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Solar Irradiance Variability since 1978

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Abstract. Since November 1978 a set of total solar irradiance (TSI) measurements from space is available, yielding a time series of more than 25 years. From measurements made by different space radiometers (HF on NIMBUS 7, ACRIM I on SMM, ACRIM II on UARS, VIRGO on SOHO, ACRIM III on ACRIMSat and TIM on SORCE) a composite record of TSI can be constructed. Presently, there are three such composites available, called PMOD, ACRIM and IRMB, which all are based on the same original data, but use different ways to correct for sensitivity changes. The PMOD composite is the only one which also corrects the early HF data for degradation and can provide reliable data for TSI around the maximum of solar cycle 21. The results from the detailed analysis of the VIRGO radiometry allow 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 and ACRIM-I was performed. The results are not only important for solar radiometry from space, but they also provide a more credible TSI during cycle 21. Thus the revised PMOD composite allows to better quantify the behaviour of solar cycle 21 relative to the two recent ones which differ in several aspects.

Key words. Sun: Irradiance

1. Revision of the PMOD Composite during Solar Cycle 21

The detailed analysis of the VIRGO radiometry (see e.g. Fröhlich 2003) allowed the development of a consistent model for the sensitivity changes due to exposure dependent changes such as early increase, degradation, etc. Its success made a re-analysis of the short and long-term behaviour of ACRIM-I on SMM and HF on NIMBUS 7 worthwhile. Detailed description of the methods used have been presented in Fröhlich (2004, 2006) together with the implications on our knowledge of the solar-cycle related changes of TSI. Here we present a summary of the method and the main results.

The degradation model is based on a hyperbolic function which takes the dose of irradiation as a function of time into account. The dose is calculated from a normalized MgII index (from e.g. Viereck et al. 2004) at the exposure times of the radiometer considered. The most important effect is what is normally called degradation. As this effect depends on the time of exposure to solar radiation it can be determined by comparison with a less exposed back-up radiometer of the same type. This is possible for ACRIM-I, but not for HF. For the latter, no co-located back-up exists, so ACRIM-I data together with a calibrated proxy model are used for the time before ACRIM-I

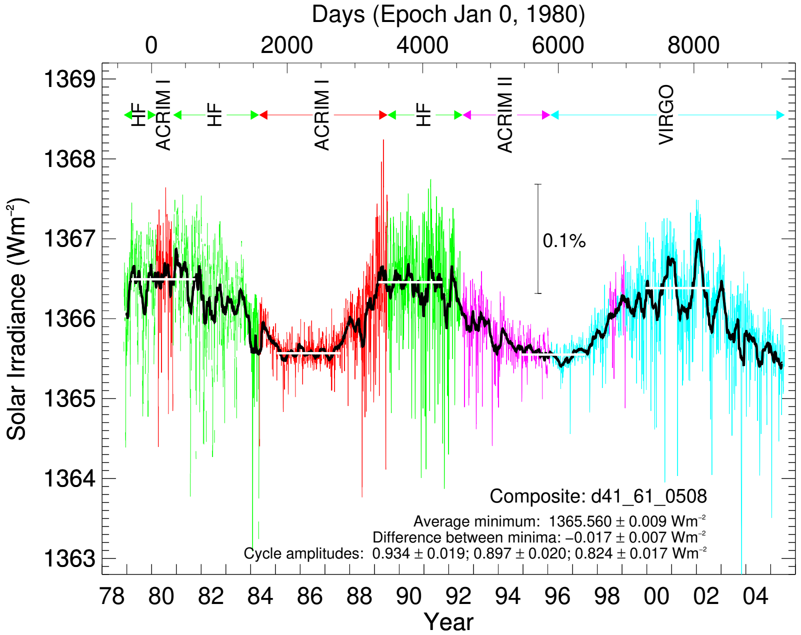

Fig. 1. Shown is the final version of the PMOD composite. Compared to the earlier versions the maximum of cycle 21 is at about the level as before, but has less noise, especially in the early part. This may indicate that the early HF corrections have indeed improved the record. Finally, the difference between the minima has also not changed.

and ERBS and the proxy model for the time after.

Another effect is an early increase in sensitivity of radiometers in space which was first identified for the PMO6V radiometers on VIRGO. By investigation of the retrieved SOVA-2 radiometers, which were an year in space during the EURECA mission (Crommelynck et al. 1993), we learned that the early increase is due to an increase of the absorptivity of the primary aperture and its influence on the sensitivity by extra IR radiation emitted into the cavity. As this effect depends on exposure it could in principle also be determined by comparison with less exposed backups. As the darkening happens in a rather short time interval at the beginning of the mission there may not be enough points to compare and the irradiance to compare with has to be taken from some other radiometer.

In a first step ACRIM-I is revised by determining and correcting the early increase and then taking into account a revised degradation determined by a hyperbolic function with the effective dose which is rather low during the spin mode operation of SMM. The HF record is first cleaned for the many slips, which are mainly due to changes in pointing of the spacecraft not taken into account in the original evaluation. This includes the important one of 28 September 1989, which is responsible for the difference between the PMOD and ACRIM composite and was originally detected by Lee III et al. (1995) and Chapman et al. (1996). Then hyperbolic functions are fitted for an early increase and the long-term degradation. Moreover, a long-term sensitivity increase is also taken into account, which may be of similar origin as the one observed by DIARAD within VIRGO on SOHO. The result is now internally consistent and yields a corrected HF record from the beginning in November 1978 until the very end in January 1993. This data set can now be directly used for the construc-

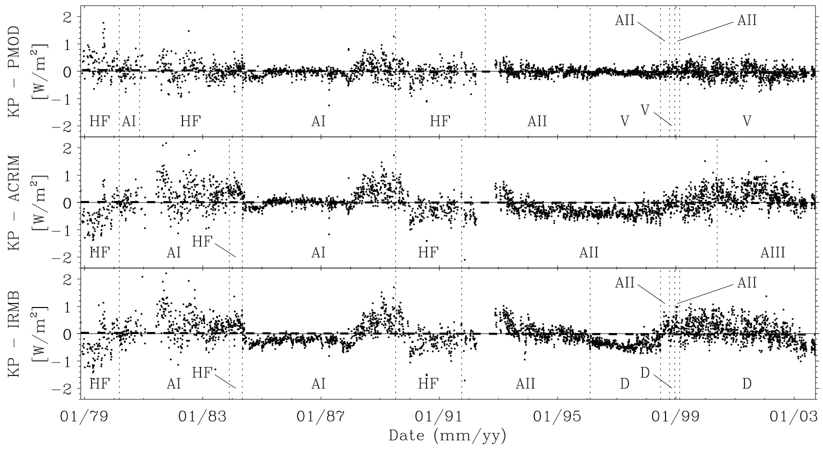

Fig. 2. The comparison of the three composites with a reconstruction of TSI from Kitt-Peak magnetograms by Wenzler (2005). The tags HF, AI, AII, AIII, V, D label the radiometers used as HF, ACRIM-I, II, III, VIRGO and DIARAD.

tion of the PMOD composite and more specifically to trace ACRIM-II to ACRIM-I.

Figure 1 shows the final result for the PMOD composite as derived by Fröhlich (2006) with the above explained corrections. The differences between this and earlier ones are mainly around the maximum of solar cycle 21, which is now more reliable than before. The amplitudes of the three cycles are very similar with 0.934, 0.897 and 0.842 Wm^{-2} although e.g. the sunspot numbers are quite different with 129, 134 and 98, respectively. This indicates that for the association of TSI with solar activity the sunspot number is not a reliable proxy.

A comparison of the three composites with a reconstruction of TSI from Kitt-Peak magnetograms by Wenzler (2005) is shown in Figure 2. The best agreement is with the PMOD composite explaining 83% of the variance; the ACRIM and IRMB explain only 70 and 76%, respectively. Around the maximum of cycle 21 this is mainly due to the fact that the others do not correct the HF data for degardation. After 1996 the differences between PMOD and IRMB are due to the different treatment of the VIRGO radiometers by Fröhlich (2003) and Dewitte et al. (2004), which is due to the neglect of the non-exposure dependent change of DIARAD by IRMB. There are still some small deviations with the PMOD composite which could come from the composite time series, the corrections applied or from the analysis of the Kitt-Peak magnetograms. These remaining discrepancies need some further investigation.

2. Conclusions

The presented corrections are based on the improved understanding of the short and long-term changes of classical radiometers in space, and have substantially improved the reliability of the composite. A detailed error analysis shows that the PMOD composite has a long-term uncertainty of less than about 90 ppm per decade (Fröhlich 2003), which makes the observed trend not significantly different from zero. The close agreement with the reconstruction from the Kitt-Peak magnetograms by Wenzler (2005) and also with the 3-component proxy model shown by Fröhlich (2006) supports the PMOD composite as the most reliable representation of the solar irradiance variability during the last three solar cycles. The PMOD composite is available from `http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant`, the ACRIM and IRMB composites from `http:`

//www.acrim.com/Data%20Products.htm and http://remotesensing.oma.be/solarconstant/sarr/SARR.txt respectively.

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