Solar Activity and the Sea-Surface Temperature Record - Evidence of a Long-Period Variation in Solar Total Irradiance?

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There have been many suggestions over the years of a connection between solar activity and the earth's climate on time scales long compared to the 11-year sunspot cycle. They have remained little more than suggestions largely because of the major uncertainties in the climate record itself, and the difficulty in trying to compile a global average from an assembly of measurements that are uneven in both quality and distribution. Different climate time series have in fact been used to draw conflicting conclusions about the existence, or even the sense, of a presumed response to solar activity, some suggesting a positive correlation, some a negative correlation, and some no correlation at all. The only excuse for making yet another such suggestion is that much effort has been devoted in recent years to compiling climate records for the past century or more that are internally consistent and believable, and that a decadal-scale record of solar total irradiance is emerging from spacecraft measurements, and can be used to set limits on the variation that is likely to have occurred on these time scales.

The work described here was originally inspired by the observation that the time series of globally averaged sea-surface temperatures over the past 120 years or so, as compiled by the British Meteorological Office group (Folland and Kates, 1984), bore a reasonable similarity to the long-term average sunspot number, which is an indicator of the secular variability of solar activity. The two time series are shown in Figure 1, where the sunspot number is shown as the 135-month running mean, and the SST variation is shown as the departure from an arbitrary average value.The simplest explanation of the similarity, if one accepts it as other than coincidental, is that the sun's luminosity may have been varying more or less in step with the level of solar activity, or in other words that there is a close coupling between the sun's magnetic condition and its radiative output on time scales longer than the 11-year cycle. Such an idea is not new, and in fact the time series shown in Figure 1 can be regarded as a modern extension of the proposal put forward by Eddy (1977) to explain the covariance between various global climate indicators and solar activity as revealed by the C^{14} record over the past millenium.

Spacecraft measurements of the sun's total irradiance have only become available since about 1979, and they have indeed shown a long-term variation that appears to be positively linked to the sunspot number. Whether the variation is simply related to the 11-year cycle, or whether it contains longer-period components, remains unresolved, but Fröhlich (1987) has pointed out that earlier individual measurements from balloons, rockets, and spacecraft can be taken as indicating the existence of a longer term variation. Figure 2 is based on the data compiled by Fröhlich (1987), and shows measurements made between 1967 and 1985 with instruments similar to those used in the more recent spacecraft measurements. While the earlier measurements show a considerable scatter, only two of them are as high as the later sequence, and there is an average difference of about 4 W m^{-2} between the values obtained around the peak of solar cycle 20 in 1969 and those obtained near the peak of solar cycle 21 in 1980. Fröhlich (1987) suggested that this might be evidence for a 22-year cycle in irradiance, but it might equally well be taken as evidence for the kind of long-term relationship between solar activity and solar irradiance inferred above.

Making the very simple assumption that the long-term component of the irradiance is linearly proportional to the envelope of the sunspot number time series shown in Figure 3, we can use the difference of 4 W m^{-2} between the maxima of cycles 20 and 21 to calibrate the relationship. The empirical relation derived in this way is

$$S\ (\mathrm{W\ m^{-2}}) = 1353.6 + .089\ N \qquad (1)$$

where S is the total irradiance and N is the sunspot number envelope. Figure 4 shows a scatter plot of the annual values of globally averaged SST and the sunspot-number envelope. The correlation coefficient is 0.71, maximizing at zero lag, and a calculation of the number of degrees of freedom taking autocorrelation into account indicates that the correlation is significant at a level between 95% and 99%.

structure of the ocean developed by Hoffert et al. (1980), and the resultant variation of sea-surface temperature has been computed. The upper mixed layer of the ocean is assumed to have a uniform temperature, determined by solar radiation from above and by loss of heat by radiation to space, by downward diffusion into the deep ocean, and by upward advection of cold water forming the global thermohaline circulation. The calculation was started during the Maunder Minimum in 1660, when the temperature was assumed to be at its equilibrium value for a sunspot-envelope number of 5, and ended in 1990, where the sunspot envelope was estimated on the basis of the progress of solar cycle 22 through 1989. The time step used was 6 months, and the calculations were carried to the bottom of the 4000-meter deep ocean in steps of 100 m.

The result is shown in Figure 5, where the solid line shows the model output, and the smoothed measurements of globally averaged SST (C.K. Folland, private communication, 1987) have been superimposed. The SST values are shown as departures from an arbitrary mean, and have been positioned so as to overlay the model curve. The two scales, however, have the same dimensions.

Until we know more about how the sun's total irradiance varies on long time scales, the picture presented here must remain speculative. Taken together with the evidence presented earlier by Eddy (1977), however, the possibility remains that solar irradiance variations keyed to the long-term changes in solar activity have played a major role in influencing terrestrial climate over the past millennium.

References

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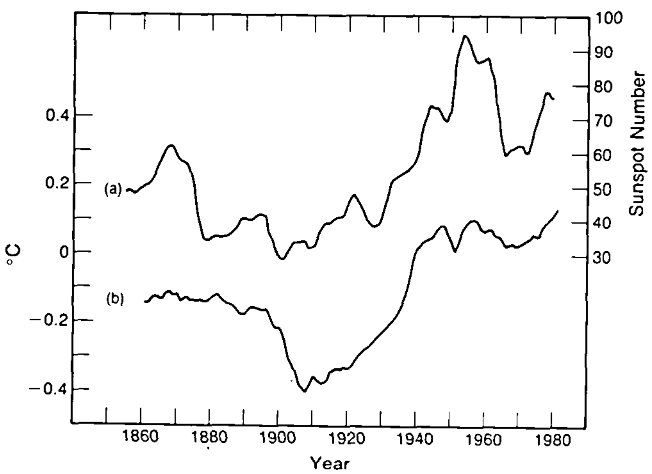

Fig. 1. (a) 135-month running mean sunspot number; (b) global average sea-surface temperature.

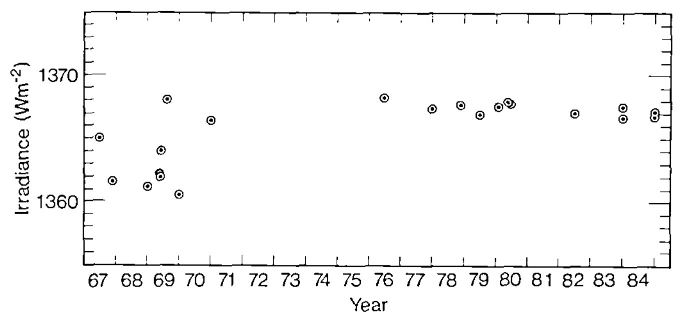

Fig. 2. Measurements of the sun's total irradiance made from balloons, rockets and spacecraft (redrawn from Fröhlich [1987]).

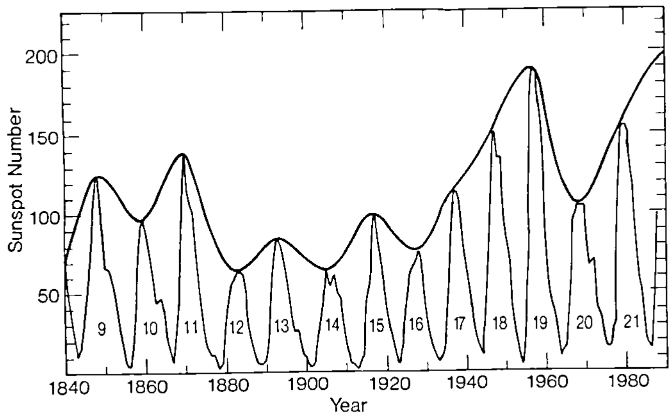

Fig. 3. Sunspot number 1840-1988 and its envelope.

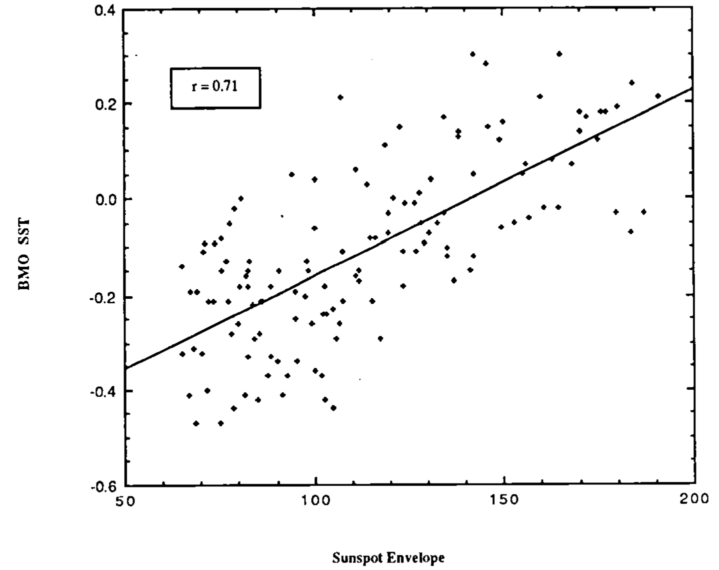

Fig. 4. Annual values of globally averaged SST versus sunspot-number envelope.

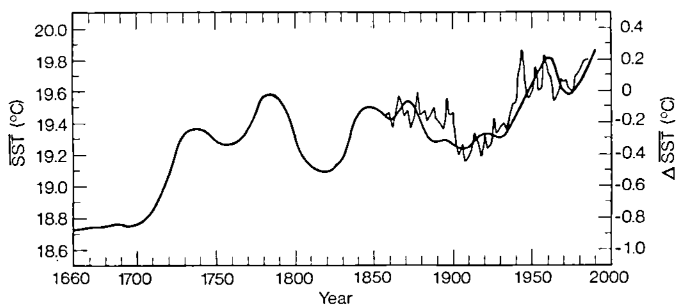

Fig. 5. SST predicted by the model (LH scale), and the smoothed globally averaged observed SST, expressed as the departure from an arbitrary mean.