Re-Analysis of the Short- and Long-term Changes of the ACRIM-I/SMM and HF/NIMBUS-7 Radiometers and Revision of the PMOD Composite*

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Abstract

The results from the detailed analysis of the VIRGO radiometry provide a good understanding of the effects influencing the long-term behaviour of classical radiometers in space. Thus, a re-analysis of the long-term behaviour of HF/NIMBUS-7 and ACRIM-I/SMM became obvious. For the former the situation is complicated by the fact that there are no in-flight means to determine changes due to exposure to solar radiation by comparison with a less exposed radiometer on the same spacecraft. The geometry and optical property of the cavity of HF is, however, very similar to the PMO6-type radiometers, so the results from the PMO6V radiometers on VIRGO can be used as a model. Also ACRIM-I had to be revised mainly due to a henceforth undetected early increase and a more detailed analysis of its degradation. The results are not only important for solar radiometry from space, but they also improve the reliability of TSI during cycle 21. The revised PMOD composite allows now to better quantify the behaviour of solar cycle 21 and to compare it with the two recent ones which differ in several aspects.

1 Motivation

Figure 1 shows the original time series which are the basis for a composite. It is clear that not only the absolute values are quite different, especially at the beginning of the series, but there are also differences between the series. This is obvious for e.g. the beginning of the HF measurements on NIMBUS7. The corrections for HF used by Fröhlich and Lean (1998) for the original composite were based on early results from VIRGO and used simple exponential functions

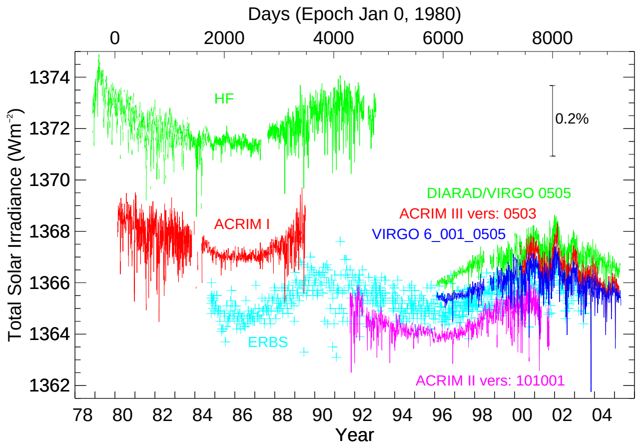

Figure 1: Compared are daily averaged values of the Sun's total irradiance from radiometers on different space platforms as published by the instrument teams since November 1978. Note, that the VIRGO TSI is determined from both VIRGO radiometers (PMO6V and DIARAD), whereas the DIARAD TSI is only based on that one.

to fit the changes due to the early increase and degradation. Also the corrections for the degradation during the first year of ACRIM-I needs some revision.

The detailed analysis of the VIRGO radiometry (see e.g. Fröhlich, 2003) allowed the development of a consistent model for the sensitivity changes and its success made a re-analysis of the short and long-term behaviour of ACRIM-I and HF worthwhile. The model is based on the equations describing 'sun-burning' of quartz by siliconizing its surface and yield a hyperbolic function which takes the dose as a function of time into account. The dose is calculated from a normalized MgII index and the exposure time of the radiometer considered. From our experience with the radiometer series for SOVIM, an experiment to be flown on the International Space Station, and by investigation of the retrieved radiometers from EURECA we learned that the early

*This is an updated and extended version of the poster presented at the AGU Fall Meeting 2004 (Fröhlich, 2004) increase is most probably due to a change in absorption of the primary aperture and its influence on the sensitivity by extra IR radiation emitted into the cavity. So, it became clear, that this influence may be important for all radiometers used in space missions, which have their primary aperture directly in front of the cavity.

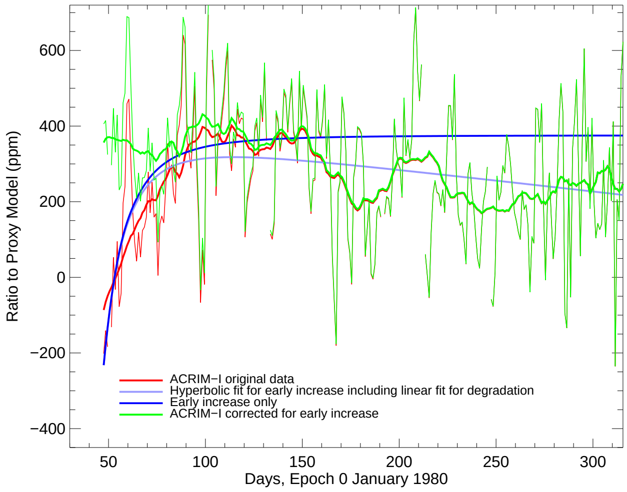

Figure 2: Shown are the early measurements of ACRIM-I together with a fit of a hyperbolic function describing the early increase and a linear fit taking the yet non-corrected degradation into account.

And, indeed it could be detected in ACRIM-I with similar amplitudes as observed for the PMO6V radiometers of VIRGO (Figure 2). Furthermore the early increase is followed by a decrease which is interpreted as bleaching after initial darkening. This behaviour is confirmed by inspecting the apertures of the SOVA-2 radiometers which were an year in space during EURECA mission: the aperture of the less exposed is still quite dark, whereas the one of the most exposed have become yellowish.

2 Radiometric corrections

To correct for the early increase of ACRIM-I the application of two hyperbolic functions was not successful, probably because of the insufficient number of data points and the rather large number of parameters to be fitted. So, only one hyperbolic function was fitted to describe the early increase as shown in Figure 2. In a next step degradation has to be modelled. This is complicated by the fact that during the spin-mode operation of SMM (after failure of the pointing system in late 1980 until repair in 1984) the exposure was drastically reduced which was not accounted for in the original corrections (Willson and Hudson, 1991). The result of the improved degradation analysis is shown in Figure 3. The s-shape of the blue curve represents the change

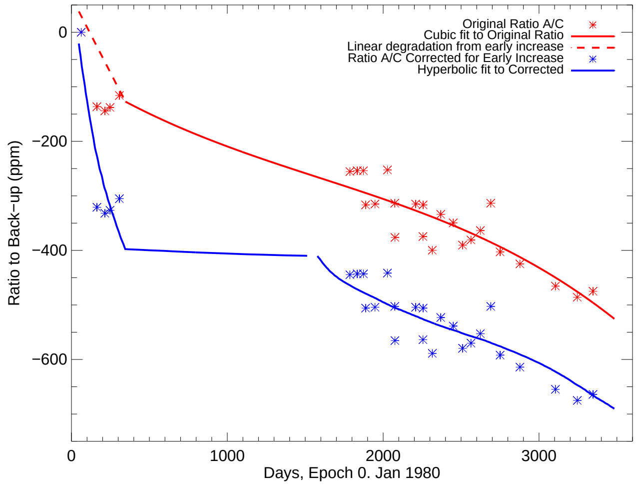

Figure 3: The original ratios of sensor A to sensor C (red symbols) are from Willson and Hudson (1991). The cubic fit corresponds to the correction originally applied and the dashed line includes the linear fit found by fitting the early increase. The blue symbols are corrected for the early increase and then fitted with a hyperbolic function.

of solar activity from the maximum at the beginning through the minimum from days 2000–2600 into cycle 22 and is determined by the influence on the rate of degradation by a changing dose. This also illustrated how well the model describes the details of the degradation. The flat part from days 320-1500 represents the spin-mode data with much less exposure. After the repair of SMM a further complication has been observed as shown in Figure 4 which needed a small correction. The final result is presented in Figure 5.

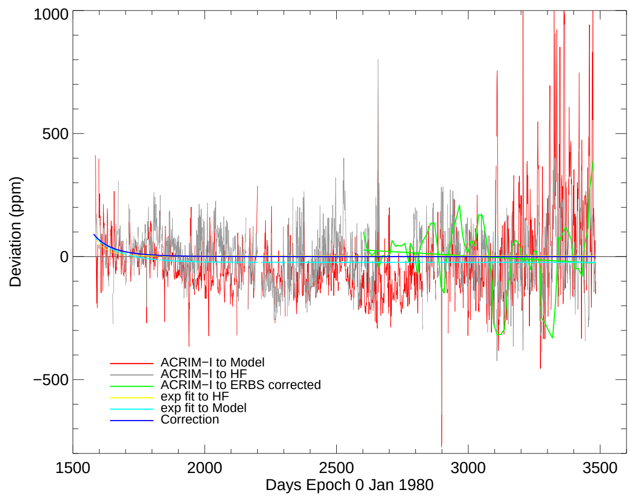

Figure 4: During the repair of SMM the payload was obviously switched-off. The temporal behaviour of ACRIM-I after switch-on indicates a recovery over about an year which is corrected. Also plotted are the corrected ERBS data (see Figure 6).

After the detection of the early increase in the ACRIM-I data set and due to the fact that the ERBS radiometers are copies of ACRIM-II (manufactured by TRW for NASA Langley) this radiometer should behave very similarly and as

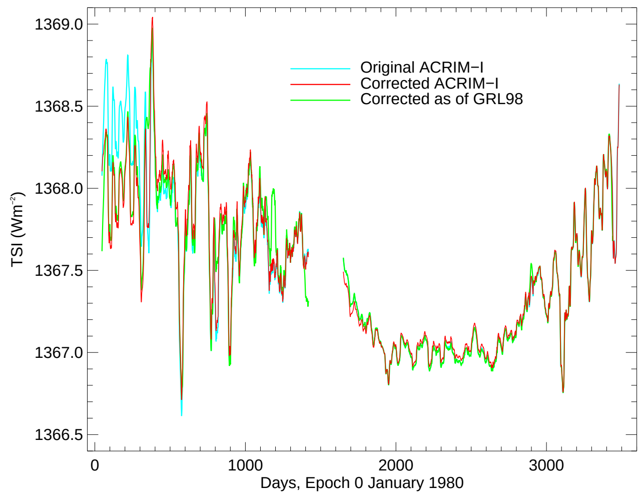

Figure 5: The original ACRIM-I record is compared to the corrected one as described. Also plotted is the record as it was used in Fröhlich and Lean (1998).

the total exposure time is less than 3 days only a correction for the early increase is needed as shown in Figure 6.

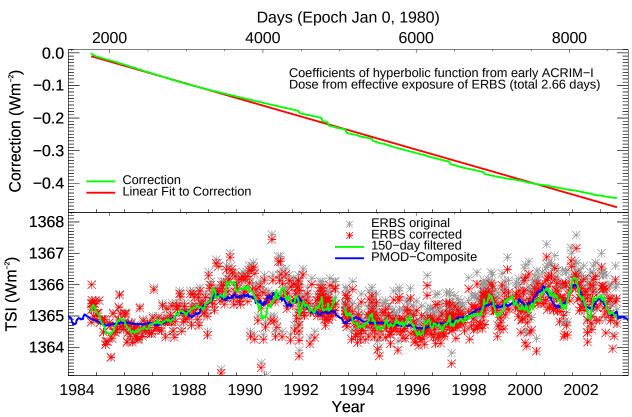

Figure 6: From the analysis of ACRIM-I we have learned about the early increase and here we use the coefficients of the hyperbolic function determined for ACRIM-I together with the dose received by ERBS (Figure 2).

For the HF radiometer the situation is more complicated as there is no back-up instrument which can be used for in-flight corrections. So we need a reference for the early observations, which is build from the proxy model calibrated with ACRIM-I and used to extrapolate ACRIM-I back to November 1978, the start of NIMBUS-7. Another complication is the fact that the time series has many slips which are mainly

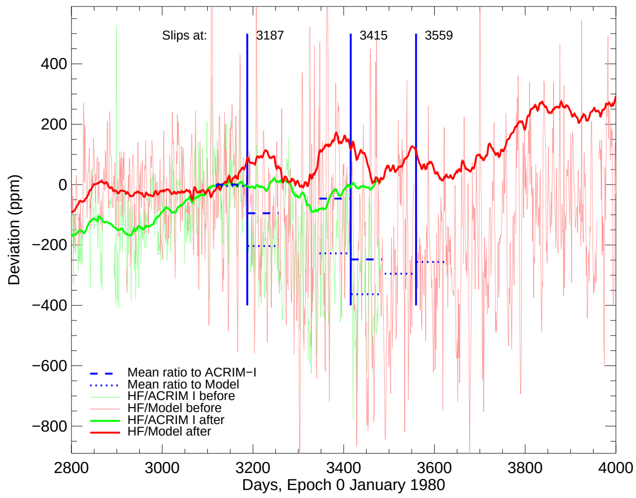

Figure 7: Shown is the period around the end of the ACRIM-I record with two slips during ACRIM-I and one just after. The latter is the famous one responsible for the difference between the PMOD and ACRIM composite. Originally it was detected by Lee III et al. (1995) and Chapman et al. (1996). It was earlier determined as 305.2 ppm (Fröhlich, 2000) and is now increased to 347.3 ppm.

due to changes in the orientation of the spacecraft and which have not been taken into account in the original evaluation. An example is presented in Figure 7.

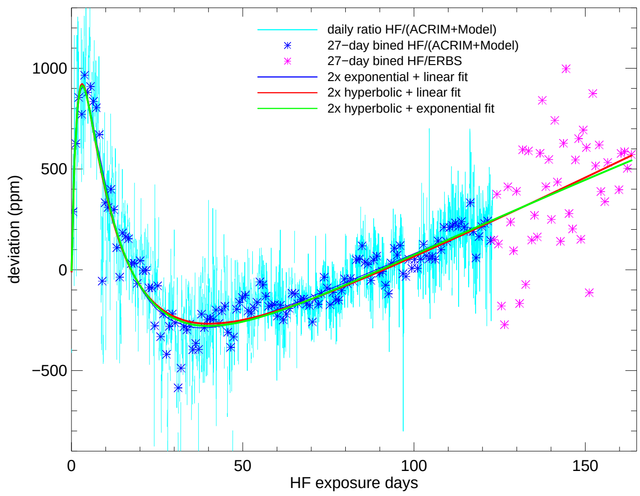

Figure 8: As the earlier analysis has shown, the HF needs for the correction an early increase, some degradation and a long-term increase. The former two effects are modelled with hyperbolic functions, whereas the latter is a non-exposure dependent effect similar to the one found for DIARAD/VIRGO which is modelled with an exponential function.

Figure 8 illustrates the procedure and the results. In contrast to the earlier analysis we determine the sensitivity changes of HF over its full period and the trend needs no longer to be determined by comparison with ERBS and the Model as in Fröhlich (2000). The data set used as reference is a combination of the proxy model, ACRIM-I and ERBS data (see Figure 8). The final result of the corrected HF data set is shown in Figure 9 which demonstrates how important these corrections are (up to 1 Wm^{-2}). The internal consistency of the corrections demonstrates their reliability and need.

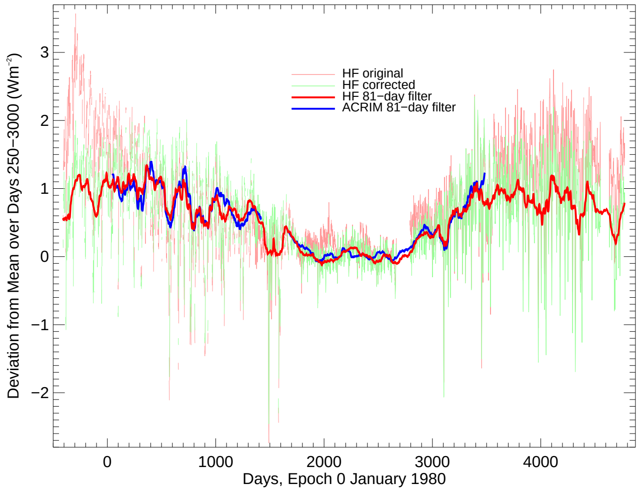

Figure 9: The final result of the HF corrections is compared to the original data set and to ACRIM-I. Differences between the corrected and original data is up to 1 Wm^{-2}.

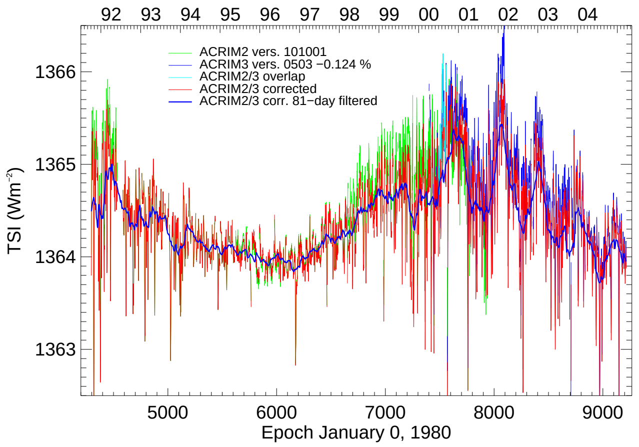

Figure 10: This plot illustrates the corrections of ACRIM-II. Major corrections are needed for changes of the operational radiometer around mid 1992 and beginning of 1998

3 The PMOD composite

The corrections to ACRIM-II have been described in Fröhlich (2004) and are mainly due to changes in the operational radiometer as shown in Figure 10. With these corrected time series and the VIRGO data we are almost ready to construct the composite. Before staring we have to refer ACRIM-II to ACRIM-I, which will then be the radiometric reference This is done by a weighted average of the ratios of ACRIM-I to the corrected HF and ERBS data and the corresponding average ratios of ACRIM-II. The result is shown in Figure 11.

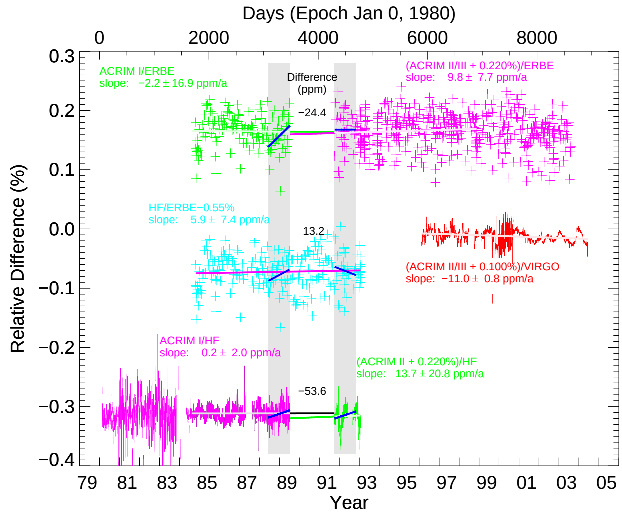

Figure 11: This plot illustrates the tracing of ACRIM-II to ACRIM-I. The change of the ACRIM-II level is determined by a weighted average of the comparison of ACRIM-I and II with HF and ERBS during the periods indicated by shading.

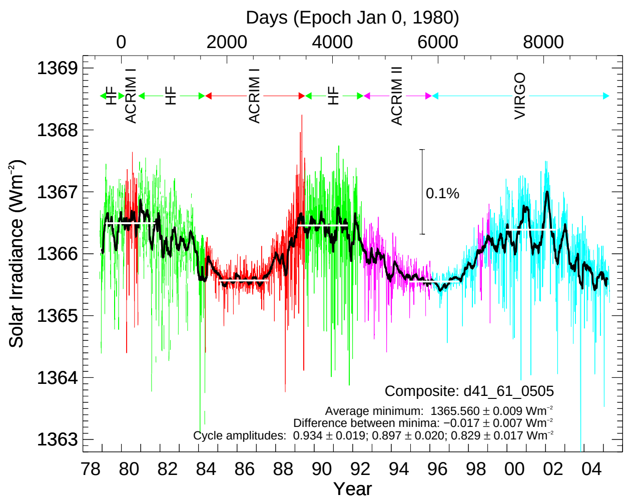

Figure 12: Shown is the final version of the PMOD Composite. Compared to the earlier versions the maximum of cycle 21 is at about the level as before, but has less noise, especially in the early part. This may indicate that the early HF corrections have indeed been improved. Finally, the difference between the minima has also not changed.

practical reasons and is shown in Figure 12 and the comparison to the original data in Figure 13. Furthermore, the PMOD, ACRIM (Willson and Mordvinov, 2003) and IRMB (Dewitte et al., 2004) composites are compared as ratios to the corrected ERBS time series (Figure 14).

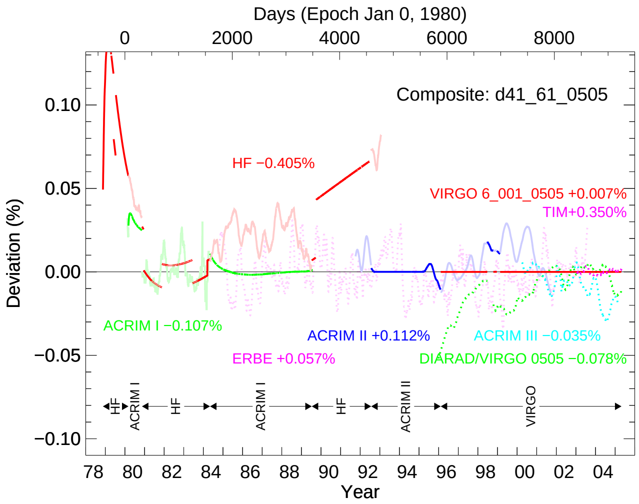

Figure 13: Comparison of the PMOD composite with the original data. The many and important corrections for the HF radiometer are obvious, also the ones for ACRIM-I and II. For VIRGO the corrections have been applied before its use in the composite. The time series plotted as dotted lines are not used in constructing the PMOD composite.

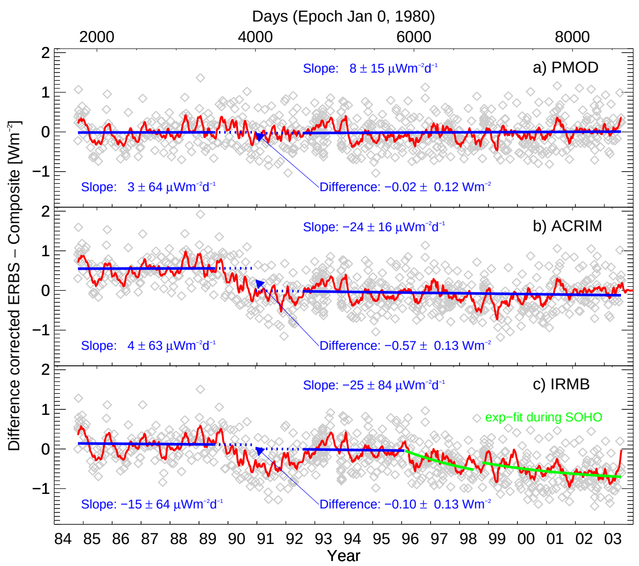

Figure 14: Shown is the comparison of the PMOD, ACRIM and IRMB composites with ERBE, which is corrected according to Figure 6. For the ACRIM composite the step over the ACRIM gap is mainly due to the neglect of the HF corrections during this period. The deviation of the IRMB composite during the time of SOHO is due to the fact that their evaluation does neglect non-exposure dependent changes of DIARAD.

Having done this scaling the rest is straight-forward and consists in adjusting the HF and VIRGO measurements to the ACRIMs leaving them at their respective levels. The result is then scaled to SARR (Crommelynck et al., 1995) for

4 Comparison with a 3-component proxy model

Multiple regression of a 3-component proxy model against TSI is used to 'calibrate' it and explains somewhat less than 80 % of the variance. The three components are the photometric sunspot index (PSI) and a short- and long-term MgII index (see e.g. Fröhlich and Lean, 2004). The results are shown in Figures 15 and 16. The coefficients for the MgII short and long-term vary by only ±10% between the cycles and it is interesting to note that the short-term is lowest for cycle 21, whereas the long-term is highest. The opposite situation is found for cycle 23. The highest coefficients for the short and long-term are observed for cycle 22.

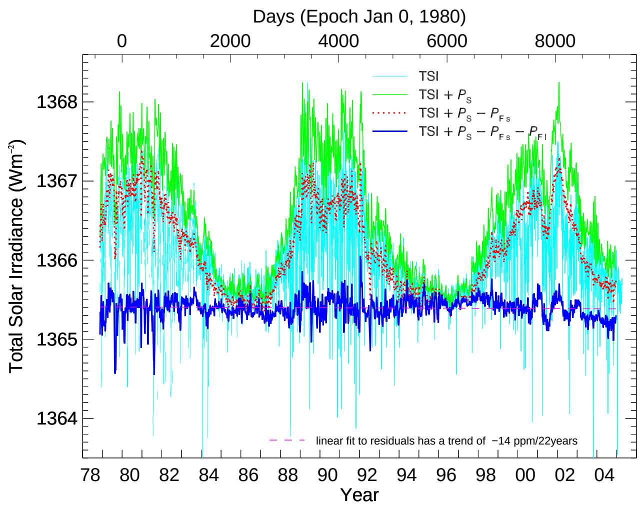

Figure 15: The comparison of the PMOD composite with a 3-component model (PSI P_S, short- P_{FS} and long-term MgII P_{Fl}). This model has been calibrated against the composite for each cycle separately which makes the overall trend of the residuals zero. Both cycles 21 and 23 show a decreasing trend of the irradiance during the descending part of the cycle not suggested by the model. Morover, there seems to be a trend difference during cycle 23 which may be due to instrumental effects.

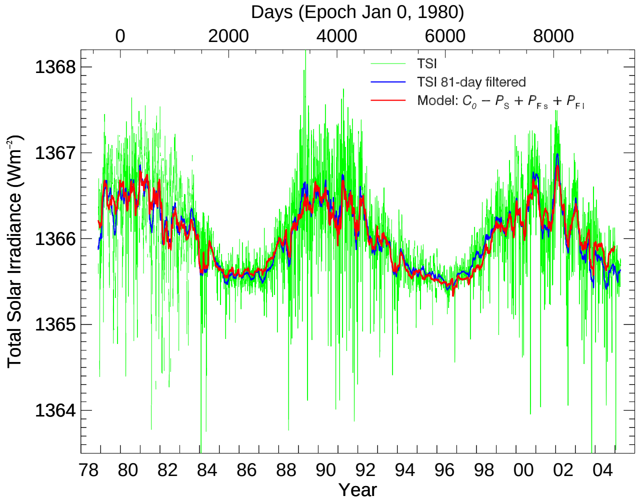

Figure 16: Although in detail some discrepancies are obvious, the overall fit is quite impressive. The coefficients for the MgII short and long-term vary by ±10% between the cycles which may not be significant in terms of representativeness of the model.

5 Conclusions

The corrections, mainly based on the improved understanding of the short- and long-term changes of classical radiometers in space, have improved the reliability of the composite substantially. A detailed error analysis shows that the PMOD composite has a long-term uncertainty of less than about 90 ppm per decade, which makes the observed trend not significantly different from zero. The close agreement with the 3-component model also supports the PMOD composite as a reliable realization of the solar irradiance variability.

The data are available from `http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant` and this poster from `ftp://ftp.pmodwrc.ch/pub/claus/AGU-Fall2004/AGU_poster_Fall2004.pdf`. The ACRIM composite is available from `http://www.acrim.com/Data%20Products.htm` and the IRMB one from `http://remotesensing.oma.be/solarconstant/sarr/SARR.txt`.

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