TOTAL SOLAR IRRADIANCE VARIATIONS

The Construction of a Composite and its Comparison with Models

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Abstract. Measurements of the total solar irradiance (TSI) during the last 18 years from spacecraft are reviewed. Corrections are determined for the early measurements made by the HF radiometer within the ERB experiment on NIMBUS7 and the factor to refer ACRIM II to the ACRIM I irradiance scale. With these corrections a composite TSI is constructed for the period from 1978–1997. This time series is compared with a model that combines a magnetic brightness proxy with observed sunspot darkening and explains nearly 90% of the observed short and longterm variance. Possible, but still unverified degradation of the radiometers hampers conclusions about irradiance changes on decadal time scales and longer.

1. Introduction

The radiation from the Sun at the mean Sun-Earth distance (1 AU), integrated over all wavelengths, hence total solar irradiance (TSI), is traditionally called the "solar constant" although it has been shown to vary on time scales from minutes to decades. The largest amplitude variance of up to a few tenths percent occurs on time scales from days to several months and is related to the photospheric features of solar activity: decreases in the irradiance during the appearance of sunspots, and increases when bright faculae are present. This modulation of TSI is conceptually well understood, but a detailed understanding is still missing. While the long-term modulation of TSI by the 11-year activity cycle is well documented and generally accepted, understanding of the mechanisms governing the variations is incomplete, and limits conclusions about longer term changes of TSI, such as those which may have occured during the Maunder Minimum associated with the Little Ice Age in Europe. Knowledge of such changes is important for the understanding of possible solar forcing of climate change during the past, present and future.

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The radiometric accuracy of irradiance measurements made by individual instruments, of the order of 0.2%, is insufficent to determine long term changes of only about 0.1% that occur during the 11-year modulation. While the instrument repeatablility is adequate to monitor short term changes, the long term behaviour can only be retrieved by careful tracing of one experiment database to the other, incorporating good knowledge of the degradation of radiometers operating in space. Fortunately several time series of TSI exist, made from different spacebased platforms by different radiometers. This allows the construction of a composite time series having improved long term precision, thus yielding an unbiased estimate of TSI variability during the past 18 years. In the following a critical review of TSI measurements is presented and some new corrections for the early periods of the ERB experiment on NIMBUS-7 introduced. A composite TSI is then constructed by combining overlapping time series. Comparing this composite with empirical models deduced from proxies for TSI variability sources permits an independent 'adjustment' of the extrapolated degradation behaviour of the ERB experiment. We use our newly constructed composite time series to compare the behaviour of the TSI during the last two solar cycles which in turn improves our understanding of this type of modulation.

2. Review of Total Solar Irradiance Monitoring Programmes

The TSI measurements from satellites discussed here have been performed by the following experiments (ordered chronologically) and are shown (already corrected, as discussed below) in Fig. 1:

- Hickey-Frieden radiometer (HF) of the Earth Radiation Budget (ERB) experiment on the NIMBUS-7 satellite from November 16, 1978 until January 24, 1993 (Hoyt *et al.*, 1992 and references therein). The measurements are performed during the passage of the Sun through the angle of view at the southern terminator of the satellite and last for a few minutes. Only daily values with more than 5 readings (orbits with measurements) per day are included. Thus no interpolated values, as listed in the published time series are used. It is important to note that for the periods of the '3-days-on–1-day-off' operation, the ERB experiment yields interrupted lines in Fig. 1. Data prior to the end of 1980 have been adjusted downward corresponding to a slip in the NIMBUS7 orientation relative to the sun. The need for this correction is explained below together with the correction for degradation. Moreover, the data after October 1, 1989 have been decreased by 0.31 Wm^{-2} and after May 8, 1990 by another 0.37 Wm^{-2}. The need for these latter adjustments are indicated from comparison with ERBE data (Lee *et al.*, 1995) and models deduced from photospheric observations (Chapman *et al.*, 1996).
- ACRIM I (Active Cavity Radiometer for Irradiance Monitoring) on the Solar Maximum Mission Satellite (SMM) from February 14, 1980 until June 1, 1989 (Willson & Hudson, 1991 and references therein). Only those data are taken which have a standard deviation of < 0.2 Wm^{-2}. Moreover, a correction has been added for unamended degradation during 1980 as described below.
- Solar Monitor of the Earth Radiation Budget Satellite (ERBS) which is similar to the radiometer ACRIM (Lee *et al.*, 1987) since October 25, 1984 with a 4 months gap in 1993 due to battery problems of the satellite and consequent switch-off of the experiment (Lee *et al.*, 1995). As for HF on NIMBUS7 the

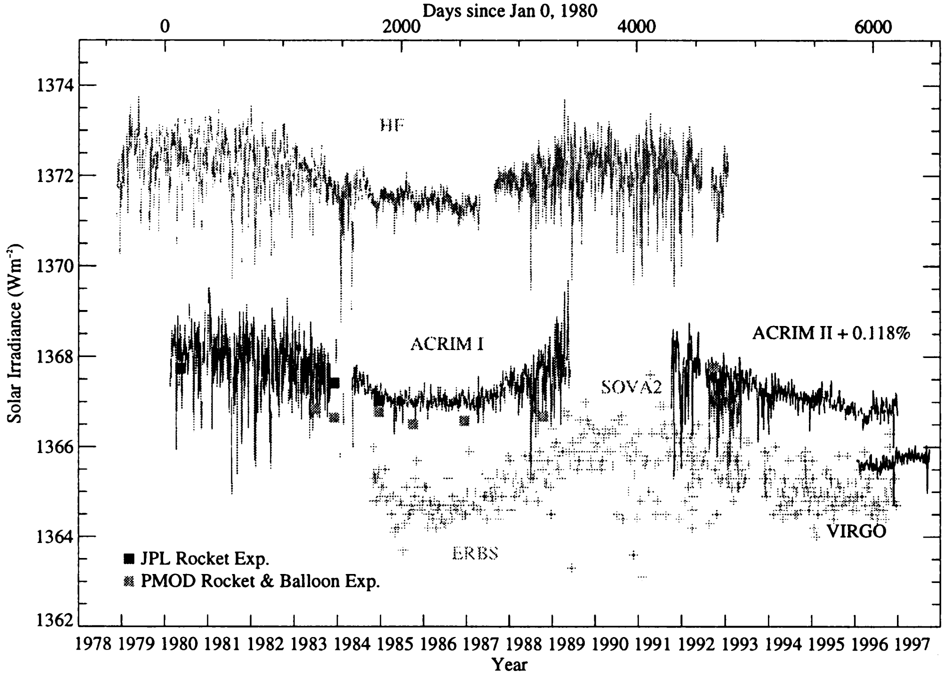

Figure 1. Time series of daily values of total solar irradiance in Wm^{-2} as observed by HF/ERB on NIMBUS7, ACRIM I & II on SMM and UARS, the solar monitor on ERBS, SOVA2 on EURECA and VIRGO on SOHO. For corrections applied to the original time series see text. The results of the rocket and balloon experiments of JPL and PMOD/WRC are also plotted for comparison.

measurements are performed during the drift of the Sun through the angle of view of the instrument, but only once in two weeks. No corrections are applied.

- ACRIM II on the Upper Atmospheric Research Satellite (UARS) since October 1991 (Willson, 1994). As for ACRIM I only those data are taken which have a standard deviation < 0.2 Wm^{-2}. No corrections are applied.
- PMO6 of SOVA (Crommelynck *et al.*, 1993) on the European Retrievable Carrier (EURECA) from August 11, 1992 until May 14, 1993 (Romero *et al.*, 1994)
- DIARAD and PMO6-V of VIRGO (Variability of solar IRradiance and Gravity Oscillations, Fröhlich *et al.*, 1995, 1997a) on SOHO (SOlar and Heliospheric Observatory) since January 18, 1996. The VIRGO values used here are composed of the PMO6-VA values 'adjusted' to the long-term behaviour of the DIARAD-L as described in Fröhlich *et al.*(1997b).

For comparison, Fig. 1 also includes the rocket-based irradiance measurements made by JPL and the rocket and balloon-borne measurements made by PMOD/WRC; these experiments were used in 1986 to provide additional evidence that the

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downward trend of solar irradiance during the declining phase of the cycle 21 was real and not of instrumental origin (Willson *et al.*, 1986).

The differences among the absolute values of the various spacebased datasets in Fig. 1 are due to differences in their absolute calibrations which are accurate to 'only' about $\pm 0.2\%$ in absolute terms. The repeatability of the daily measurements within each dataset is generally much better than 0.01% per year. The HF time series is essentially uninterrupted and can be used (with adjustments noted above and described below) as an overlapping reference for over 14 years. It cannot be proven, however, that the sensitivity of HF has no long term trend or that the changes in operational procedures have not influenced the absolute values more than that accounted for here (see also comments and corrections by Lee *et al.*, 1995 and Chapman *et al.*, 1996). Moreover, sensitivity changes early in the NIMBUS7 mission have never been assessed. Similarily, the ERBE data are uninterrupted, starting 6 years after NIMBUS7 and continuing still. The low duty cycle of the ERBS measurements (once every 2 weeks) hampers their usefulness as a reference data set; as a cross check they are, however, valuable.

To utilize the early HF/ERB data (before 1982), corrections for degradation of this radiometer have to be made. Before proceeding, however, we have must address the issue of early degradation of ACRIM I first raised by Foukal & Lean (1988) and extensively discussed by Willson & Hudson (1991). The issue was that during 1980 the ACRIM I data decreased more rapidly than did proxy variability models which could be interpreted as an uncompensated degradation. Willson & Hudson (1991) justified their determination of the ACRIM I data by the fact that they were based on measurements with two back-up radiometers, and that the result was also in agreement with recently evaluated HF data. However, they overlooked the fact that the degradation as measured after the repair in 1984 happened effectively in 1980. Since the exposure time during the spin mode phase was about hundred times less than during normal operation, and equivalent to only about 15 days, no significant degradation happened during the spin mode phase of more than 3 years. This factor corresponds to the ratio of available data points during spin mode compared to normal operation as stated in Willson & Hudson (1991). Thus, from Fig. 3 of Willson & Hudson (1991) the degradation at the end of the normal operation in 1980 is about 300 ppm, corresponding to the value measured in 1984. If we account for an early degradation (before day 62) of about 40 ppm, the total amounts to 340 ppm compared with 180 ppm used by Willson & Hudson (1991). Two corrections are needed to account for this: the data have to be reduced by $340 - 180 = 160$ ppm to refer them to the 1984 value and the downward trend has to be corrected by $340 - 180 = 160$ ppm over the period of normal operation in 1980. Thus, the '300-ppm excess' can be compensated for by taking the full degradation into account and the corrected irradiance in Fig.2 of Willson & Hudson (1991) fits the proxy model as well as it does later on.

With the corrected ACRIM I the HF degradation can now be assessed. The original analysis of the HF could not correct for this because of lack of information from e.g. a backup instrument. Thus, any correction has to be based on assumptions about the instrument performance. The HF has the same geometry of the cavity as does the PMO6 type instruments (inverted 60° cone) and uses the same specular black paint; so these radiometers may give guidelines. The analysis of the PMO6V radiometers within VIRGO on SOHO has shown that the overall degradation can be modelled by an exponential function with a time constant $\tau \approx 280$ days exposure time (Anklin *et al.*, 1997). Moreover, these radiometers show at the very beginning of exposure to the sun an increase in sensitivity which is very fast and can be modelled with an exponential function with $\tau = 4 \ldots 10$ days exposure time. This effect is not readily understood, but observed in both PMO6V radiometers consistently in amplitude and τ with exposure-to-mission times differing by a factor of ≈ 50. The degradation and initial increase are evident in Fig. 2b. Fig. 2a shows the correction for the slip at the end of 1980 together with a comparison to the corrected ACRIM I after the shift has been removed. The lower 81-day running mean of the ACRIM I comparison is prior to correcting HF for degradation; the curve above is after. The exposure-to-mission time is about 1:25 for the HF during the phase of the 3 days operation out of 4. The time constant of the increase is about $\tau_{incr} = 70$ mission days and similar to that observed by the PMO6V, the amplitude (145 ppm) is, however, much higher. The HF degradation corresponds to a time constant of $\tau_{degrad} = 385$ mission days and an amplitude of 510 ppm, which is also larger than observed by PMO6V. This may be due to the different environment in a Earth orbit relative to the one at SOHO orbiting around the Langrange point $L1$.

The time series of the two ACRIM instruments without adjustment of their respective irradiance scales demonstrate the difficulty in bridging gaps in data if no other overlapping irradiance experiments are available. The ACRIM I and ACRIM II absolute scales differ by more than 0.1% as shown below, which is larger than the peak-to-peak modulation amplitude of the 11-year cycle. In relation to the state-of-the-art of room temperature radiometry this is a very good result, but quite insufficent for the long-term monitoring of TSI variability. Fortunately the time-series of NIMBUS7 (corrected for degradation) and ERBE both overlap the ACRIM I and II and can be used for intercomparison. The intercomparisons are performed for each pair of TSI observations for the days when both time series have valid data. For ACRIM I only the data after the repair in 1984 are used in this comparison as the earlier data need some correction, as described above, and the spin mode data are less reliable and should not be used. The calculations, as first presented in Fröhlich (1997), have been refined by minimizing $\chi^2 = \sum((y_i - \alpha x_i)/\sigma_i)^2$ with y_i being the mean ratios of ACRIM I to HF and ERBS and x_i the corresponding ones of ACRIM II, σ_i is the geometrical mean of the standard deviations of the means to ACRIM I and II mean respectively and α is the scaling factor to refer ACRIM II to ACRIM I. The results of the comparisons are shown in Fig. 3 and listed in Table 1. The averages used for the determination of α are indicated as horizontal lines and the periods are listed in Table 1. The correction factor for ACRIM II amounts to $\alpha = 1.001180 \pm 0.000153$. The unweighted fit gives a slightly higher value of 1.001222 ± 0.000165 which means that the ERBE data pull the ratio up. The indicated uncertainty is a formal 1σ error and the change relative to the formerly reported value of 1.001245 is mainly due to the fact that the averages are weighted by their standard deviations which gives less weight to the ERBE data and that the period for the fit has been reduced to the period after the repair in 1984. This is justified in order to avoid influence of the early corrections. The individual values of the comparisons are the listed in Table 1. For the corrected ACRIM II ratios a regression line is calculated primarily to check for possible trends; their slopes are not significantly different from zero; the trend against VIRGO is due to low values of ACRIM II in January to March 1996 which are believed to be less reliable because of adverse operational conditions as indicated by the many gaps in the ACRIM II data.

This cross calibration exercise demonstrates the possibility of increasing the relative precision of the TSI temporal data. But it shows also the limitations of this

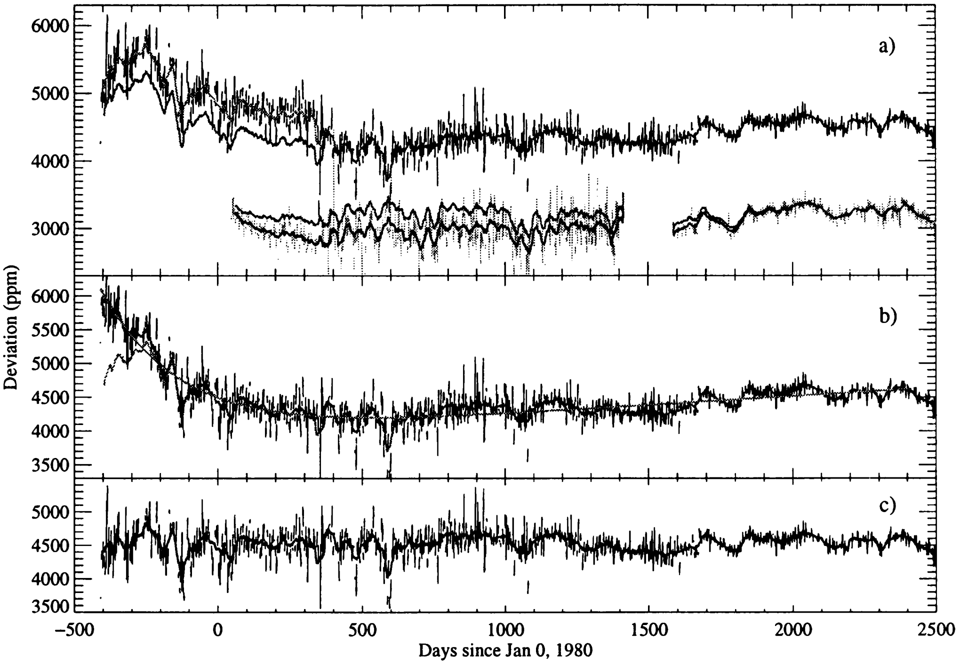

Figure 2. Determination of the degradation and initial increase of the HF radiometer sensitivity and the correction for the slip at the end of 1980. The thin lines are running means through daily values, the thick ones are 81-day running means. *a)* The upper curve corresponds to the comparison with the model and the lower two curves to ACRIM I, before and after the correction for degradation. The correction around day 350 is indicated by the downward shifted line in the HF data. Both comparison show a steady increase of about 0.3 ppm/day which must be due to the performance of HF. *b)* Comparison to the model with the fitted exponential and linear increase for the degradation and the correction for the early increase in sensitivity. *c)* Comparison with the model after all corrections.

approach: Since one time series covers the maxima of cycle 21 and 22 and the minimum in between (HF/NIMBUS7), and another covers both minima and the maximum in between (ERBE), the comparability of both cycles in terms of their absolute level and amplitude may still be questionable. The ratios in Fig. 3 illustrate another problem: the different instruments (e.g. ACRIM I and HF) can record the short- and medium-term variations quite differently. Part of these differences may be related to the way the radiometers are operated: continuous measurements during the sunlit part of an orbit as for ACRIM I and SOVA, or only short periods with the sun sweeping through the field of view as for NIMBUS7 and ERBE, or an intermediate way as for UARS where a solar pointing mechanism allows for measurements during an extended period of time, but still not during the full sunlit part of an orbit. The different standard deviations of the ratios as listed in Table 1 may reflect such effects. The smaller standard deviations of the ACRIM II comparison with VIRGO and SOVA are due to

TABLE 1. Comparison of the different TSI results.

Instruments	Mean Ratio	Std.Dev.	Number of Data Points	Period
ACRIM I/HF	0.996790	0.000142	1622	18-May-84 – 1-Jun-96
ACRIM I/ERBE	1.001596	0.000260	132	25-Oct-84 – 24-May-89
ACRIM I/PMOD	0.999574	0.000319		
ACRIM II_{corr}/HF	0.996861	0.000240	360	5-Oct-91 – 24-Jan-93
ACRIM II_{corr}/ERBE	1.001441	0.000286	215	9-Oct-91 – 18-Dec-96
ACRIM II_{corr}/SOVA2	1.000400	0.000088	269	11-Aug-93 – 15-May-94
ACRIM II_{corr}/VIRGO	1.000882	0.000115	282	29-Jan-96 – 30-Dec-96

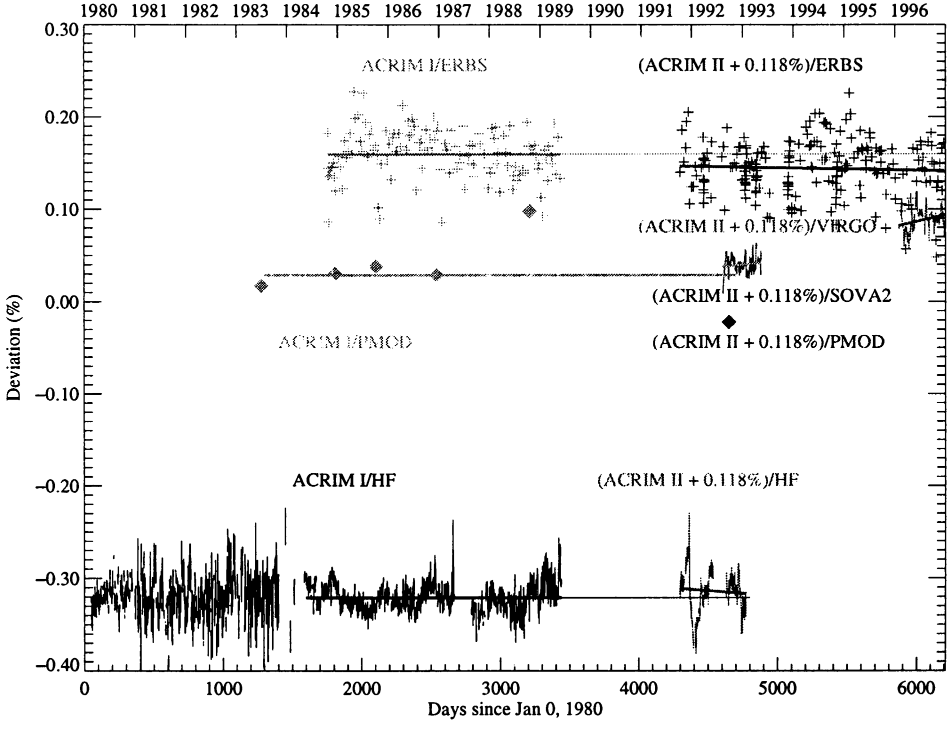

Figure 3. Comparison of ratios of different TSI time series for the determination of the scaling factor for ACRIM II in order to refer it to ACRIM I.

the fact that these results are the only comparison with similar sampling strategies. This result emphasizes how important it is to define the 'mean' value to which the observation corresponds. The comparisons with the results from the rocket and balloon experiments show the difficulties of using single point measurements to deduce longterm variability; but the reproducibility is still better than 0.1% and, perhaps fortuitously, the SOVA2 results are very close to those. Significant differences exist between the amplitudes of medium term variations evident in the 6 months modulation of TSI during the solar minimum between cycle 21 and 22 where HF shows twice the amplitude of ACRIM I (Fig. 1 and 3). Within VIRGO a similar difference in behaviour has been observed between the readings of PMO6-V and DIARAD (Fröhlich *et al.*, 1997b). As the sensitivity of all radiometers to sunspot blocking is very similar, the observed difference may be explained by a difference in their spectral sensitivity to UV radiation which is much stronger relative to the total during enhancement of TSI, as observed during minimum. Definitive conclusion about this effect requires a thorough investigation of the spectral sensitivity of the different radiometers which is under way.

TABLE 2. Time series used for the composite TSI and correction factors F_1 at the beginning of the period (relative to the time series before) and F_2 at the end (relative to the time series after) determined for a period of overlap of 80 days. The data are scaled with F_{aver} listed in the last column.

Period	Instrument	F_1	F_2	F_{aver}
16-Nov-80 – 6-Mar-80	HF		0.996783	0.996783
7-Mar-80 – 22-Nov-80	ACRIM I			1.000000
23-Nov-80 – 3-May-84	HF	0.996869	0.996912	0.996890
4-May-84 – 2-Jun-89	ACRIM I			1.000000
3-Jun-89 – 4-Oct-91	HF	0.996924	0.997069	0.996996
5-Oct-91 – 17-Jan-96	ACRIM II_{corr}			1.000000
18-Jan-96 – 31-Dec-96	VIRGO	1.000923		1.000923

3. Construction of a Homogenious Composite TSI Time Series

For constructing a composite TSI time series we need a reference irradiance scale. As the absolute accuracy is still insufficient compared to the solar variability, any choice of a reference instrument is acceptable. Until the advent of SOHO, ACRIM was the only experiment which secured a reliable determination of the degradation of the operational radiometers by virtue of its redundant receivers. Thus, ACRIM I and the corrected ACRIM II values are used as an initial reference scale for the composite time series. Before the repair of SMM in spring 1984 and in the gap between ACRIM I and II values from the HF instrument are used. After the start of the observations by VIRGO (18 January 1996) those data are used. VIRGO's continuous sampling yields reliable time series and improved determination of the degradation because two completely different radiometers PMO6V and DIARAD and their backups are used. The analysis of the degradation by Anklin *et al.*(1997) emphasizes the difficulty in attaining levels of 10 ppm repeatibility. Table 2 summarizes the time series used

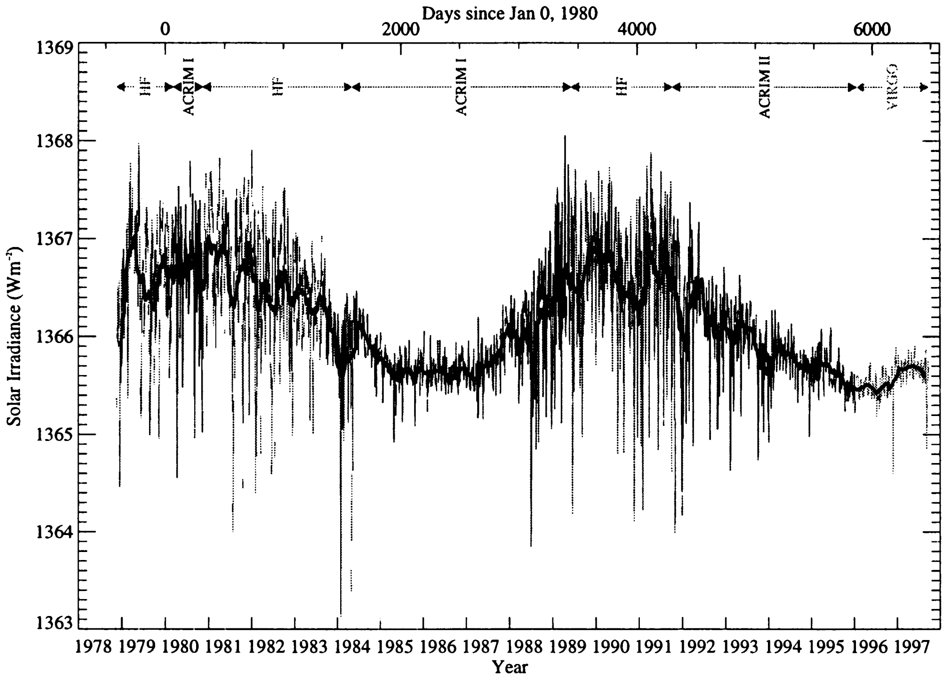

Figure 4. Composite total solar irradiance for 1978-1997. Its absolute value is referred to SARR. Note the '3-day-on-1-day-off' periods of the HF operation which is seen as 'dashed line' e.g. before 1984.

and the corresponding correction factors for the different periods. The four values ACRIM I/HF show an overall upward drift of about 290 ppm indicating a possible degradation of HF not yet compensated. This underscores the care that is needed for the interpretation of individual time series, and the importance of redundant instruments on the same platform to assess the degradation of the operational data by comparison with measurements by less often exposed radiometers. The ratios at the end of ACRIM I and at the beginning of ACRIM II are very close, a result of the adjustment of ACRIM II as described in the previous section. The difference of 145 ppm is due to the fact that only 80 days at the end of ACRIM I and at the beginning of ACRIM II are used to determine the ratios. After the adjustment of the HF and VIRGO values to fill the gaps within and between the ACRIMs the whole time series is adjusted to the Space Absolute Radiometer Reference (SARR) defined by Crommelynck *et al.*(1995) by applying the factor for ACRIM II_{corr} of 0.998996. This does not improve the absolute accuracy, but allows comparison of repeated space experiments with the same radiometer.

The composite TSI is shown in Fig. 4. Willson (1997) suggested that the 1996/97 minimum is about 0.5 Wm^{-2} higher than the one in 1986/87; our composite would rather indicate a decrease of about 0.13 Wm^{-2}. The difference between these two

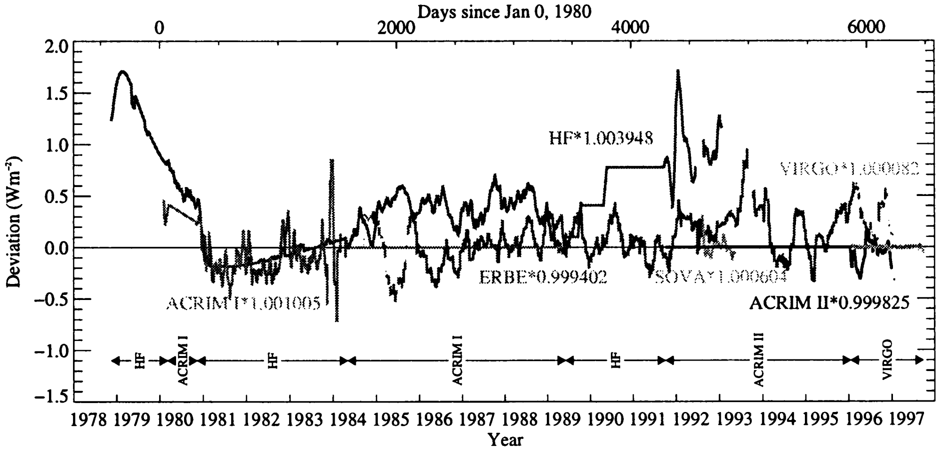

Figure 5. Comparison of the original, uncorrected time series with the composite TSI. The factors listed are the ratios to scale the original data to the composite referred to SARR.

estimates of decadal TSI variability corresponds almost exactly to the sum of the two corrections applied to the HF data in October 1989 and May 1990 of 0.68 Wm^{-2} which were not taken into account by Willson (1997). The significat uncertainties in the knowledge of the degradation indicate that our decrease of 0.13 Wm^{-2} is probably not significant (see Fig. 4). As to the differences between the behaviour of the two cycles the following can be noted: Although no significant activitiy of the new cycle has been observed before mid 1997 it seems that – at least for the irradiance – the minimum after cycle 22 is shorter than the former one. A slight increase after the sunspot in November 1996 – one of the old cycle – is observed; the first important sunspot, however, of the new cycle arrived only in September 1997. Comparison of the maxima is more difficult as the variance is greater. In order to illustrate the effect of the corrections made to the different time series Fig. 5 shows the comparison of the uncorrected values with the composite TSI record.

4. Comparison of the Composite with a Proxy Model

Models have been developed to reconstruct solar irradiance from parameterizations of independently measured proxies of magnetic variability sources, specifically dark sunspots and the bright faculae and network. White light images made most recently from the US Airforce SOON sites and archived by the NOAA World Data Center (WDC) provide information about the areas and locations of dark sunspots from which to quantitatively determine the net irradiance reduction on a daily basis. Summing the irradiance deficit due to all sunspots present on the disk yields a parameterization variously termed the bolometric sunspot blocking function, P_S, (Foukal, 1981) or the photometric sunspot index, PSI, (Hudson *et al.*, 1982; Chapman and Meyer, 1986). We calculate a time series of daily sunspot blocking following Foukal

(1981) and Fröhlich *et al.*(1994), incorporating results from recent studies of the dependence of sunspot residual intensity contrast on sunspot area, in the sense that larger sunspots are darker than smaller spots (Brandt *et al.*, 1994).

An analogous approach is in principle applicable for the estimation of facular brightening, also called the photometric facular index PFI. But uncertainties in observational determinations of the area, contrast and center-to-limb functions of faculae are much larger than for sunspots. In lieu of a reliable facular brightness specification directly from solar imagery, use is made of full disk measurements of solar emissions whose variations predominantly arise from magnetic sources associated with photospheric faculae. The index of Ca K core emission relative to the nearby continuum (Livingston *et al.*, 1988), an analogous Mg II core-to-wing ratio (de Toma *et al.*, 1997), and the He I (1083 nm) equivalent width (Harvey & Livingston, 1992) all vary in response to enhanced emission from chromospheric plages that overlay photospheric faculae, and from the surrounding chromospheric network. We have constructed a composite facular brightening time series using the NOAA Mg index obtained from Solar Backscatter Ultraviolet data from 1978 to 1992, the Solar Stellar Intercomparison Experiment Mg II index thereafter, and the He EW from 1976 to 1978. The composite is placed on the scale of the NOAA Mg index and extended by linear relationships determined from the data in the period of overlap. Although chromospheric proxies track bolometric brightness changes relatively well over solar cycle and active region time scales (Foukal and Lean, 1988), differences in center-to-limb variations and filling factors of the sources of variability in the chromospheric proxies limit their ability to track photospheric faculae brightness changes on shorter times scales of days to months.

We first obtain an empirical representation of TSI variability from multiple regression of our composite TSI time series with parameterizations of sunspot blocking, as calculated above, and the Mg index proxy of facular brightening. This two-component empirical model accounts for 80.0% of the variance in the composite TSI and its components are shown in Fig. 6a and for the sunspots in c. Recognizing that the chromospheric brightness sources may relate somewhat differently to photospheric facular brightness sources over shorter (rotational) versus longer (solar cycle) time scales, we separate the Mg II index proxy into a smoothly varying longer term component and a shorter term component associated with rotational modulation, as shown in Fig. 6b and c. Multiple linear regression of the sunspot darkening, slowly varying Mg II index and short term Mg II index facular proxies yields an empirical model that now accounts for 82.9% of the TSI variability, and, if the shortterm variability and the TSI are smoothed, for 88.0%. Besides the fact that the three-component model yields quite different factors for the slow (130.2) and the fast (78.2) Mg II index, the factor for the PSI is much closer to one (0.9913) than in the two-component model, where it is 1.082, indicating that part of the faculae compensate the sunspots. As Fig. 6d indicates, the differences of the composite and the empirical model show only a small long term trend of the same order as the downward trend seen in the composite. This could be taken as confirmation that indeed the trend is due to unrecognized degradation. Although some non neglectible differences exist during high activity, the overall agreement is quite good, implying that this representation captures the predominant solar cycle variability sources.

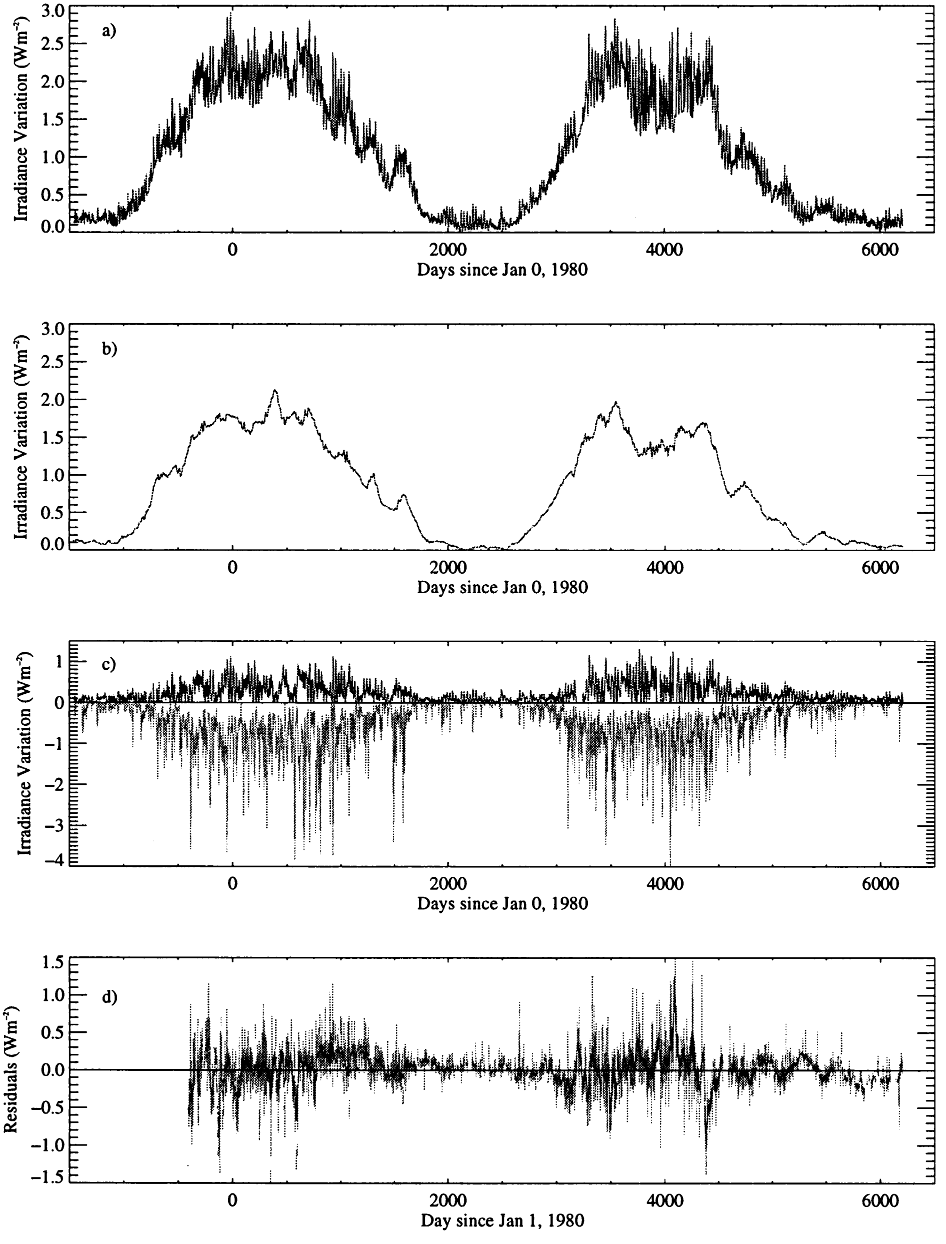

Figure 6. *a)* Facular brightening from Mg index, *b)* Longterm enhancement of the irradiance, *c)* Shortterm variability due to faculae and sunspots, and *d)* the residuals between the model and the composite *TSI* without and with smoothing the short term variation over 21 days. The parameters are plotted as a result of the multiple regression in Wm^{-2}: two-component model for a), and three-component for b)–d).

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5. Conclusions

ACRIM II can be reliably traced back to ACRIM I only with both the HF and ERBE data sets and the recognition of instrumental changes in HF. This underlines the importance for having even more than two experiments simultaneously in space to measure TSI. With only one radiometer even the medium term variability would be questionable. The results from the comparison of these four data sets – ACRIM I, II, HF and ERBE – permit the construction of a reliable composite TSI. As demonstrated by the god agreement with a proxy model, this composite promises to be very valuable for the study of solar irradiance variability for time scales up to the solar cycle modulation. The assessment of the intercycle variability, however, is still hampered by the fact that undetected long term trends of the radiometers can not be conclusively excluded. However, some conclusion about the longterm variation of the Sun may still be drawn from the understanding of the difference between the behaviour of the two cycles which is now well documented by the composite TSI.

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