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Closing Remarks: Geophysical

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Closing remarks: geophysical

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The search for a connection between solar variability and the Earth's climatic variations has given rise to much controversy: given the great instabilities of the atmosphere and the relatively short span of accurate observations this was inevitable. Meteorologists, very conscious of the complexity of modelling the atmosphere, even assuming a constant energy input, have often been very critical of claims to have detected the solar cycle, and even hostile to the search for one. Now, as so often is the case in science, important evidence has come from an entirely different field; ^{14}C dating. One can therefore have sympathy with the distinguished meteorologist who, when informed of the 200-year period in the Sun inferred from this work and its possible effect on the climate, said 'Dear Professor Suess, you must understand that the Sun has nothing to do with the climate.' I trust that it is not an apocryphal story!

It is almost an invariable rule in geophysics that a phenomenon has more than one cause. The spectrum of ^{14}C variations shows lines of about 200 years and 2000 years. The ^{10}Be data appears to show the 200-year period and because both isotopes are produced by similar nuclear physics processes in the high atmosphere but find their way to the ground by different physico-chemical processes, we seem on firm ground in attributing the 200-year period to modulation of the cosmic-ray flux by magnetic field changes around the Sun with this period. The apparent absence of a 2000-year line in the ^{10}Be spectrum suggests that it is possible that in the C^{14} inventory a fundamental role is played by the oceans, which have such overturn times and store much of the CO_2.

In these discussions it has always been tacitly – although reasonably – assumed that the sunspot periods are accompanied by periodic variations in the solar bolumetric luminosity. This assumption has now been proved by the satellite measurements of the solar constant over recent decades.

Attempts to find in meteorological data evidence for the solar cycles has naturally focused hitherto on the 11-year and 22-year periods and has attracted, as we have pointed out, much criticism because the variations, which evidently result from instabilities of the atmosphere, are so great. But an analogy from another geophysical field may be useful. The geomagnetic field as observed over historical times presents a complex picture, many harmonics are required to describe it and its secular variation. This reflects the magnetohydrodynamics, a turbulence, of the Earth's core, but when averaged over thousands of years, the field is a dipole aligned along the axis of rotation and its moment depends on the power driving the dynamo process. Therefore, it is not unreasonable to expect that suitably averaged and appropriately selected meteorological data in certain areas of the globe will reveal periodic or quasi-periodic variations in the solar energy input to the atmosphere. The evidence seems now at last becoming more convincing. The analysis of time series goes back to the work of Udny Yule

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(1927), the newer methods being elaborations of his autocorrelation one, but it is now possible to test the statistical significance of the periods found, an important theme in this Symposium.

The historical records of sunspots and the discovery of minima of solar activity are in agreement with the ^{14}C data in showing the existence of an approximate 200-year cycle. These minima are the Maunder (1645–1715 A.D.), the Spörer (1420–1530 A.D.), the Wolf (1280–1340 A.D.), the Oort (1010–50 A.D.) and a possible later one, the Dalton (1790–1830 A.D.). The correlation of these minima with cold winters in western Europe (Lamb 1982) aroused much interest and we now know that for the 11-year cycle at least the solar constant is greatest at the sunspot maximum, not immediately obvious perhaps as the dark sunspot areas are cooler. The quiet Sun is associated with a higher ^{14}C generation rate in the high atmosphere as fewer cosmic rays are deflected in the surrounding plasma of the Sun. The maxima of the Suess wiggles do correlate with the 'Little Ice Age' associated with the Maunder Minimum, i.e. the correlation has the correct sign.

The modulation of the sunspot cycle over 200 years might be expected to have a larger effect on the climate than the 11-year period, so it is reasonable to ask whether archaeological evidence can contribute to this study. Obviously, migrations of early peoples could be caused by slow climatic changes. The archaeologist ideally requires from the geophysicist annual records of mean temperatures and rainfall in the areas which he studies. It is possible that ^{18}O studies of tree rings may yet yield information about temperature. Leona Libby (1983) worked on that and published a record of temperature over the past few millennia for Europe, the last 200 years agreeing well with mean European temperatures based on the exhaustive compilations of recorded temperatures since Fahrenheit's invention of the thermometer. The mechanism by which the ^{18}O ratio in trees depends on temperature is obscure unlike that in the palaeo-temperature study of fossils and microfossils pioneered by H. C. Urey and C. Emiliani. A careful new approach is described in this Symposium by S. Epstein and R. V. Krishnamurthy. The results referred to above on European trees over recent millenia have been disputed and should be repeated. But the geophysicist would be much stimulated if the archeologist were able to point to certain migrations that seem best explained by climatic changes. We can look forward in this study of variations of climate and the Sun to as fruitful an interaction between archaeologists and geophysicists, as that during the development of ^{14}C dating. I well remember W. F. Libby coming to Newcastle and saying that in the previous few days he had been convinced by the Keeper of Egyptology, I. E. S. Edwards, in the British Museum that his ^{14}C dates were wrong by about 1000 years and he wished to know whether there was evidence that the geomagnetic field intensity had changed over these times sufficiently to alter the cosmic-ray flux into the Earth. This led to the need for an independent calibration of the ^{14}C dating method, which was achieved by Professor Hans Suess using tree rings and which has now led to the new evidence of solar variability, which has been the origin of this meeting.

The greenhouse effect points to the need for a better understanding of the atmosphere and of climatic change. By studying the effect of the changes of solar output with periods of 11 and 200 years on the atmosphere from the historic and archaeological records, we may hope to come to a better understanding of the Earth's atmosphere and how it responds to changing energy input. In geophysics we have to wait for Nature to do the experiment. But in assessing the influence of the greenhouse effect from observations over the past 150 years, the possibility that some of the change may be due to the 200-year cycle in the Sun must be considered. We

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showed in the Introductory remarks that the global increase in temperature over the second half of the last century and the first half of this – as strikingly illustrated by the frontispiece – correlates with the Sun's activity, as determined by geomagnetic disturbances. This implies that at least some part of the observed increase in temperature is due to increased solar energy output.

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