VIRGO Radiometry

From raw measurements to a reliable record of Total Solar Irradiance (TSI)

Introduction

The VIRGO Experiment on the ESA/NASA SOHO Mission has two types of radiometers to measure total solar irradiance (TSI): DIARAD and PMO6V. The former has been developed and built by IRMB, the latter by PMOD/WRC. For the VIRGO radiometers detailed descriptions of the principle and performance can be found in Fröhlich et al. (1995), Fröhlich et al. (1997). The analysis of the data in order to assess and characterize the long-term behaviour is described in Anklin et al. (1998), Fröhlich & Finsterle (2001), Crommelynck et al (2002), Fröhlich (2002). Most of these publications can be found as reprints or pre prints on our anonymous ftp server.

The scientific objective of VIRGO related the total solar irradiance, as stated in the original proposal and in Fröhlich et al. (1995), is to provide a reliable time series of TSI, which takes full advantage of the two types of radiometers. This final product was termed data level-2 and includes corrections for exposure dependent changes which can be determined for each type of radiometer separately - yielding data level-1.8 - and corrections for exposure independent changes which can only be determined from a comparison of the two level-1.8 time series. Obviously, the final objective is to provide a time series of TSI which is as close as possible representing the output of the Sun and does not depend on the radiometer used.

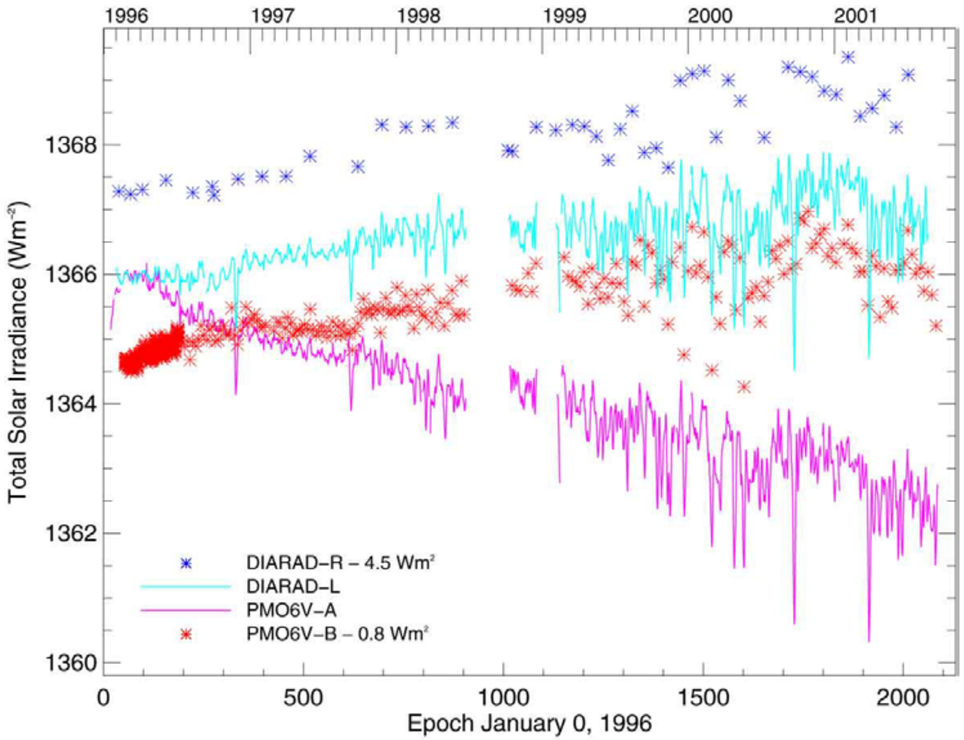

Figure 1: Level 1 data of the VIRGO radiometer: DIARAD-L, DIARAD-R, PMO6V-A and PMO6V-B. (pdf-Figure)

From level-0 to level-1

The raw data (**level-0**) as transmitted from the spacecraft to ground are transformed into physical units using the radiometric factor which is determined for each individual radiometer by characterization experiments in the laboratory. Furthermore corrections for all a-priory known effects, are applied such as temperature, distance and radial velocity to the Sun. These data are labelled **level-1**. The algorithms for the calculation of level-1 data were developed by the corresponding institutes: by IRMB for DIARAD and by PMOD/WRC for the PMO6V radiometers. These algorithms are described in Fröhlich et al. (1997).

From Fig.1 it is obvious that these time series do not show the variations of the solar irradiance alone, but also changes of the radiometric sensitivity which are quite different for the different types radiometers. It is also obvious that DIARAD shows less sensitivity changes than PMO6V. It is interesting to note that for the latter a linear fit to the decrease of sensitivity, normally termed as degradation, corresponds almost exactly to the one observed during the EURECA mission. In contrast to this behaviour DIARAD, which flew also on EURECA shows on SOHO much less change than then.

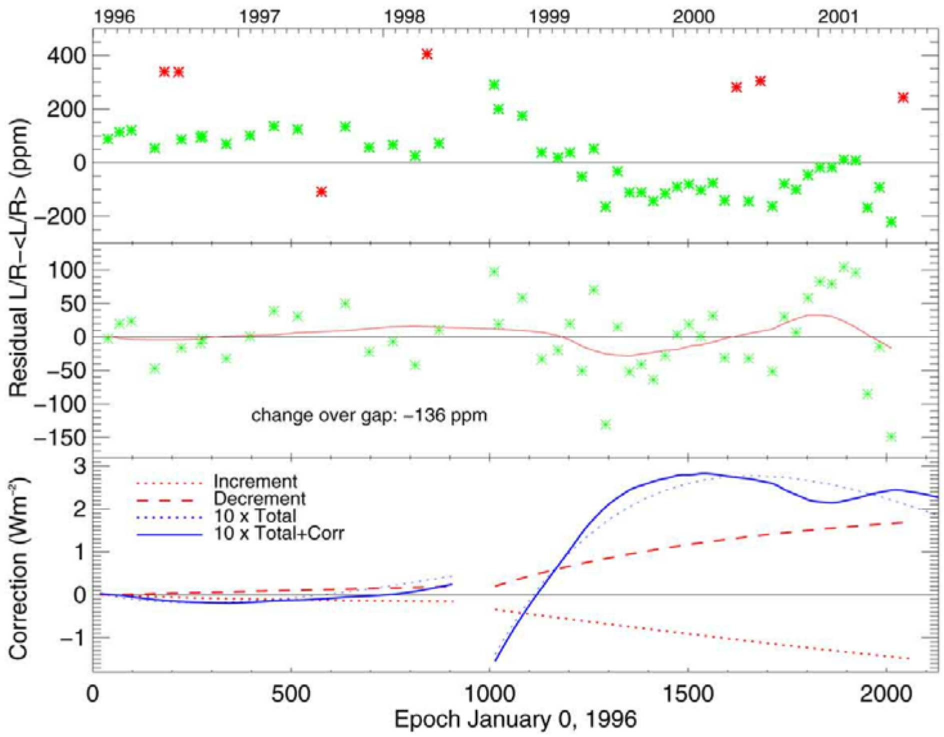

Figure 2: The top panel shows the ratio of DIARAD-L/R, the middle panel the deviation after applying the final corrections which are shown in the bottom panel. The red points in the top panel are discarded as outliers for the further evaluation. [(pdf Figure)](pdf Figure)

From level-1 to level-1.8

It is normal practice to use comparison of radiometers of the same type - but with different exposure times - to determine exposure dependent changes. The incorporation of these changes as corrections leads then to level-1.8 for DIARAD and PMO6V separately.

In general the exposure time for the rarely used instruments is much lower than for the operational ones so that only a very small , and possibly negligible sensitivity change is observed for the former ones. In the case of DIARAD the exposure times of the L and R channels have reached until September 2001 962 and 1.2, and for PMO6V-A and B 1961 and 15.3 days. Thus for DIARAD-R the exposure time is low enough to assume no change. For the PMO6V radiometers, however, this is not the case because of the rather frequent exposure of PMO6V-B during the first 200 days, the test phase of a new operational procedure. The reason for the new procedure was a failure of the electronic circuit to operate the shutters of the PMO6V and the necessary change to use the covers for the reference phase which was set to be every 8 hours (instead of the 1-minute-open-1-minute-closed phases).

In order to understand the long-term behavior of the radiometers a model for such changes has been developed, which is based on hyperbolic functions taking the effective dose of radiation

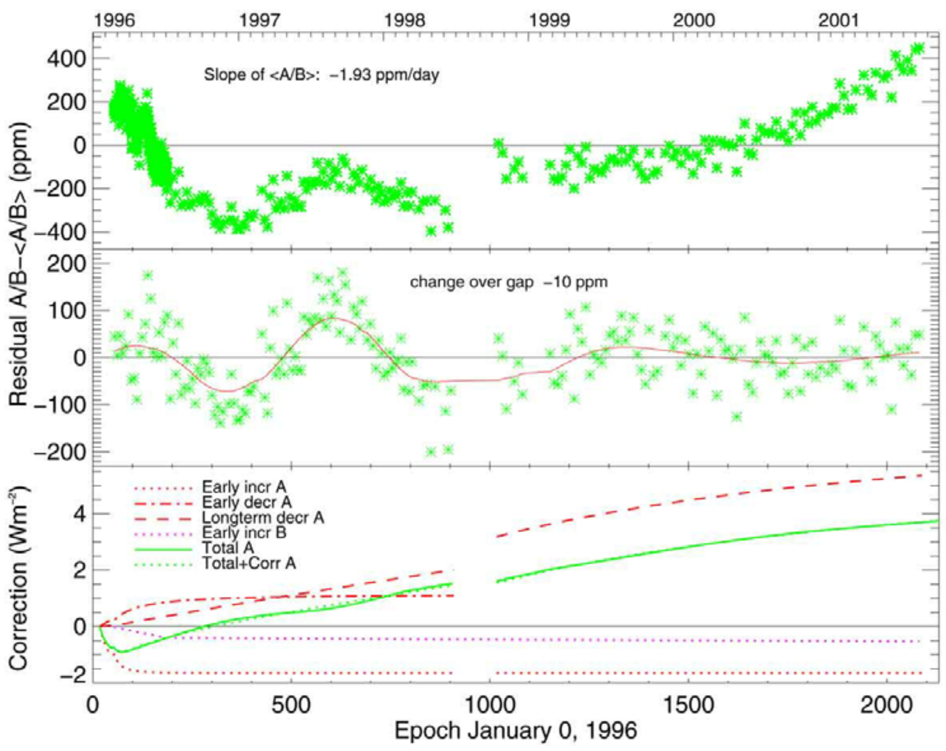

Figure 3: The top panel shows the ratio of PMO6V-A/B as a deviation from a fitted straight line with a slope of about 2 ppm/day. The middle panel shows the deviation after applying the final corrections which are shown in the bottom panel. (pdf Figure)

received by each radiometer (according to their exposure time) into account (Fröhlich & Finsterle, 2001). The period before and after the SOHO vacations are treated separately and a possible slip over the gap is introduced. Two such functions are used to describe the behavior one with an increase, the other with a decrease. For DIARAD this is sufficient; for the PMO6V radiometers the two functions are supplemented by a short term decrease at the beginning of the mission. For both radiometers the starting point is the comparison of the radiometers L/R and A/B respectively. In the case of L/R some points are obvious outliers and left out. For PMO6V all available points have been used; during the extensive measurement period at he beginning of the PMO6V-B operation only one point every week has been used in the analysis in order not to falsify the statistics of the analysis. The results of the fits for DIARAD are shown in Fig.2 and those for PMO6V in Fig. 3. The deviation from the combination of the fitted functions is used to finalize the correction. The value of the fitting process is to learn more about the behaviour (discussed in Fröhlich, 2002), but it does not influence the determined corrections and the final level-1.8 result. Time series of DIARAD and PMO6V at level-1.8 are included in the final VIRGO hourly and daily data sets (columns 4 and 5) . The result presented here for DIARAD are essentially identical to the one presented in Crommelynck et al. (2002) and on the DIARAD page.

From Level-1.8 to Level-2

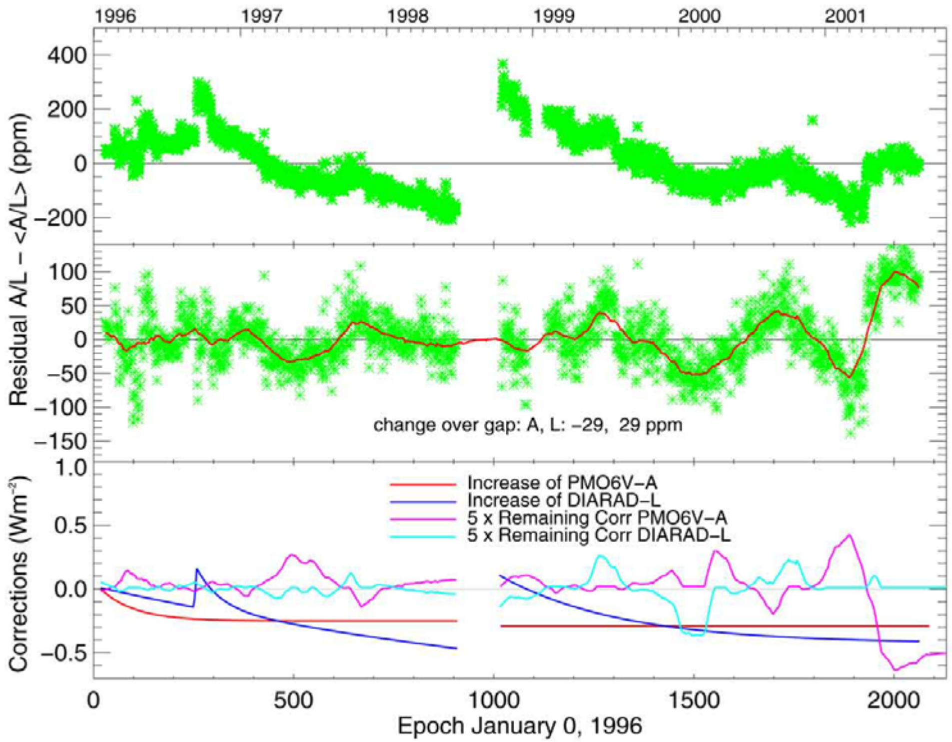

Figure 4: The top panel shows the ratio of PMO6V-A/DIARAD-L,. the middle panel the deviation after applying the final corrections which are shown in the bottom panel. (pdf Figure)

Up to this point the procedure to determine the corrections for the long term behavior is straightforward. Now we are faced with the problem of deriving a best estimate for TSI from two time-series which are obviously different. The ratioA/L of the level-1.8 data are shown in the top panel of Fig.4 and the deviation of this ratio from its mean covers a range of more than 600ppmwhich is most likely incompatible with the uncertainty of the corrections derived above. Thus, this is a strong indication that there must be other effects influencing the radiometry than exposure dependent changes. It is the first time that we have such direct evidence, thanks to (i) the fact that VIRGO comprises two type of radiometers which measure side-by-side the same Sun and (ii) the very quiet thermal environment we have on SOHO. There is obviously no way that metrological arguments can resolve the issue, all arguments have been exhausted in preparing level-1.8; nor can we leave a user of TSI with the decision which of both time series to use, if the experts are unable to resolve the issue. On the other hand, this is obviously a great opportunity for the advancement of room-temperature radiometry and is a real challenge.

An easy solution would be to take the average of both time-series, but from Fig.4 it is obvious that there are significant changes of the ratio with time, before the SOHO vacation for the period after day 200 represented by a more or less steady decrease of the ratio A/L at about the same rate

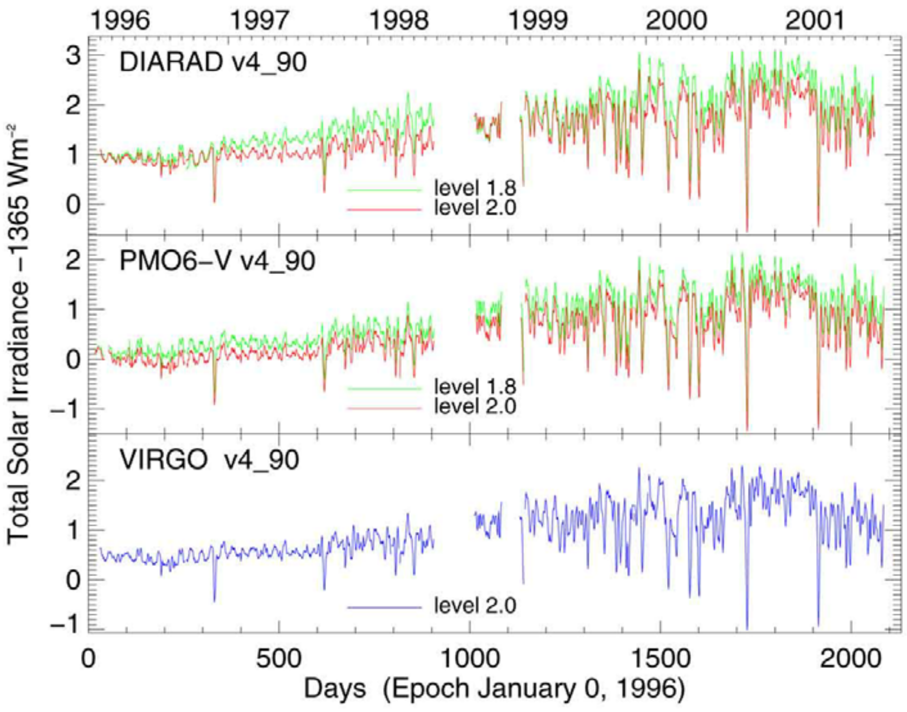

Figure 5: DIARAD, PMO6V,. and VIRGO level-1.8 and level-2 time series. (pdf Figure)

before and after the vacation. This may be due to an increase of DIARAD or a decrease of PMO6V. The decision cannot be taken from internal arguments, we need some guidelines from other sources. There are two possibilities: comparison with measurement by ACRIM and ERBE and comparison with empirical models. Before the availability of the version-2 ACRIM II data in spring 2002, both ACRIM II and ERBE data sets were too noisy to reach a sound conclusion. The improved version-2 ACRIM-II data show a more or less constant TSI over the period of two years (1996-1997) of solar minimum. The same is indicated by the empirical models based on the influence of sun spots, faculae and magnetic network. This is an indication that DIARAD increased during that period. Thus, we try to fit exponential functions to both time series with different amplitudes and time constants, independently to both periods before and after the vacations. These exponential functions are representing exposure independent changes which start at switch-on of the radiometers. Arguments for these assumptions can be found in Fröhlich & Finsterle (2001). As we had an accidental switch-off of VIRGO in September 1996, a corresponding change can be observed in DIARAD which is - interestingly enough - not seen in the ratio L/R (the two outliers are well before the time of switch-off) . DIARAD seems to be influenced by switch-off/on with an amplitude and time constant for the recovery after switch-on which depends on the duration of the switch-off period. Before the vacation the DIARAD behaviour can be modelled by two decreasing exponential starting at the beginning, and one starting after the switch-off in September 1996. During the same period one decreasing exponential is needed to correct PMO6V to finally reduce the standard deviation of the ratio A/L from several hundreds of ppm to 33 pmm. After the vacation one decreasing exponential for DIARAD is sufficient to reduce the standard deviation to 39 ppm, a slightly higher value due to higher variability of the ratio which is influenced by the changes of the ratio towards the end of the record. The remaining deviations shown in the middle panel of Fig.4 have now to be distributed among the two radiometers. This is done by using the absolute deviation of the ratios to ACRIM II from a boxcar running mean with 365 days ; if one of the ratios exceeds a certain limit, that radiometer gets the correction, if both are below the limit the correction is equally distributed. It is interesting to note that the larger deviations are mainly due to the behaviour of PMO6V (probably due to the way its operated and due to the uncertainty in the corrections needed for this operation).

This yields to the final TSI record. The difference of the corrected DIARAD and PMO6V is now essentially constant in time and corresponds to the difference in absolute values. Although the noise of PMO6V is slightly higher than the one of DIARAD the plain average of the corrected values is presented as the final VIRGO hourly and daily TSI. The increasing sensitivity of DIARAD for short term variation during the first 3 years (see Fröhlich and Finsterle, 2001) is not corrected because it may not be significant relative to the higher noise of PMO6V.

References

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