Some Thoughts about the Reliability of Reconstructions of Total Solar Irradiance into the Past

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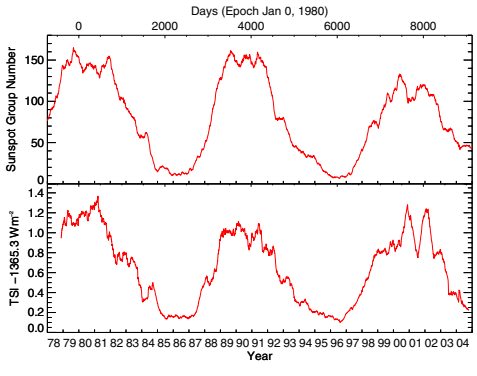

Figure 1: The upper panel shows the sunspot group number and the lower 243-day filtered TSI during the last 3 cycles. It is clear that the rather good resemblance for cycles 21 and 22 has been lost during cycle 23 which shows quit a different behaviour.

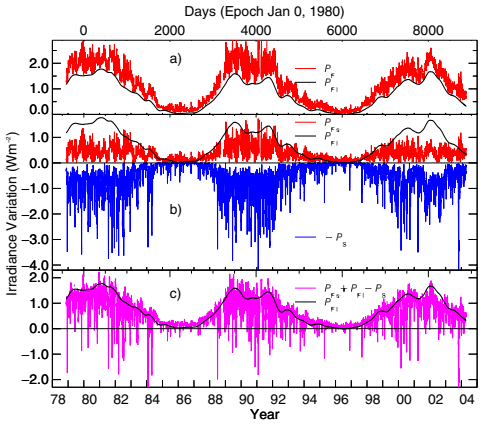

Figure 2: Models of total solar irradiance variability that combine the influences of sunspot darkening and facular brightening can account for a significant fraction of the observed variance in the total solar irradiance composite record. Shown in a) is the facular influence P_F together with P_{Fl} determined as the lower envelope of P_F. Shown in b) is P_{Fs}, P_{Fl} and $-P_S$, and in c) the net effect on total solar irradiance of the combined sunspot and facular changes (all calibrated by linear regression against the PMOD composite).

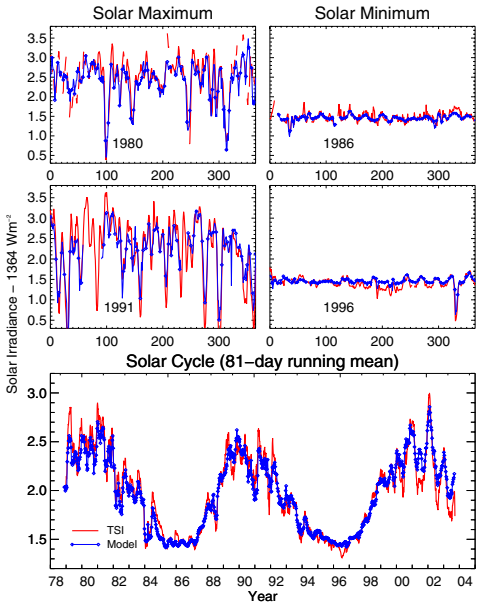

Figure 3: The empirical model from Figure 2 is compared with the composite irradiance record during solar rotation during high solar activity (upper left panels) and low solar activity (upper right panels). Compared in the bottom panel are the smoothed model and measurements during two solar cycles.

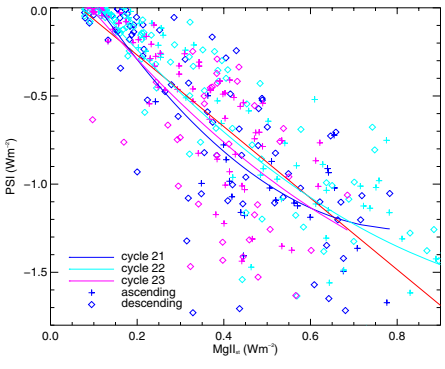

Figure 4: The correlation between P_{Fs} and $-P_S$ for both averaged over the 27-day rotational period. The correlation is much better than for daily values which indicate that sunspots and faculae are related only at the spatial and temporal level of active regions.

1 Introduction

Reconstructions of total solar irradiance (TSI) are based on proxies extending back in time. The translation from the proxies into TSI is calibrated against the existing data for the last 3 solar cycles. As the most recent one seems to have properties which differ from the two previous ones the basis for the reconstructions have become shaky. In the present study we use a proxy model which has proven to explain nearly 80% of the variance during the last 25 years of TSI.

2 Proxy model and Sunspot Group numbers

Information about the two primary sources of irradiance variability, sunspots and faculae (associated with both plages and active network), is available from a variety of solar observations which enable the quantitative modelling of irradiance variability independently of direct measurements. The daily facular brightening, P_F, and sunspot darkening, P_S (normally called photometric sunspot index, PSI) time series shown in the upper panel of Figure 2 since 1976 are two indices that are used widely for this purpose. The facular brightening index is a composite of directly measured flux ratios of emission from the center of Fraunhofer features, primarily the MgII h & k index, relative to emission in the line wings. It can be further separated into a short and long-term part as shown in Figure 2. White light solar images that record the locations and areas of sunspots provide the primary inputs for the sunspot darkening index.

Multiple regression of the 3-component model against TSI is used to 'calibrate' it and explains 78.6 % of the variance. This approach better accommodates possible differences in the short and long-term sources of irradiance variability. The fact that the coefficients determined with the three component model are notably different for the short and long-term facular proxy may indicate differences in the physical sources that produce the longer-term irradiance variations, presumably associated with bright network inside and outside the active regions. Direct observations from MDI/SOHO of the fractional disk areas of bright features and their contrast as a function of the magnetic field indicate that this difference may just be due to the fact that the MgII index depends on the specific contrast, C/B, of the network and faculae and not on C. This indicates also that the long-term changes are due to the network in and outside active regions, whereas the short-term is from what is normally called faculae.

The model results are now used to asses the reliability of using other proxies. As detailed information for sunspot areas and position are available from Greenwich back to 1882, PSI can be calculated for the whole series. Although facular are have been also recorded they have less reliability and an other approach to take facular area into account may be followed. As active regions contain both faculae and sunspots a correlation of both may help to estimate the former from PSI. The result is shown in Figure 4 and indeed the correlation is high and does not seem to depend on which cycle is used. So this result can be used to determine facular influence from PSI.

In a next step the correlation between the combined short-term effect from faculae and sunspot as $P_{Fs} + P_S$ and the sunspot group number is looked at. The result is shown in Figure 5 and looks quit promising.

The most problematic correlation is between the long-term and the sunspot group number as already clear from Figure 1. From the results as shown in Figure 6 the correlation is quite good for values below about 1.2 Wm‘−2 of the long-term influence besides the descending part of the present cycle, which deviates substantially. At higher values the deviations become substantially larger, especially for cycle 23. The going in circles is also interesting which is present for all cycles but most pronounced for 23. The Figures 7 and show that errors up to 40% may occur, even if a quadratic fit is used. Moreover, there seem to be also a problem around zero.

3 Conclusions

The short-term variability can be modelled from the PSI alone and also with the Sunspot Group Number. For the long-term, we seem to be in trouble and all the long-term reconstructions based on sunspot numbers seem to be questionable, as the good correlation between them and TSI during cycles 21 and 22 was unique and is no longer present for cycle 23.

Further studies are needed to either improve the long-term representativeness of the a newly defined sunspot number or to search for other proxies. Maybe ^{10}Be could be a candidate, and/or combined with some magnetic indices.

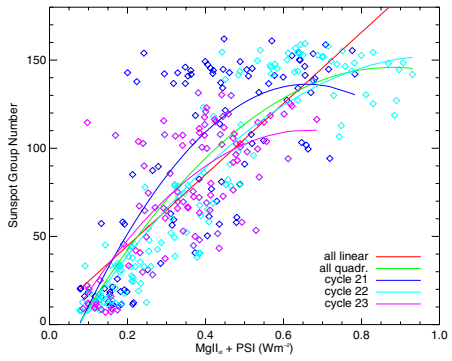

Figure 5: Correlation between Sunspot Group Number and the combined influence of faculae and sunspots as $P_{Fs} + P_S$.

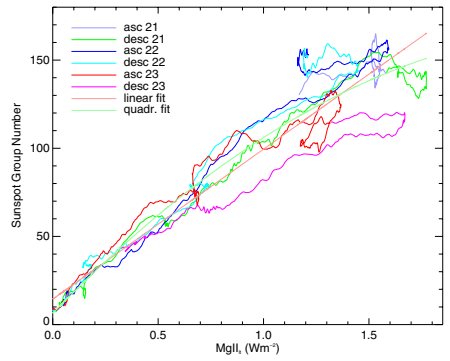

Figure 6: Correlation between Sunspot Group Number and P_{Fl} for the the last 3 cycles. The correlation observed during cycles 21 and 22 fails during cycle 23, especially at maximum and during the declining phase of the cycle.

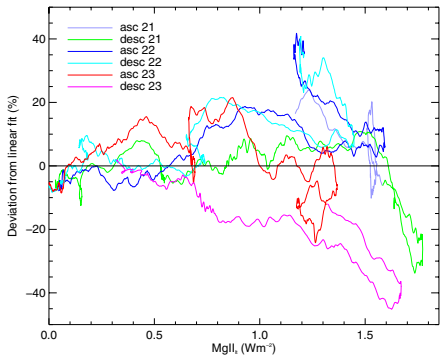

Figure 7: Correlation between Sunspot Group Number and P_{Fl} for the the last 3 cycles plotted as deviation from the linear fit to all data.

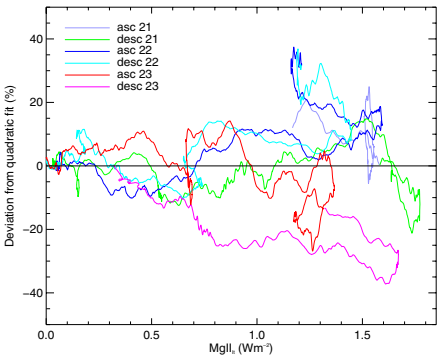

Figure 8: Correlation between Sunspot Group Number and P_{Fl} for the the last 3 cycles plotted as deviation from the quadratic fit to all data.