Assessment of Degradation of VIRGO Radiometers Onboard SOHO

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Abstract. The determination of the total solar irradiance (TSI) from the SOHO/VIRGO experiment is made by first correcting the time series for all *a priori* known influences and, second, to correct the data for instrumental degradation, using the back-up instruments PMO6-VB and DIARAD-R. The long term behaviour of PMO6-VA shows an exponential decrease in its sensitivity with a time constant of τ=390 days and a 1/e amplitude of 528 ppm, whereas DIARAD-L exhibits a general increase in its sensitivity of about 0.25 ppm/day combined with an early exponential decrease of τ=405 days and an 1/e amplitude of 65 ppm. After correcting PMO6-VA and DIARAD-L for their degradation, the VIRGO TSI shows a minimum around July 1996 and has been increasing since then by about 0.4 Wm^{-2}.

1. Introduction

Within the VIRGO (Variability of solar IRradiance and Gravity Oscillations) experiment onboard the ESA/NASA mission SOHO (SOlar and Heliospheric Observatory) total solar irradiance (TSI) is investigated. Two different types of radiometers are used: DIARAD (DIfferential Absolute RADiometer) and PMO6-V (deduced from institute's name - Virgo). A detailed description of the instrumentation is given in Fröhlich *et al.* [1]. The raw measurements are first corrected for all *a priori* known influences such as distance from the sun (adjusted to 1AU), radial velocity to the sun, and thermal and electrical corrections, leading to level-1 time series shown in Figure 1. Long term sensitivity changes of the radiometers can only be corrected for *a posteriori* by comparing measured irradiances from the main instruments with the back-up instruments. The change of sensitivity of radiometers can be due to several different reasons, where the most obvious ones are related to changes in the absorptance of the black coating of the cavity. The absorptance, and thus the reflectivity of the cavity may change due to

- solar irradiation, especially due to UV and EUV irradiation, e.g. Ly-α. This effect depends on the duration the instrument has been exposed to the sun.
- the space environment, e.g. by increasing the diffusivity of specular paint. Such an effect depends on the accumulated time of the instrument in space.

On VIRGO, two types of radiometers with different cavity geometries and different black coatings (Aeroglaze Z302 for PMO6-V and 3M Nextel VELVET Black 2010 for DIARAD) are used in order to distinguish between different degradation effects. Furthermore, the back-up instruments are operated only rarely to keep their degradation low: DIARAD-R is operated every 60 days during 90 minutes

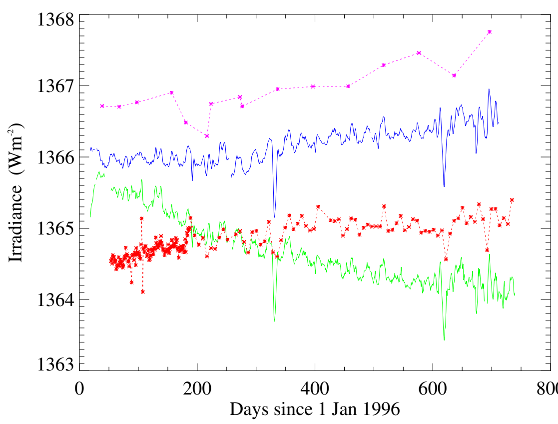

Figure 1. PMO6-V and DIARAD data corrected for all a priori know influences (reduced to level-1). These data sets are not yet corrected for degradation. The four lines are from top to bottom on the left side of the plot: DIARAD-R, DIARAD-L, PMO6-VA, PMO6-VB.

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(30 minutes until 7 August 1996) and PMO6-VB is operated once a week during 39 minutes (daily 3 times 39 minutes until 6 July 1996). A first assessment of the degradation characteristic of the VIRGO radiometers has been described by Fröhlich *et al.* [2] using the first 320 days of measurements. In [2] a linear change of the sensitivity with a slope of -0.29 ppm/day for DIARAD-L and of -3.34 ppm/day for PMO6-VA was deduced. With the extension of the time series to nearly 2 years of observations we are now able to determine a much more accurate degradation characteristic of the VIRGO radiometers. The analysis and the results are described in the following sections.

2. Characteristics of PMO6-V sensitivity changes

The degradation of the operational PMO6-VA is determined by using information of the identically built back-up instrument PMO6-VB, DIARAD-R and DIARAD-L. The analysis shows that three different superimposed effects characterize the sensitivity changes of PMO6-V radiometers.

a) The overall sensitivity decreases with exposure to solar radiation. This degradation can be modeled by an exponential behavior with a time constant τ = 390 exposure days and an 1/e amplitude of 528 ppm.
b) During the first few days, the sensitivity is rapidly increasing. An exponential function with a time constant of 5 exposure days explains the behavior well, as shown in Figure 1 at the beginning of the PMO6-VA operation. Both PMO6-V instruments show consistently an exponential increase with an 1/e amplitude of about 150 ppm (0.2 Wm^{-2}). This effect depends on the time the instrument has been exposed to solar radiation. Although the reason for this increase is still unclear, solar radiation may improve the quality of the reflectivity of the cavity, which would increase the overall sensitivity of the radiometer. The observed improvement of about 500 ppm would be greater than the measured reflectivity of about 300 ppm. However, the measurement might underestimate the reflectivity due to e.g. geometrical effects.
c) A non-exposure dependent degradation of -0.3 ppm/mission day is found by comparing PMO6-VB with DIARAD-R. This effect can only be seen in the back-up radiometer because of its long duration in space (700 days) together with its short exposure time to the sun (13 days).

The effects a) and c) have previously been expected. Effect a) is in good agreement with earlier results from the EURECA mission [3]. Effect c) has been unambiguously determined for the first time. As the time series will be further extended, the characteristic of effect c) might be better described by an exponential than a linear behavior, since we would expect this effect to weaken with time. An increase in sensitivity (effect b) has also been observed for the HF radiometer onboard Nimbus 7 [4], which has a similar cavity geometry and black coating as the PMO6-V radiometers. The time constants for the increase described in c) are for HF, PMO6-VA, PMO6-VB, 3, 5, and 10 exposure days, respectively.

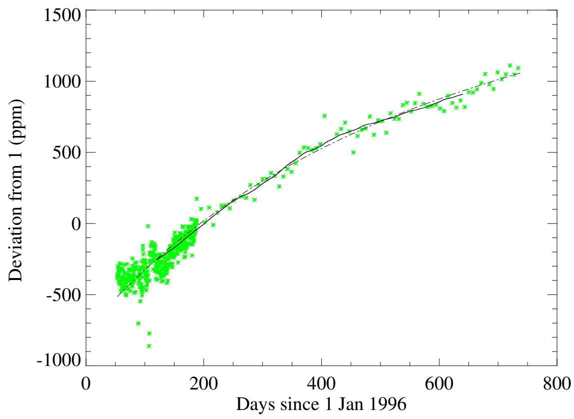

Figure 2. Ratio PMO6-VB$_{corr}$/ PMO6-VA. This ratio is used to correct PMO6-VA for degradation. The degradation as 201-day running mean (full line) is in good agreement with the exponential fit, which has a time constant of 390 days (dashed line).

Before PMO6-VB can be used as long term reference for the solar irradiance, we apply three corrections as described above: First, an overall degradation of -3.9 ppm/exposure day is used, which is taken from the early analysis of PMO6-VA. This is a minor correction of less than 50 ppm (0.07 Wm^{-2}) since PMO6-VB has been exposed by less than 13 accumulated days. The second correction is determined from the ratio PMO6-VB to PMO6-VA by adjusting the time constant and 1/e amplitude to yield a reasonable exponential degradation characteristic of PMO6-VA during the first 50 mission days as shown in Figure 2. To calculate the ratios in Figure 2, the daily average of PMO6-VB$_{corr}$ is compared with the measurements from PMO6-VA taken within one hour of the PMO6-VB measurements. The third correction for PMO6-VB has already been described in c) and the result of all three corrections are shown in Figure 3 as ratio PMO6V-B$_{corr}$ to DIARAD-L . The final corrections are deduced by combining all the back-up information as described in Section 4.

Table 1: Results from the exponential/linear fit to the ratios of DIARAD-R and PMO6-VB$_{corr}$ to DIARAD-L and the ratio of the combined DIARAD-R and PMO6-VB values to DIARAD-L .

Ratio	1/e Ampl. (ppm)	time const. (d)	Slope (ppm/d)
DIARAD-R/DIARAD-L	65 ±3	405±18	-0.365±0.007
PMO6-VBcorr/DIARAD-L	218±1	521±2	-0.681±0.002
Combined/DIARAD-L	87 ± 3	525±15	-0.401±0.006

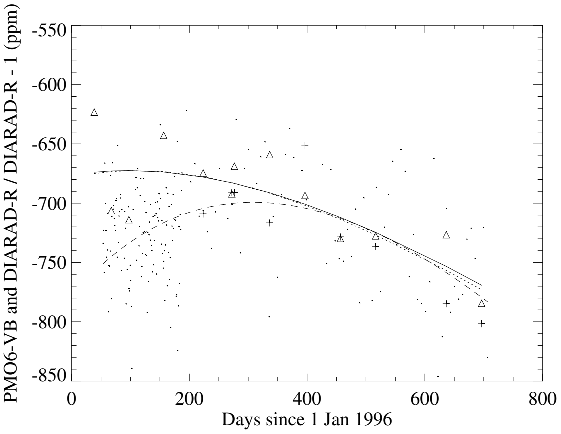

Figure 3. Ratio PMO6-VB$_{corr}$/ DIARAD-L (dots) and DIARAD-R/DIARAD-L, shifted down by 0.51% (triangles). The dashed line is a exponential/linear fit to PMO6-VB$_{corr}$/ DIARAD-L, the dotted line the one to DIARAD-R/DIARAD-L and the full line the fit to the combined data. For the coefficients see Table 1.

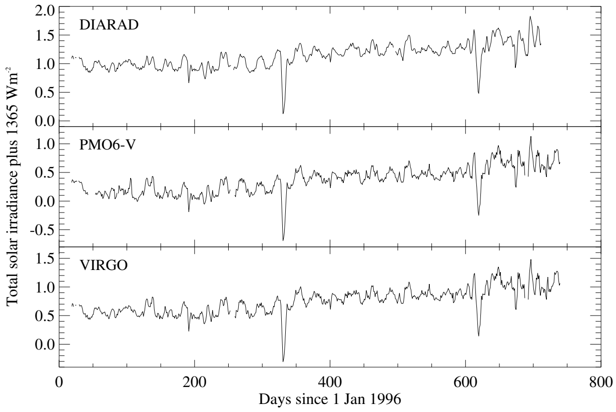

Figure 4. Total solar irradiance for DIARAD, PMO6-V and VIRGO, corrected for degradation (level-2 data).

3. Characteristics of DIARAD sensitivity changes

The behavior of the DIARAD-L is shown in Figure 3 by the two ratios DIARAD-R / DIARAD-L and PMO6-VB$_{corr}$ / DIARAD-L. Both ratios are fitted to a combination of exponential and linear function of the form

$$ratio = a_0 e^{a_1 t} + a_2 + a_3 t \qquad (1)$$

with the resulting coefficients summarized in Table 1. The 1/e amplitude corresponding to a_0/e, the time constant to 1/a_1 and the slope to a_3. The result show that the degradation of DIARAD-L can be described by an exponential decrease superimposed on a linear increase in its sensitivity. The initial decrease of DIARAD-L, as determined by the ratio PMO6-VB to DIARAD-L is nearly three times the initial decrease of the ratio DIARAD-R to DIARAD-L. However, without the first point of the ratio DIARAD-R to DIARAD-L the initial decrease would become similar to the one determined by the ratio PMO6-VB to DIARAD-L.

Another correction for DIARAD-L is due to the switch-off/on of the VIRGO experiment in September 1996. The switch-on led to a change in the response of DIARAD-L of about -0.2 Wm^{-2}, which recovered within about 6 weeks. DIARAD-L is corrected for this shift during day of year 1996 (DoY96) 225-310 by comparing DIARAD-L to PMO6-VA, which does not show such a change in response after the switch-on, as indicated in Figure 4.

4. Corrections for degradation

Since PMO6-VB needs a correction for its exponential increase during the first 230 mission days this early part is neglected for the final correction of the VIRGO radiometers. Thus, the final behavior of the degradation is composed by the ratio DIARAD-R / DIARAD-L alone until DoY96 200 and, thereafter, by averaging both ratios, DIARAD-R /DIARAD-L and PMO6-VB$_{corr}$ / DIARAD-L. For the latter averaging we calculate the ratio mean PMO6-VB$_{corr}$ / DIARAD-L around ±17 days for each data point given by the ratio DIARAD-R / DIARAD-L. The combined exponential and linear fit (Eq. 1) is represented in Figure 3 as full line with the coefficients summarized in Table 1. This fit is used to correct DIARAD-L and PMO6-VA for their degradation behavior. For the latter we first correct PMO6-VB by the difference between the PMO6-V fit (dashed line in Figure 3) and the final one, and then we calculate the 201-day running average of the ratio PMO6-VA to PMO6-VB as shown in Figure 2. To correct PMO6-VA for its degradation, we use the running average in Figure 2 rather than the exponential fit. Doing this, we account for possible deviations of the degradation characteristic from its ideal exponential behavior. A running average can only be used to correct the PMO6-V data, because there is a sufficiently large number of back-up measurements available.

5. VIRGO total solar irradiance

The VIRGO TSI is composed from the corrected measurements of PMO6-VA and DIARAD-L. Intervals with quiet sun conditions are used to determine the long term differences between the two time series. This is justified by the fact that - at least during the first 300-500 days - DIARAD seemed to be less sensitive to facular increases of the irradiance than PMO6-VA [2]. A linear regression to the ratios DIARAD-L / PMO6-VA yield a downward trend of 0.040±0.025 ppm/day, which indicates that a long term accuracy of better than 10 ppm/year would be difficult to achieve. The scatter around this ratio is ±14 ppm, which illustrates the good comparability of the two radiometers. This linear regression is used to determine VIRGO time series from PMO6-VA. Because of gaps in the short term variability of PMO6-VA until DoY96 113 we use the DIARAD-L directly for the first period of the VIRGO total solar irradiance. The final time series corrected for their degradation are shown in Figure 4 for all three total solar irradiances, DIARAD, PMO6-V, and VIRGO. TSI shows a minimum around July 1996 and has been increasing since then by 0.4 Wm^{-2}.

6. Conclusions

The degradation characteristic of each radiometer within VIRGO is determined in a consistent way by using all information from the operational and back-up instruments. The PMO6-VA sensitivity decreases by -3.9 ppm/day at the beginning and by -1 ppm/day at the end of the time series, as shown in Figure 2. The DIARAD-L instrument shows a combination of decrease and increase of sensitivity which results in an initial increase of less than 0.05 ppm/day climbing up to about 0.25 ppm/day at the end of 1997. The different behavior of the degradation characteristic of PMO6-VA and DIARAD-L may mainly be due to the different cavity geometries and the different black coatings of the radiometers. Without the two different types of radiometers we would not have been able to get a reliable determination of the long term behavior of the radiometers, and thus of the TSI. These findings illustrate the importance of the use of two different type of radiometers within the same mission to ensure a reliable determination of the degradation characteristics. On the other hand we also illustrate how difficult it is to guarantee a long term stability of single type radiometers, even if there is more than one back-up instrument available.

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