PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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Introductory Remarks

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Introductory remarks

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The search for periodic or quasi-periodic variations in the solar constant through the analysis of climatic and meterological data has proved elusive. The reason is evident: the atmosphere is a wet gas with much energy stored as latent heat and is in complex interaction dynamically and thermally with the oceans and land areas. This confronts the investigator with a hydrodynamic problem of awesome difficulty and has hitherto frustrated attempts at weather prediction over more than a few days. The instabilities, what we call the weather, cause not only day-to-day but also year-to-year variations so great that many experts have concluded that these would have completely masked possible small changes due to fluctuations of the energy input from the Sun. Yet, as the seasonal changes of solar energy falling on each hemisphere result in such obvious effects, it should not be impossible to detect in the climatic records much smaller changes in the total global input of heat energy into the atmosphere, especially if these are cyclical, by integrating out short-term fluctuations.

That the Sun varies with one or more periods has long been known. Solar physicists noted the time variations of the spotted parts of the Sun as soon as they identified the spots as a solar feature. Scheiner (1630), in the first half of the seventeenth century, used them to determine the solar rotation axis: the spots stayed visible during 14 days after which they disappeared at the west solar limb, eventually reappearing at the east limb. It was also noticed that spots have a short life, a few months, and they differ one from another. It was only much later that the German amateur astronomer, Schwabe (1838), suspected from his observations over the years from 1826 to 1837 and later concluded (Schwabe 1844) that the number of spots on the solar disk was a regular, perhaps periodic, function of time. Since Schwabe's work this clear periodicity of about 11 years has been monitored continuously. It was quickly noted that one 'solar cycle' does not look like another: in some the number of spots rises slowly and the maximum is often of moderate importance, whereas some other cycles, more conspicuously active, have the quickest rise from minimum to maximum.

The magnetic nature of spots was discovered later at Mt Wilson by G. E. Hale (1908), who found the signature of the Zeeman effect in their line spectra. Then he discovered (Hale 1924) a pattern in the magnetic polarities of the spots: that they usually occur in pairs of opposite polarities in the same latitude. In both hemispheres one polarity leads during one 11-year period. In the following period, these magnetic properties are reversed in sign: the leading and following spots of the pairs change from N to S, suggesting that a physical or magnetic cycle of 22 years, rather than one of 11 years, is the basic phenomenon. These researches have been carefully refined over the past 50 years or so: the inequality of the observed cycles suggested strongly that other periods should be looked for. Gleissberg (1958) suggested from the sunspot

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data a 75–80-year cycle which also appears in auroral frequency data (Gleissberg 1965) and this seems well established. From meteorological data, Link (1968) suggested a 300–400-year cycle and now (see later) we see a 200-year modulation. The obvious difficulty is that one has good magnetic records only since the beginning of this century, complete sunspot records only since the beginning of the nineteenth century, but only uncalibrated and incomplete data in western Europe and China in earlier centuries.

This explains why solar physicists take so much interest in those terrestrial phenomena that might be associated with solar behaviour: if these relations could be demonstrated safely, Earth records (not only of meteorological conditions, but also of human migrations and geological evolution perhaps) could help to understand the processes within the Sun. And this is why the two typical solar signatures – the 11-year periodicity and 27-day rotation – have been carefully searched for in terrestrial data of all kinds. In fact it was precisely with that object that an astronomer, A. E. Douglass, a devoted and curious mind, at the end of the last century and during the first decades of this, noted the regularity in the distribution of a tree-ring thickness. As an astronomer he first searched for a clear 11-year periodicity, each tree ring being the result of the annual growth of the tree, mostly at springtime, with a thickness depending on climatic factors (Douglass 1919). The presence of such a periodicity remained difficult to prove statistically, but the study led Douglass to show how absolute dating could be done by using tree rings.

It also encouraged many scientists to look everywhere on Earth for the 11-year signature. Mitchell (1979), for example, has found correlations between the 22-year solar activity and the recurrence of drought in western U.S.A. Long ago Beveridge in an early application of time series analysis in economics claimed to find the solar cycle in the price of wheat, which, because it is linked with climate, may merit being taken seriously! In such indices as wheat price, or tree-ring thickness, climatic effects, rainfall or sunshine, are averaged, or integrated, over a year. Some meteorological data, and some indices of the higher atmosphere (auroral frequency and geomagnetic indices) have been collected at much more frequent intervals than a year. The wealth of data has thus become much larger, and research of solar–terrestrial relations more securely based: in the tropospheric layers, climatic patterns are now observed for example, as convincingly discussed in this meeting. An early example is R. A. Fisher's statistical studies of rainfall in southern Australia. Another of the same kind is the study of rainfall in polar and moderate latitude stations by Xanthakis (1967). Rain is an element of the daily meteorological patterns: therefore, one might think that meteorologists, and not only climatologists, should be interested in looking for the solar signature in continuous weather records, perhaps for use in their short-term prediction. This has recently been attempted. May & Hitch (1989) of the Meteorological Office conclude from British weather records from 1881 to 1986 that heavy rains occur at the climax of the 11-year cycle of sunspot activity.

One might mention in this context the interesting work by Shapiro (1956), who found a persistence of a meteorological pattern a few days after a large geomagnetic disturbance associated with solar corpuscular emission followed by 10 days of decreasing persistence correlation. Unfortunately, this showed only the difficulty of the forecasting in periods of marked activity, but it has not proved helpful in improving forecasts.

Nevertheless, the search either for a 27-day or the 11-year signature, or for some systematic relation, is one way in which the mechanisms of solar interaction with the climate may be better understood in the future: it is wise to look at these early findings, or hints – be they only that – sceptically, but also with some care, for in spite of the statistical problems some studies may have uncovered real effects and quite recently stronger suggestions of this connection has been published.

Many investigations have been made by suitably averaging climatic data from different parts of the globe to search for periodic variations in the Sun's output: the implicit assumption being made that certain parts of the atmospheric circulation may be especially sensitive to them. To take a recent example: Colacino & Rovelli (1983) have analysed the long series of air temperature measurements made in Rome from 1782 to 1975. The annual mean temperatures, mean maximum and mean minimum temperatures were calculated, the latter increasing due to human activity as the city grew. The natural climatological effects were thus separated and maximum entropy analysis gave a spectrum with a sharp peak at 11 years. Analysis of trends show a decrease in temperature from 1810 to 1880 and an increase from 1880 to 1950 with a decrease since.

The problem with all such investigations is that they are studies of data from small areas of the globe, yet the variations are being attributed to a cause affecting the whole Earth. It is therefore interesting that Russell (1975) has discussed the records of the geomagnetic field, in which certain days feature disturbances different from the quiet day magnetic variation which arises from the tidal motions in the ionosphere. The disturbances arise in the magnetosphere and have long been measured in the celebrated geomagnetic indices. As has long been known, the sunspot cycle is clearly present in these geomagnetic disturbances, but Russell shows that there is a long-term variation of geomagnetic activity: the solar cycle average increases from 1872 to 1950 and decreases since. This correlates with the trend in air temperature in Rome since 1880 described above. Are we therefore in addition to the sunspot cycle seeing a much longer cycle of solar activity with a period of between 150 and 200 years? The absurdity of discussing this question on data available over such a short period is evident. Such a longer period of solar variability had become a matter of debate when the sightings of sunspots before Galileo's observations were collected from historical sources. Maunder (1922) called attention to Spörer's (1889) studies of a marked absence of sunspots in the seventeenth century and earlier such minima have now been established from geophysical studies, suggesting an approximate 200-year modulation of the solar cycle.

We need to study a record spanning recent millenia if progress is to be made. As is so often the case in scientific research, a much more convincing record comes from an unexpected field, tree rings, hitherto entirely a tool for archaeological dating. This relatively new, but so far only partly explored, source of information on solar activity is the spectrum of the ^{14}C variations during the past millenia found from tree rings. As early as in 1956 H. de Vries in Groningen, The Netherlands, found indications of variations in the ^{14}C-content of wood that grew in the seventeenth and fifteenth centuries. These variations could be explained by variations in the cosmic-ray production rate of ^{14}C in the atmosphere. Their existence was soon confirmed by other ^{14}C-laboratories and their significance for the reliability of ^{14}C dating was soon appreciated. However, an explanation of this so called 'de Vries effect' was not possible, except that it seemed probable that it was caused by variations in the modulation of the cosmic-ray flux by magnetic fields from the Sun. This contention was then supported by the observation that the ^{14}C-variations are not random fluctuations, such as produced by 'red' noise, but they are due, as was first shown by Hans E. Suess (1973, 1974), to a consistent line spectrum with a dominant 200-year line that can be recognized to be present with varying intensities for the whole time recorded by tree rings back to about 5000 B.C. It is this ^{14}C record from tree rings of known date which has given a new impetus to the study of variations in the Sun and climate

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over recent millenia. These proceedings therefore begin with an account of the discovery of the Suess wiggles. The early data from which Suess derived the 200-year cycle was noisy and was not at first accepted by other laboratories, although later their reality was generally agreed. Harold C. Urey used to say that true progress in science is only possible if the record of such progress 'is kept straight'. In this case it was only after some years that Suess's discovery was independently verified by another laboratory using German oak tree rings (de Jong *et al.* 1979).

It is significant that since the meeting two papers have been published finding the solar cycle in global temperatures. Newell *et al.* (1989) find from the analysis of global and hemispheric marine temperatures for 1856–1986 a prominent 22-year period which they concluded may be related to the solar magnetic cycle. Barnett (1989) also in studying global sea surface temperatures concludes that the quasi-biennial variation is modulated with the 11-year period. Thus earlier negative conclusions reached by meteorologists – for instance, Pittock (1978), who concluded that 'little convincing evidence has yet been produced for real correlations between sunspot cycles and the weather/climate,' – may need revision.

It would not be right to conclude without reference to the work of D. J. Schove (1983), who over many years, in season and out of season, argued for a connection between sunspot cycles and the climate. His contributions, with many other papers, were brought together by him just before his death. Discussion of some of these questions has recently been reopened by a NATO workshop (Stephenson & Wolfendale 1988).

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