PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Some Thoughts on Sun-Weather Relations [and Discussion]

J. A. Eddy, Jenny Allsop, J.-C. Pecker and William McCrea

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Some thoughts on Sun–weather relations

By J. A. Eddy
University Corporation for Atmospheric Research, Boulder, Colorado 80307, *U.S.A.*

Recent measurements of variations in the total solar irradiance now offer a quantitative mechanism through which year-to-year changes in solar activity may influence surface temperature. It follows that at least a part of the global warming of the last century could be ascribed to changes in solar output, and that effects of solar radiative forcing may need to be taken into account in predictions of greenhouse warming. A number of questions still remain, however, before this thesis rests on a firm foundation.

I am one who believes in a real and physical connection between long-term trends in what we know of climate through the past several hundred years and similar long-term changes in the level of solar activity through the same period. I also carry a prejudice that the solar effects on climate will show a marked frequency dependence: more pronounced and of greater practical importance for changes of longest term. This kind of purported long-term connection between the Sun and the climate has many fathers, advocated or at least pointed to by almost any in the past who believe in a Little Ice Age (*ca.* 1400–1800) and who accept the realities of the Spörer and Maunder Minima of solar behaviour (A.D. 1450–1540, 1645–1715). Once that leap of faith is taken, it is an easy step to accept as further evidence the coincidence of the subsequent Dalton Minimum in solar and auroral activity (*ca.* 1790–1830) and the cold decades that characterized climate the turn of the nineteenth century, and the striking correspondence between what has happened on the Sun through the present century (a rise of a factor of three since 1890 in the long-term envelope of recorded sunspot numbers) and at least a part of the coincident rise of about 0.6 °C in land surface temperature in the Northern Hemisphere.

These connections, however tempting, have lacked until recently a convincing demonstration of a mechanism, related to solar surface activity, that invokes sufficient energy to drive decadal changes in the climate system.

What is new, and worth the attention of this Symposium, are the emerging bulwarks of observational and analytical research that now make the connection more credible. What has moved the subject into a new realm of importance is the possibility that solar-forced changes in surface temperature in the past (and hence potential, solar-forced changes in the future) are of the same order of magnitude (though smaller, by a factor of two to four) as the changes now predicted through greenhouse warming in the first half of the next century.

Dr Foukal's interpretation (this Symposium) of our new knowledge of activity-related changes in the most energetic output of the Sun provides a quantitative mechanism that links decadal changes in sunspot numbers to decadal trends in the so-called solar constant: by far the most energetic of known changes in the output of the Sun. Professor Wigley's work (T. M. L. Wigley & P. M. Kelly, this Symposium) tests this relation through the device of quantitative climate models, against the most carefully compiled record that climatology can offer: the collected and corrected surface temperature record of the modern era. His results strengthen what he and independently, George Reid, had more tentatively claimed at a similar meeting in Durham several years ago.

As with most apparent, simple connections in science, there are parts of the thesis that are weak or missing altogether, some important unknowns, and for those who would seek it, room for doubt. Given the potential of solar forcing in decadal climate forcing, and current concerns regarding effects of future climate change, we need to give priority to clarifying the case.

Among outstanding questions are the following.

1. The measurements from spacecraft tie observed trends in the solar constant to changes in sunspot number, made since 1980, possibly in phase with the 11-year cycle. How secure is the conclusion that the effect is one of 11 years, as opposed to 22 years, or a longer period? How does the observed effect extrapolate quantitatively to solar changes of longer term, such as the twentieth century rise in activity, or the prolonged depression of the Maunder Minimum? Is it possible that secular or long-term trends in surface activity are related to proportionately greater modulations in total solar flux than are the year-to-year changes now associated with the 11-year solar cycle?

2. The value to climatology of a long-term connection between solar activity and solar constant depends upon an ability to forecast long-term trends in solar behaviour over more than one solar cycle. On what basis can this be done? Is the so-called 'Gleissberg cycle' of 80–90 years a predictable, periodic feature of the Sun? How firm is the evidence for an overriding cycle of 200–210 years? Is long-term solar behaviour periodic or chaotic?

3. Our longest, quantitative records of solar activity come from proxy records (principally tree-ring ^{14}C and ice-borne ^{10}Be) that are linked to solar surface activity (sunspot number, now tied to variations in the solar constant) through a chain of connection that is less than perfectly known. The mechanism through which galactic cosmic rays are modulated by conditions in the solar wind is imperfectly known; nor is there a simple relation between solar wind flux or velocity and sunspot number. How reliably may we substitute these indicators for the solar surface parameters that provide the apparent new linkage with changes in photon flux?

4. The purported connections linking solar activity to solar constant changes to variations in surface temperature are of the coarsest, spatial nature. The effect of changes in the solar constant on terrestrial climate can be expected to be a function of duration or persistence, and to be globally heterogeneous, greater for persistent or long-term changes and more pronounced in the centres of large land masses, where the thermal intertia of the oceans is less felt. To what extent do available climate data bear this out? Can spatial differences be used as a tool to separate the effects of solar forcing from that due to past changes in globally well-mixed greenhouse gases? What was the spatial pattern of the climatology of the Little Ice Age?

5. What fraction of the gradual global warming since the fading of the Little Ice Age can be attributed to the solar forcing that must have accompanied the gradual rise in the level of solar activity, and how much to the coincident increase in CO_2 that followed, through the same period, the dawn of the industrial age?

The case for a significant decade-to-century connection between solar activity and terrestrial surface temperature may seem to many of us convincing. But until we can answer these and other fundamental questions it rests on a less than solid foundation.

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Discussion

JENNY ALLSOP (*Deep Geology Research Group, British Geological Survey, Nottingham, U.K.*). The importance of the historical background in relating changes in the ^{14}C calibration curve to variations in the Earth's climate has already been illustrated for the medieval period: fourteenth-century documents describe a dramatic change from arable to sheep farming on a large scale that was purely due to social and economic events and not to climatic change. Therefore, the use of earlier archaeological data in assessing climatic changes may be misleading in the absence of documentary evidence. A few excavated sites with dateable material may show evidence of climatic variation (e.g. crop changes), but such evidence cannot necessarily be extrapolated over large geographical areas. Furthermore, the human influence on these changes may also be more difficult to assess. The deforestation of large areas of Europe, before the end of the Bronze Age, may have had as profound an effect on climate as the clearance of large areas in South America today. Further difficulties might occur if a variation in climate due to human activity were to coincide with any rhythm or cycle recognized in the ^{14}C calibration curves or similar stable isotope profiles before the discovery of new archaeological evidence.

J.-C. PECKER (*Collège de France, Paris, France*). I want to add two additional words of warning about the use of *R* (Wolf's number) as a unique index of solar activity.

1. The solar data are far from simple. Spots have different heliographic latitudes. Their average latitude changes during the cycle, as shown by the 'butterfly' diagram, in an equatorward trend. Effects on the Earth are affected by this average heliographic latitude, not only by the Wolf's number.

2. If one wants a single, unique, index for solar activity, is *R* the best one? One has used also the 'spotted area' and both are very highly correlated. However, in both cases, any given spot is counted at every of its successive passages, in successive rotations. Perhaps only newly born spots are really interesting; or at least one might conceive that any spot may have different effects at different stages of its development.

SIR WILLIAM MCCREA, F.R.S. (*Astronomy Centre, University of Sussex, U.K.*). With regard to the historical evidence from records of auroras, Professor Wilfried Schröder of Bremen-Roennebeck has published recent critical discussions (Schröder 1984, 1988*a*, *b*). He considers that 'the absence of auroral observations [in some of the years] during 1645–1715 is not conclusive evidence for a general minimum of solar activity during this period' (Schröder 1988*a*).

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