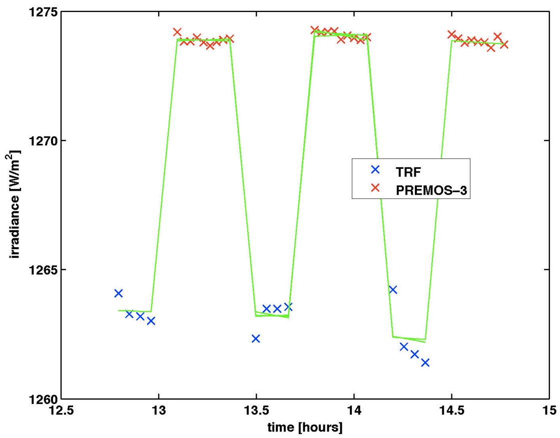

FIGURE 1. Comparison of the absolute radiometer PREMOS 3, which became the operational PREMOS A instrument, to the cryogenic radiometer at the TRF at LASP in Boulder USA. The upper measurements are the values of PREMOS 3 and the lower ones those from the TRF radiometer. The fitted offset between the two (drawn in green) allows for a slow linear drift in irradiance of the illuminating TRF beam. This offset yields the calibration of the instrument under test. The total uncertainty of the calibration for solar irradiance is given by the combined uncertainties of the comparison itself, the correction from monochromatic diffraction to the diffraction of the solar spectrum (see text), and the calibration uncertainty of the TRF, which is traceable to a primary standard cryogenic radiometer at NIST.

The characterization of PREMOS at the TRF using varying beam diameters helps understand the discrepancies between the spaceborne TSI measurements. As explained by Kopp & Lean [9], all but the TIM TSI instruments have a view-limiting aperture at the entrance to the instrument and a smaller precision aperture defining the area just in front of the detector deep inside the instrument. This design allows a large amount of additional light inside the instrument and its front baffle system. A relatively small fraction of this light is generally not fully absorbed by the baffle system and thus produces scattered light that, if not corrected, contributes to an erroneously high signal measured by the cavity.

An experiment using a 2 mm beam compared to a 11 mm diameter TRF beam was used to measure the stray light contributions to the PREMOS readings, allowing for correction of such scatter. The smaller diameter beam underfills the PREMOS's 5 mm primary aperture, providing a no-scattering contribution measurement baseline. When the beam diameter was increased to 11 mm, overfilling the PREMOS's larger front entrance aperture, it illuminates the interior of the front portion of the instrument much as the Sun does, This characterization of the PREMOS flight instrument at the TRF yielded a total stray light contribution of 1792±222 ppm (k=1), exceeding previous stray light estimates of 250 ppm for PMO6 type instruments [10].

Since the TRF uses a green laser source for its beam with a wavelength of 532 nm, an appropriate diffraction correction is applied to transfer the calibration from this monochromatic source to broadband solar measurements. In the PREMOS instruments the calculated diffraction correction results in a reduction of the readings by 551 ppm for the extraterrestrial solar spectrum [7].

Completing the traceability chain, the PREMOS instruments were compared to the World Radiometric Reference (WRR), indirectly enabling a comparison of PREMOS to VIRGO/SOHO, which was calibrated relative to the WRR prior to launch. This WRR calibration of the PREMOS radiometers has a relative uncertainty of 862 parts per million. The calibration is less accurate than the TRF calibrations because an air-to-vacuum correction must be estimated and applied for the in-air WRR comparisons. (As the calibrations of PREMOS at the TRF were done in vacuum, such air-to-vacuum corrections are unnecessary, avoiding this additional large uncertainty term for the TRF irradiance calibrations.)

RESULTS

First light of the PREMOS A radiometer was on 27 July 2010. Applying the TRF calibration to the measurements provides a TSI value of 1360.9 ± 0.4 W/m^2; applying the WRR calibration to the same data yields a much higher TSI value of 1365.5 W/m^2. This discrepancy is due to a 0.34 ± 0.18% offset by which the WRR is higher than the SI scale [7]. Applying this SI correction, the WRR-calibrated PREMOS TSI measurement is thus in agreement with the TRF-calibrated value.

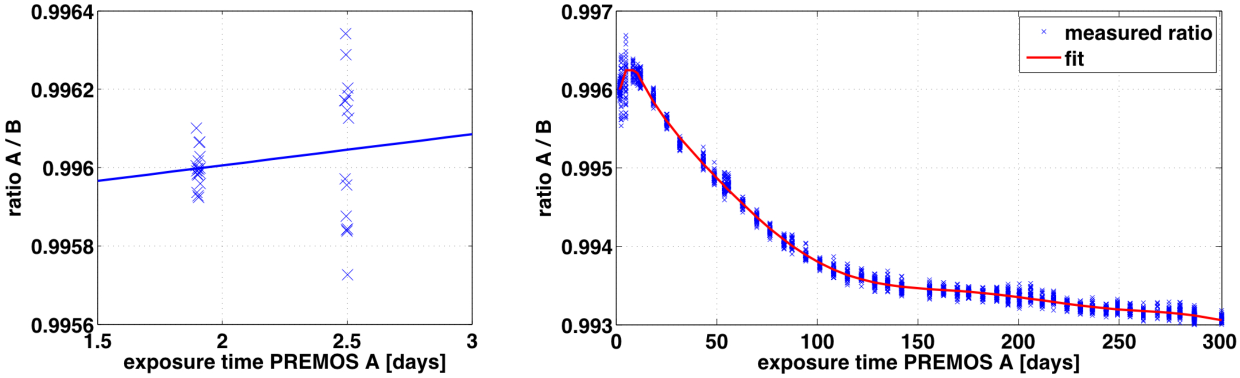

FIGURE 2. Left panel: The first two ratios of PREMOS A to B during the initial 2.5 exposure days of PREMOS A indicate that the primary radiometer initially increased in sensitivity by 81.7 ppm per day of solar exposure, taking into account that also radiometer B had a sensitivity increase by the same rate. The higher scatter in the second set of observations is caused by changes in instrument heater settings. **Right panel:** Ratios *of PREMOS A to B* since July 26 2010. The sensitivity change of radiometer A is fitted with a linear function in the beginning and during the plateau. The decrease of radiometer A's sensitivity is fitted by a 8th order polynomial function.

A VIRGO spare instrument of type PMO6-V was also investigated for stray light at the TRF, and a total stray light contribution of 2963 ppm was determined for it. Because the amount of stray light varies significantly from instrument to instrument, the uncertainty of this correction when applied to another instrument, even one of the same make, is large. Nevertheless, applying such a correction for the SOHO/VIRGO flight instruments reduces the discrepancy of VIRGO to the TIM and PREMOS by the currently reported 4 W/m^2. Thus, the higher measurements reported by VIRGO are most likely due to underestimated stray light in the VIRGO/SOHO instruments.

To create a PREMOS TSI time series, time-dependent on-orbit sensitivity changes of the radiometers must be corrected. As with other flight TSI instruments, this is accomplished using ratios of identically constructed radiometers within the instrument, namely the operational PREMOS A and the secondary PREMOS B radiometer, with the assumption that the radiometers are changing their sensitivities identically as a function of solar exposure. The PREMOS B is exposed only bi-weekly and thus the sensitivity change of PREMOS B is much lower at a given absolute time. During the first 2.5 exposure days of PREMOS A, the PREMOS B measured twice for a total of 90 minutes, giving it a net exposure of 0.06 days. Thus, PREMOS B is expected to have changed by 2.4 % as much as PREMOS A over this total time. Figure 2 shows the first two PREMOS A to B ratios fitted by a linear slope of 79.5 ppm per exposure day, indicating a sensitivity *increase* of the instruments at the beginning of their on-orbit solar exposure. After two years of operation, the total exposure time of PREMOS B remains less than 2.5 days and therefore the sensitivity change of this channel is likely still within this linear regime, giving it an 81.7 ppm per exposure day increase.

Comparing the PREMOS B measurements to TIM/SORCE observations during the first two years of PICARD similarly gives an increase of 83.6 ppm per exposure day for PREMOS B. The agreement of PREMOS and TIM to better than 5 ppm after two years of operation verifies the assumption of a linear sensitivity increase at the beginning of PREMOS's exposure to sunlight, and supports the corrections of the PREMOS observations relying only on PREMOS A-to-B ratio data.

After correcting for the linear degradation in PREMOS B, the ratio of PREMOS A to B corrects the degradation of the continuously measuring PREMOS A even when PREMOS A degradation becomes non-linear with solar exposure time. During the first half year of the mission, PREMOS experienced several anomalies including changes of the heater settings (which is the reason for the higher scatter of the second set of ratios shown in Figure 2) and power off periods, which were followed by a cooling of the PREMOS package. The latter events produced short term bumps, which are not yet fully understood in the degradation curve. However, the long-term trend of the sensitivity change is very well described by a smooth curve, which is an initial linear increase followed by a plateau and then a degradation with gradually changing slope. The resulting absolute PREMOS TSI time series starting on 1 April 2011 is shown in Figure 3.

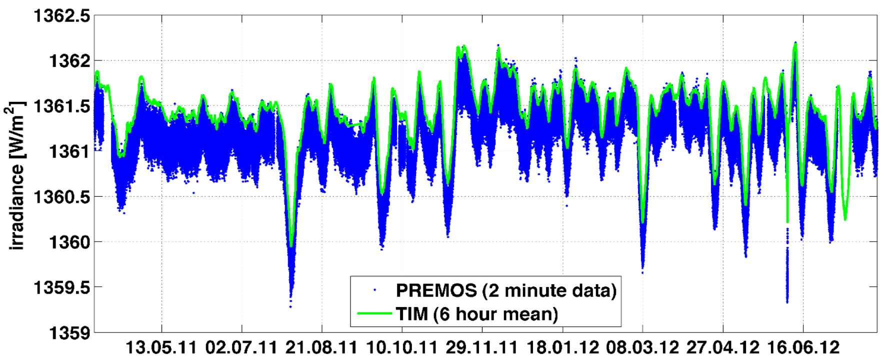

FIGURE 3. TSI time series since 1 April 2011. The PREMOS 2-minute values indicated by the blue curve are on average 0.4 W/m^2 lower than the TIM/SORCE hourly averages (green). The larger amplitudes of the PREMOS values are due to the solar variations of the irradiance dominated by p-mode modulations.

DISCUSSION

The PREMOS measurements confirm the lower value of the Total Solar Irradiance initially reported by the TIM/SORCE. The TIM/SORCE measured a TSI around 1361.3 W/m^2 at the end of July 2010, whereas other experiments, e.g. VIRGO on SOHO and ACRIM3 on ACRIMSat, yielded values of the order of 1365.4 W/m^2 at the time (prior to a 2011 update to the ACRIM3 data). The difference of 4 W/m^2 between VIRGO and TIM is a factor five to ten, respectively, larger than the uncertainties claimed by both experiments. Ground diagnostics with the flight spare VIRGO instrument indicate that the reported SOHO/VIRGO values are likely too high due to a stray light contribution within the instrument. Similar diagnostics with a ground-based ACRIM3 have subsequently yielded similar findings for that instrument, and an update to the ACRIM3 data now bring it into this same range.

At first light, the difference of PREMOS/PICARD to TIM/SORCE was 0.4 W/m^2 with PREMOS reading lower but agreeing within the combined uncertainties of the two instruments. Thus, the demonstrated measurement agreement by two independent experiments has improved by about a factor ten relative to the pre-PREMOS era.

Recent investigations have revealed that the World Radiometric Reference is too high by 3400 ppm relative to the SI system [7]. This puts the WRR-calibrated VIRGO/SOHO measurements at the same absolute level as PREMOS and TIM and yields a consistent evaluation of the TSI from all four current flight instruments: TIM/SORCE, VIRGO/SOHO (corrected), ACRIM3/ACRIMSat, and PREMOS/PICARD.

Version 1 of the PREMOS TSI data has been compiled as described above and is now available on request from the authors.

ACKNOWLEDGMENTS

AF acknowledges support by the Swiss National Science Foundation project 200020-130406 and analyses of PREMOS data was supported by the Swiss National Science Foundation projects 200020-130102 and 200020-140573. The support of CNES for operating PICARD is especially acknowledged.

REFERENCES

1. G. Kopp and G. Lawrence, *Solar Physics* **230**, 91-109 (2005).
2. G. Kopp, G. Lawrence and G. Rottman, *Solar Physics* **230**, 129-140 (2005).
3. J. J. Butler, R. Barnes, C. Johnson, J. P. Rice and E. L. Shirley, *J. Res. Natl. Inst. Stand. Technol.* **113**, 187-203 (2008).
4. G. Kopp, K. Heuerman, D. Harber and V. Drake, "The TSI Radiometer Facility - Absolute Calibrations for Total Solar Irradiance Instruments", Proc. SPIE 6677, 667709, doi:10.1117/12.734553, (2007).
5. G. Thuillier, S. Dewitte, W. Schmutz, and The Picard Team, *Adv. Space Res.* **38**, 1792 (2006).
6. W. Schmutz, A. Fehlmann, G. Hülsen, et al., *Metrologia* **46**, S202-S206 (2009).
7. A. Fehlmann, G. Kopp, W. Schmutz, R. Winkler, W. Finsterle and N. Fox, *Metrologia* **49**, S34-S38 (2012).
8. A. Fehlmann, "Metrology of Solar Irradiance", Ph.D. Thesis, University of Zürich, 2011.
9. G. Kopp and J.L. Lean, *Geophys. Res. Letters Frontier* **38**, L01706, doi:10.1029/2010GL045777 (2011).
10. R. W. Brusa and C. Fröhlich, *Appl. Opt.* **25**, 4173 (1986).