Recent Insights into the Physics of the Sun and Heliosphere: Highlights from SOHO and Other Space Missions
IAU Symposium, Vol. 203, 2001
P. Brekke, B. Fleck, and J. B. Gurman eds.

VIRGO Radiometry and Total Solar Irradiance 1996-2000 Revised.

C. Fröhlich and W. Finsterle

Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, 7260 Davos Dorf, Switzerland

Abstract. The long-term changes of the VIRGO radiometers have been re-analyzed in detail in order to resolve the puzzle of the early increase of the total solar irradiance (TSI) as observed by VIRGO. The exposure dependent changes can be described by a model which is based on a combination of an early increase of the sensitivity and a degradation with time which is modulated by the dose of solar UV radiation each detector receives. After correcting for the exposure-dependent behaviour both operational radiometers show an increase of their sensitivity which depends only on the time they are switched-on. After removing this increase the VIRGO TSI remains more or less constant during the minimum period of solar activity and reaches the solar maximum at levels comparable to the ones of former maxima.

1. Introduction

The early increase of the VIRGO total solar irradiance (TSI) shortly after the minimum in 1996 was until recently an unresolved issue (Fröhlich & Lean 1998; Fröhlich 2000), as it was incompatible with the empirical models based on the influence of sunspots (PSI), faculae and the network (Mg-II index). The long-term behavior of the VIRGO radiometry and the corresponding corrections (Fröhlich et al. 1997; Anklin et al. 1998; Fröhlich & Anklin 2000) were based on the assumption that changes depend only on the time exposed to solar radiation and thus can be determined by comparing the operational radiometers PMO6V-A and DIARAD-L with their back-up radiometers PMO6V-B and DIARAD-R which are exposed to the solar radiation 150 and 1200 times less. With increasing solar activity the VIRGO TSI achieved levels of the preceding activity maxima well before the activity maximum of cycle 23 was reached. Reaching such a high level before the maximum threw obviously some doubt on the assumption that no exposure independent changes may have occurred. An obvious question, however, is what could be the physical reason for such a behaviour and why have other radiometers of similar type in space not shown a similar increase with time. The latter question seems easier to answer: radiometers are based on thermal flux measurements and are thus very sensitive to changes in the thermal environment, which is extraordinary stable on SoHO and on e.g. Earth orbiting satellite quite variable. Under varying conditions the radiometer never reach a thermally steady state and the long-term change translate into noise. A possible answer to the first question will be presented in the following as a

https://doi.org/10.1017/S0074180900218871 Published online by Cambridge University Press

result of the new analysis. First we examine each type of radiometer separately for exposure dependent effects and then compare the resulting time series in order to determine their long-term behaviour which are independent of exposure time. The detailed analysis is described in Fröhlich & Finsterle (2001), and here we present a summary of the internally consistent description of the behaviour, which leads to *TSI* time series no longer showing the early increase. For the responsible physical mechanisms some proposals are presented, which still need to be understood in more detail.

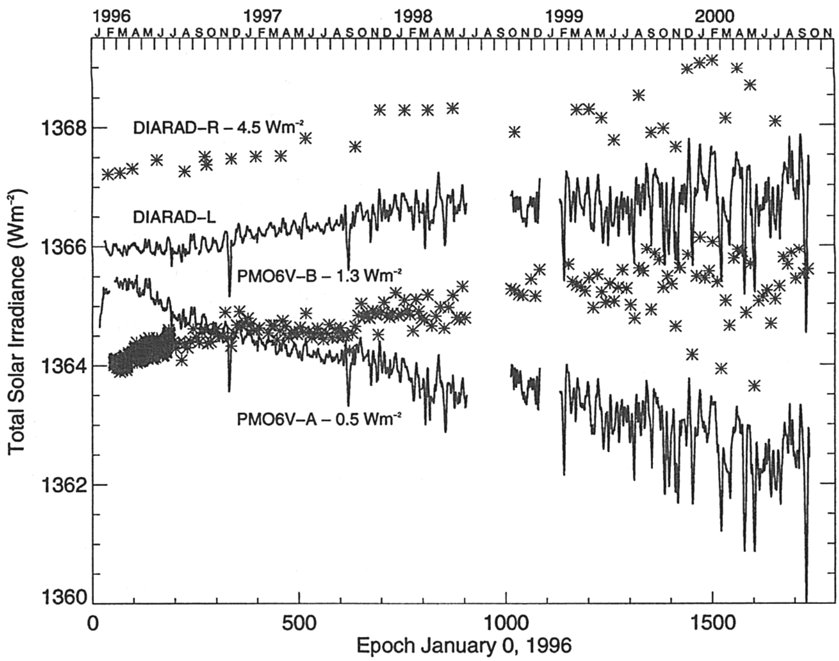

Figure 1. Time-series of the level-1 observations from the VIRGO radiometers PMO6V and DIARAD.

2. Determination of the corrections

Figure 1 shows the level 1 product as obtained after reducing the raw data to physical units and by applying all *a-priori* known instrumental effects such as electrical calibration and corrections for the thermal environment and operational corrections for distance and velocity to the sun. These data show a combination of the variation of the sun's irradiance and instrumental changes. It is also obvious that the two back-up instruments show more closely the irradiance changes whereas the operational ones are more strongly influenced by long-term sensitivity changes. Already at this stage of evaluation the different long-term behaviour of PMO6V and DIARAD is very obvious. Also prominent is the early increase of the PMO6V radiometers during the first few days of exposure. We first determine for each radiometer the exposure dependent changes

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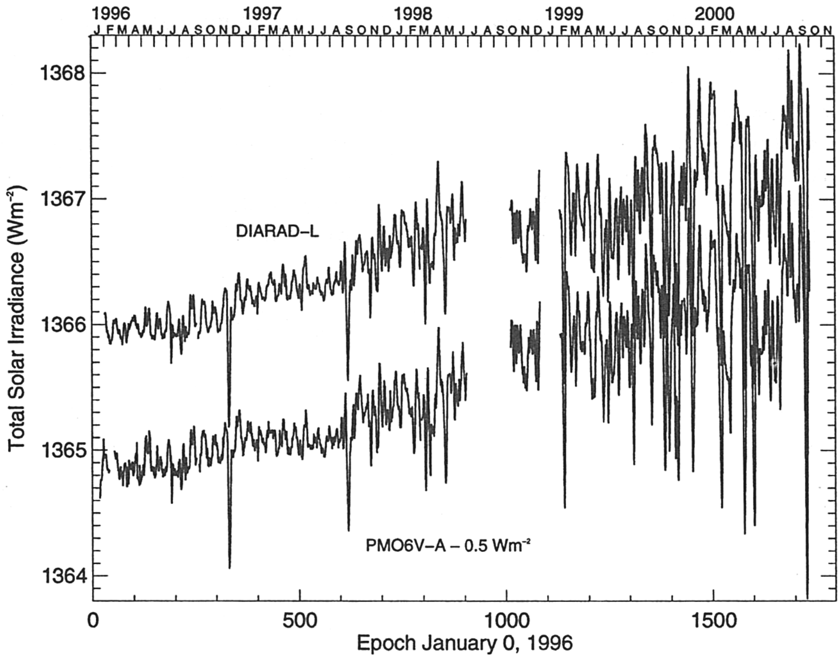

Figure 2. Time-series of the level-1 observations of PMO6V and DIARAD, after correction of their exposure dependent changes.

by comparing the operational one with its backup (for details see Fröhlich & Finsterle 2001). For both type of radiometers the degradation model assumes a sensitivity increase at the beginning and a dose dependent degradation over the whole mission time. To account for changes related to the paint we assume a hyperbolic behaviour as function of exposure time $a\,(1 + t_{\mathrm{exp}}/\tau)^{-b}$. The main reason for this choice is that a hyperbolic function describes a change in optical properties and the subsequent change in response to the radiation more physically than an exponential one. The decrease in sensitivity with exposure time, normally termed degradation, is assumed to be a linear function, the slope of which is modulated by the dose of the received radiation weighted with a hyperbolic function in time; the latter simulates the decrease of the sensitivity to irradiation with time. For the dose the MgII index from the SUSIM experiment on UARS is used (for the data see Floyd et al. 1998). For the period before and after the SoHO vacations the slope of the linear function is reduced to reflect possible sensitivity changes during the exposure to the cold environment. This reduction in slope could, however, also mean that an exponential function would better represent the long-term behaviour, including the gap. The parameters of these functions are determined for each type of radiometer assuming the same influence on each as a function of their exposure time. In the case of DIARAD-R the total exposure time is about 1.5 days after five years in space and thus it is assumed to have no exposure dependent change. For PMO6V-B, the exposure time was early in the mission quite important, and reached about 10 days when the cadence was changed from once every 8 hours to about once a week (around mission day 210) and 15 days after 5 years. The parameters are varied in such a way that the standard deviation from a linear fit to the ratio of the readings of the back-up to the ones of the operational radiometer is minimized and the slope becomes zero. It is important to note that the dose dependent degradation was essential to achieve the low variation around the horizontal line (55.5 and 35.3 ppm for PMO6V and DIARAD respectively); without the dose component the standard deviation is about a factor of two larger for both radiometers.In

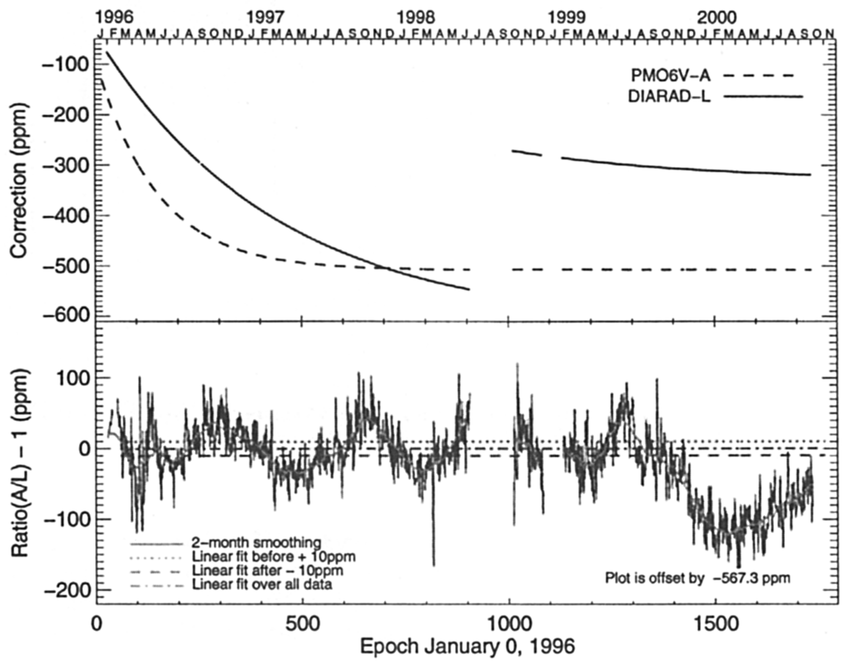

Figure 3. Corrections for the exposure independent behaviour of PMO6V-A and DIARAD-L (top panel) and the corrected ratio (lower panel).

the case of the DIARAD-L the corrections are such that the degradation at the beginning is masked by an increase in sensitivity, which was early in the mission interpreted as if DIARAD had no long-term change at all. The early increase is similar to the one of PMO6V, but with a longer time constant (66% of the sensitivity increase is reached after 13.7 and 48.5 days respectively). In parallel with this increase in absolute sensitivity an increase of the relative sensitivity to short-term variations by more than 30% is observed for DIARAD (determined by comparison with the short-term variance of PMO6V). This was first detected during the passage of an active region dominated by facular increase in May 1996 when DIARAD-L saw a smaller amplitude than PMO6V-A. For the final level 2 product this relative increase is corrected for the DIARAD-L data. The time series for both radiometers with all the exposure dependent corrections are shown in Fig. 2.

The comparison of the time series of PMO6V-A and DIARAD-L of Fig. 2 shows a trend which has to be exposure independent. As a model for this increase in sensitivity we propose an exponential function with a time constant τ and amplitude a. First, the period before the SoHO vacations is treated. We minimize the standard deviation from a regression line to the ratio PMO6V-A/DIARAD-L by varying the parameters a and τ for PMO6V-A; then we minimize τ of DIARAD-L and adjust its a coefficient so that the slope becomes zero.This is done iteratively and the procedure converges well to the curves

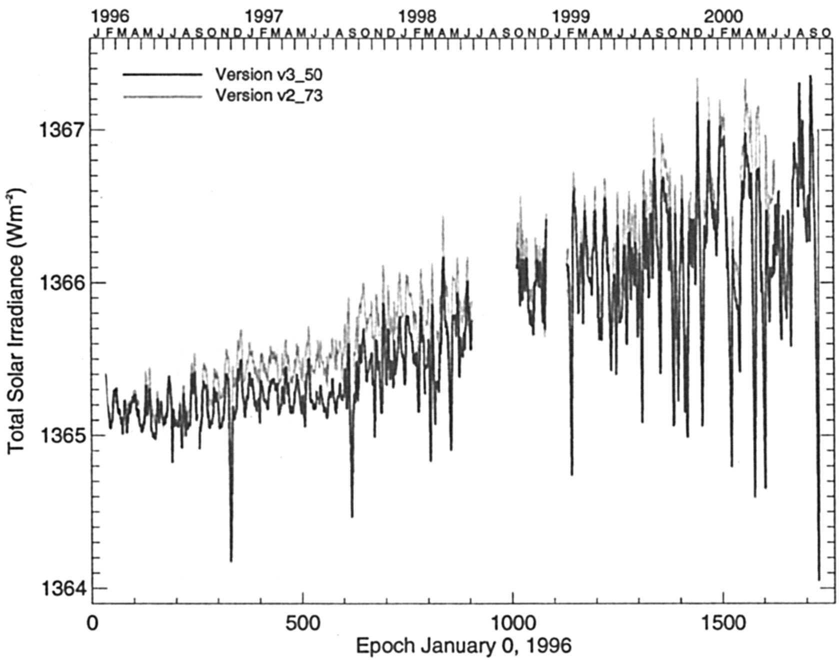

Figure 4. Comparison of the new version 3.5 to the version 2.75 (without exposure independent correction) of the VIRGO level-2 TSI data.

shown in Fig. 3, mainly due to the fact that the time constants of the two radiometers are (fortunately) quite different. After the SoHO vacations the fit is done only for the period up to day 1430 when a change in the behaviour is observed. The minimization yields parameters which are such that the curves continue from before. It is assumed that the effect starts with the switch-on of the instrument and is due to the slightly higher temperature of the cavity relative to the surroundings. Whether the effect was discontinued over the gap cannot be decided because the effect is already quite small (10% in the case of DIARAD and less than 1% for PMO6V). The effect may again be a change of the non-equivalence through a change in e.g. the emissivity of the side-walls of the cavities (inside and outside). After the SoHO vacations a change of 276 ppm of the ratio PMO6V-A/DIARAD-L is observed. Presently this change attributed to a change of DIARAD, because a similar change occurred after the an accidental switch-off of VIRGO for 3 days. More analysis is needed to fi-

https://doi.org/10.1017/S0074180900218871 Published online by Cambridge University Press

nally determine the share of this change between the radiometers, as well as their behaviour after mission day 1430 when the ratio of PMO6V-A/DIARAD-L changed. The final VIRGO level-2 irradiance is shown in Fig. 4 together with a former version, which did not include the exposure independent increase and had cruder corrections for the exposure dependent changes.

3. Conclusions

The re–analysis of the long-term behaviour of the VIRGO radiometer shows that there are changes which cannot be determined by comparing one radiometer with the same type, but much less time of exposure to the solar radiation. It seems quite possible that the exposure independent behaviour could only be detected in a thermal environment as stable as on SoHO. The Version 3.5 data of the VIRGO radiometer are available from http://www.pmodwrc.ch as well as an updated composite. The comparison of the latter over the last 20 years with a PSI-MgII-Index model shows now reasonable agreement for the increase of TSI towards the maximum of cycle 23.

Acknowledgments. The authors would like to thank many helpful discussions with and suggestions from George Lawrence, LASP, Boulder, CO. Thanks are extended to the Swiss National Science Foundation for support of the VIRGO Project at PMOD/WRC. These results would not be possible without the continuous efforts of the VIRGO and SoHO teams. SoHO is a cooperative ESA/NASA mission.

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