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Search for a Robust Index of Long-Term Facular Variations

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Abstract. We consider the five potential facular proxies with records covering more than 40 years. By suitably weighting and combining them we create a new proxy. In comparison with sunspot relative number the combined proxy exhibits enhanced values during solar cycles 16 and 17. This suggests that the Sun may have been brighter during those cycles than earlier models, which used sunspot numbers as the facular proxy, indicate.

1. Introduction

Zürich relative sunspot number, R_Z, is often used to track facular brightening on time-scales of decades to centuries (Foukal & Lean 1990; Lean et al. 1995) on the assumption that the relation between facular emission and sunspot number remains the same from one cycle to the next. In the following we compare relationships between indices of facular activity and R_Z and attempt to construct a better long-term proxy of facular emission than each individual proxy by combining them in a suitable manner. Note that we are only interested in changes of the cycle-to-cycle behavior (i.e., on time-scales longer than 11 years) and not in shorter-term variations.

2. Inter-cycle Variations of Facular Emission

We only consider indicators of solar activity that have been monitored for at least 40 years. The time-series we have considered are listed in Table 1.

Table 1. Facular proxies used and corresponding time-periods.

Zürich Sunspot Number	R_Z	1818 – present (daily values)
Sunspot Areas	A_s	1874 – present
10.7 cm radio flux	$A_{10.7}$	1947 – present
Ca II plage areas	A_p	1915 – 1984
White light facular areas	A_f	1906 – 1976

Since we search for possible departures from the R_Z record on time scales longer than a solar cycle, we consider only the ratio of the cycle-averaged value of A_x

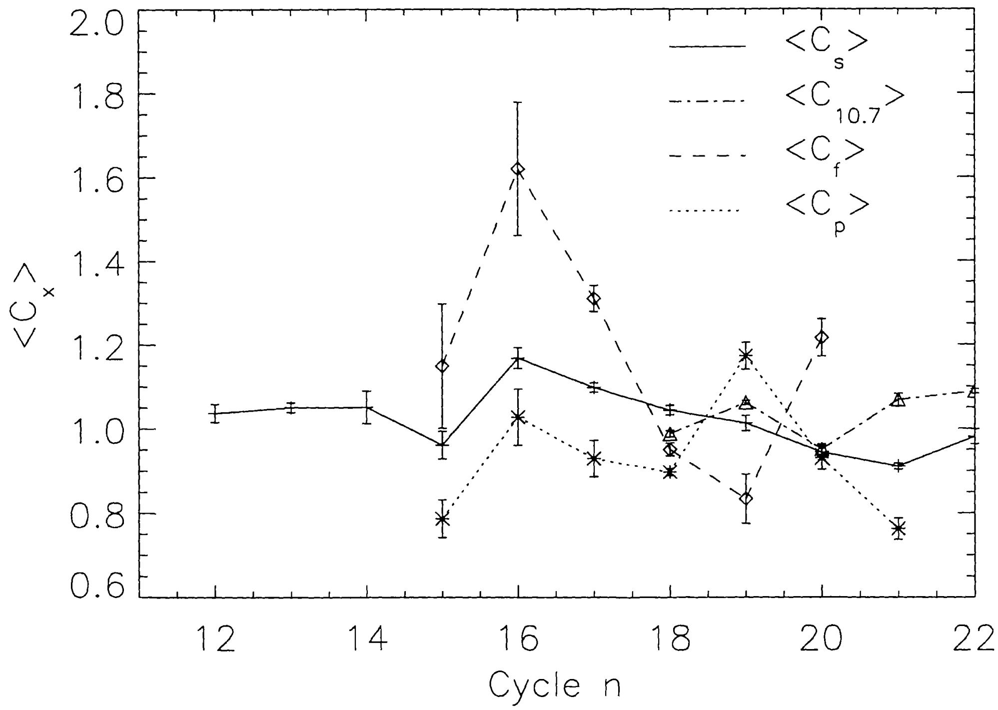

Figure 1. Inter-cycle variations of ratios of sunspot areas ($\langle C_s \rangle$, solid line), 10.7 cm radio flux measurements ($\langle C_{10.7} \rangle$, dash dotted), white light facular areas ($\langle C_f \rangle$, dashed) and Ca II K-line plage areas ($\langle C_p \rangle$, dotted) to sunspot number. The ratios are normalized and averaged as described in the text.

(where $x =$ *c, 10.7, p* or *f*) to the cycle-averaged value of R_Z. Alternatively, since A_f and A_p are not linearly related to R_Z, we also averaged over contributions from different parts of a cycle, i.e. contributions from times of low and high R_Z respectively. The resulting ratios $\langle C_x \rangle$, normalized to the mean of cycles 18 to 20, are presented in Fig. 1. Note that relative to R_Z all proxies show a distinct peak in cycle 16.

3. A Combined Proxy

In an attempt to obtain a more reliable and robust proxy of the long-term behavior of facular emission Q over the last 11 activity cycles, we combine together the four proxies by weighting them according to their estimated reliabilities, a_x. A higher value of a_x means a more reliable proxy. Hence we calculate $Q(n)$ according to:

$$Q(n) = \frac{\sum_x a_x \cdot \langle C_x(n) \rangle}{\sum_x a_x}, \qquad x = f, s, p, 10.7. \tag{1}$$

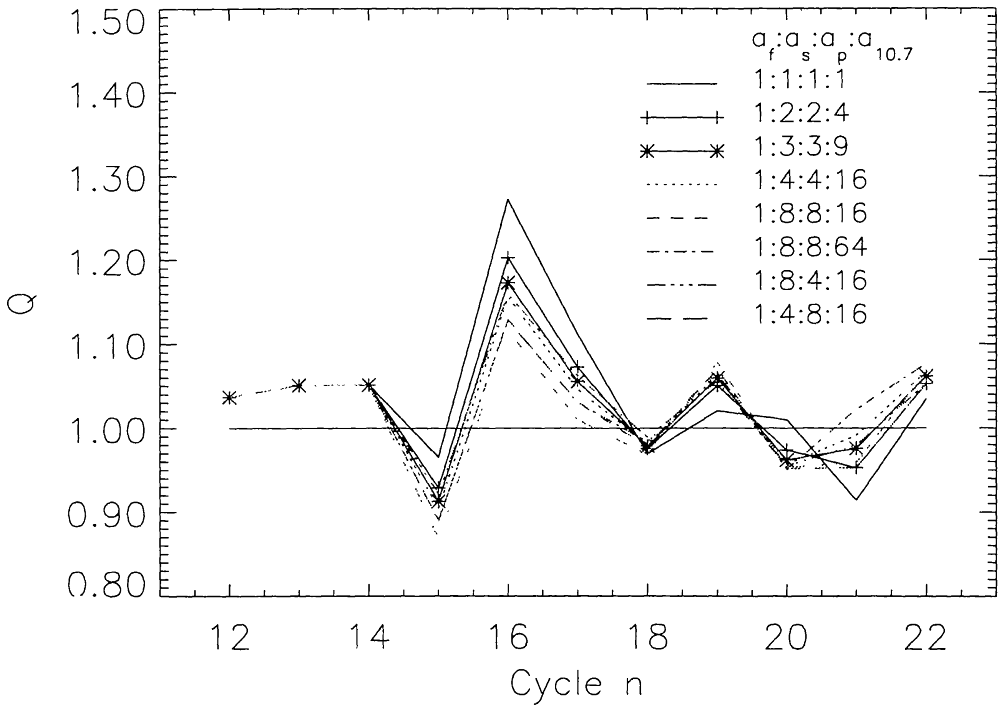

Figure 2. Inter-cycle variations of the ratio, Q, of the combined proxy relative to R_Z. The corresponding weights are given in the order of $a_f : a_s : a_p : a_{10.7}$.

Assigning a weight to each proxy is relatively subjective. We have therefore tested how strongly Q depends on the choice of weights, subject to the following general restrictions.

The time-series of white-light faculae is considered to be the least reliable and is consequently given the smallest weight: we always set $a_f = 1$. Full-disk measurements of 10.7 cm radio flux, on the other hand, are given the largest weight ($a_{10.7}$). Weights to sunspot and plage area measurements (a_s and a_p, respectively) are placed somewhere between these two extremes. A selection of the tested weights, together with the corresponding $Q(n)$ curves are plotted in Fig. 2. Note that the general shape of the combined curve is relatively insensitive to the exact choice of weights at least within the considered restrictions.

In view of the merits and demerits of the various data sets we have chosen $a_f : a_s : a_p : a_{10.7} = 1 : 3 : 3 : 9$ for our final proxy. This choice results in a Q curve that lies well inside the extremes we have found. The long-term variation of this proxy relative to R_Z is plotted in Fig. 3. The error bars take into account uncertainties introduced by considering different parts of an activity cycle, i.e. times of low/high R_Z values, separately and the uncertainty in the weights a_x.

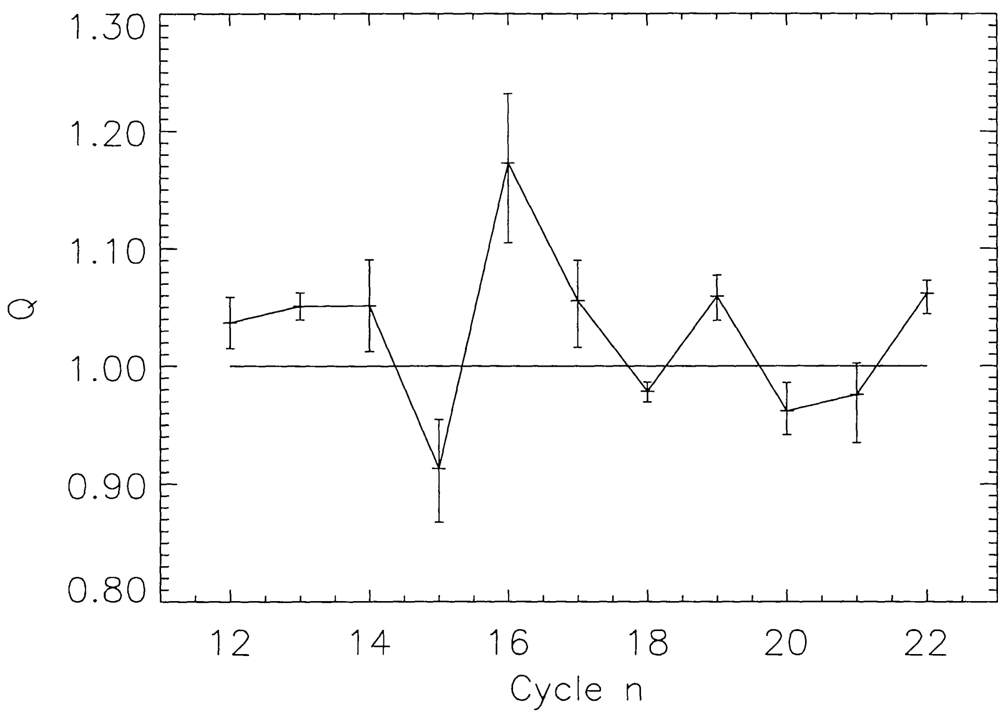

Figure 3. Ratio, Q, of the final combined proxy of long-term facular emission to R_Z over the last 11 activity cycles. The presented curve results from a combination of all four proxies using the weights $a_f : a_s : a_p : a_{10.7} = 1 : 3 : 3 : 9$. It shows a prominent increase of facular emission during cycle 16.

4. Conclusions

Current models of past solar irradiance on time-scales longer than the solar cycle generally use R_Z as a proxy of facular emission (Foukal & Lean 1990; Zhang et al. 1994; Lean et al. 1995). Our analysis, however, indicates that R_Z may not be the most appropriate parameter to track facular variations on time scales longer than the solar cycle. Other possible proxies of facular brightening show significant inter-cycle variations relative to R_Z. In particular, they all exhibit a prominent increase of facular emission during cycle 16 and to a lesser extent cycle 17. Consequently, the above models tend to underestimate the contribution of facular emission to total irradiance during the 1920s and 1930s.

In this context it is interesting that R_Z lags the global land/sea surface temperature (as provided by the International Panel on Climate Change IPCC), leading to a problem of causality between Earth's climate change and solar activity. Increased facular emission during cycle 16 (and 17) may conceivably contribute to resolving this dilemma. Detailed reconstructions of solar brightness over the past century, taking inter-cycle variations into account, are needed to answer this question in a satisfactory manner, however. Such reconstructions are currently being carried out.

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References

Foukal P., & Lean J., 1990, Science 247, 556

Lean J., Beer J., & Bradley R., 1995, Geophys. Res. Lett. 22, 3195

Zhang Q., Soon W. H., Baliunas S. L., Lockwood G. W., Skiff B. A., & Radick R. R., 1994, ApJ 427, L111

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