MODULATION OF THE COSMIC RADIATION AND ITS MANIFESTATION IN COSMOGENIC ISOTOPES

J. BEER
Swiss Federal Institute for Environmental Science and Technology (EAWAG)
CH-8600 Dübendorf, Switzerland

An issue of increasing importance in solar physics and climatology is solar variability (Sofia and Fox, 1994). It seems that most solar type stars show some magnetic variability at the surface (Baliunas and Jastrow, 1990). To understand the underlying processes and to model them is a big challenge in solar physics.

When satellites began to observe the sun outside the disturbing atmosphere it soon became clear that the solar irradiance is also variable and seems to be related to the 11- year Schwabe cycle (Willson, et al., 1986), (Foukal, this volume). This result is of great importance because the sun is the engine which drives the climate system on earth. Although the variations are small (0.1-0.2%) there is clear evidence from observational data of solar type stars (Baliunas and Jastrow, 1990) and from theoretical considerations as well that much larger fluctuations over longer time scales potentially could occur.

This raises the question what role the sun plays in today's climate change and possibly in the near future. There are basically two approaches to address this question. 1. The solar irradiance and the climate have to be monitored continuously with high precision in order to detect changes and to understand how they are caused. 2. Since there are reasons to believe that the sun also exhibits long-term changes which cannot be detected during short periods of direct observations, one has to investigate the past by looking for connections between climate and solar variability.

To reconstruct past climate changes is comparatively simple. There is a large amount of climatic observations available for the last 2-3 centuries. The climatic conditions of earlier times can be reconstructed quite reliably based on isotopic ratios, pollen assemblages, and many other parameters measured in natural archives. In the case of solar variability the situation

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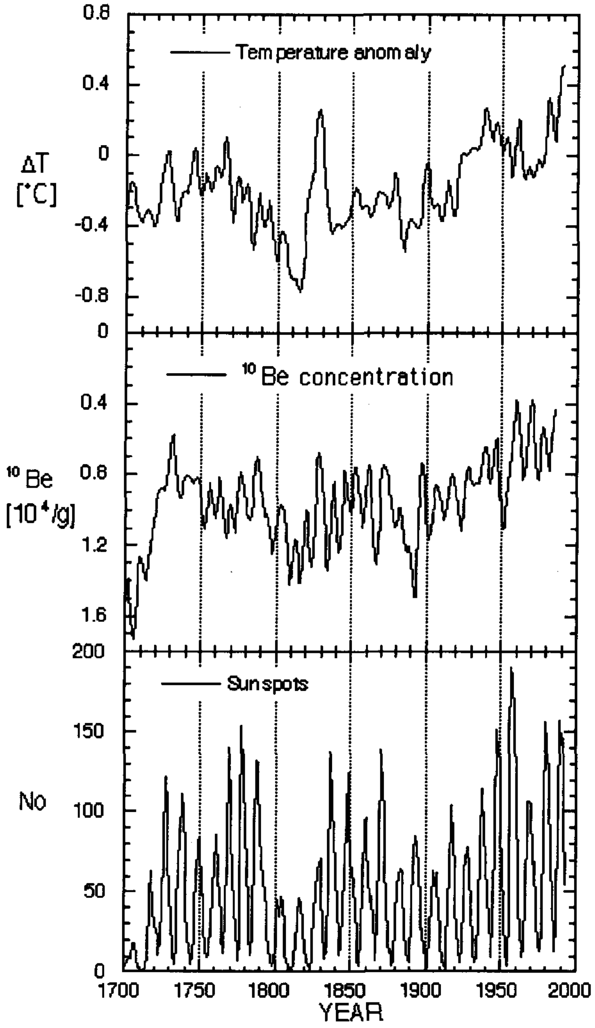

Figure 1. Comparison of the ^{10}Be record (Beer, et al., 1994) with the sunspot record and the temperature anomalies of the northern hemisphere (Groveman and Landsberg, 1979, Jones, et al., 1986).

is much more difficult. The longest direct record of solar variability is the sunspot record going back to about 1600 AD. In the pre telescopic era there is very little direct information of questionable quality.

The only way to extend our knowledge of solar variability further back in time is to rely on indirect methods. One approach which proved to be quite

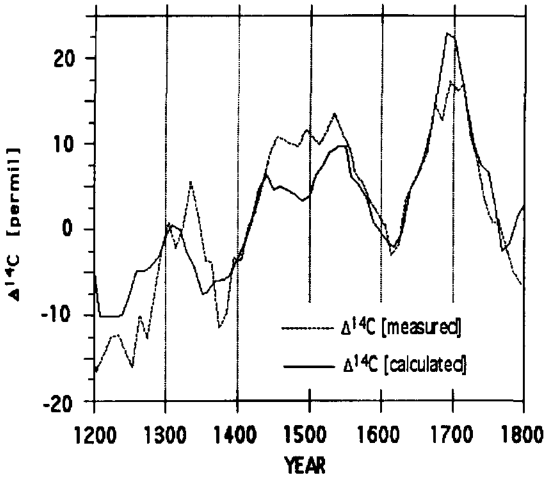

Figure 2. Comparison of $\Delta^{14}C$ measured on tree rings (Stuiver and Quay, 1980) with $\Delta^{14}C$ calculated based on a combined ^{10}Be record from Milcent (Greenland) and South Pole (Beer, et al., 1991) using a carbon cycle model.

successful is the use of cosmogenic isotopes (Beer, et al., 1990). Depending on its magnetic activity the sun ejects different amounts of mass (solar wind) through coronal holes which fills the solar system. Inhomogenitiesof the frozen in magnetic field act as scattering centres for cosmic ray particles, thus modulating the flux of the low energy particles entering the earth atmosphere. This flux interacts with the atmosphere, producing a variety of cosmogenic isotopes. Some of them are finally stored in natural archives such as tree rings (^{14}C) or ice sheets (^{10}Be). Measuring the concentration of cosmogenic isotopes therefore provides information about the cosmic ray flux and its modulation by solar activity in the past (Beer, et al., 1991).

In Fig. 1 the sunspot number, the 10Be concentration record from an ice core (Dye 3, South Grts modulation by solar activity in the past (Beer, et al., 1991). enland) (Beer, et al., 1994) and the temperature anomalies of the northern hemisphere (Groveman and Landsberg, 1979, Jones, et al., 1986) are plotted. The agreement between the sunspot number and the ^{10}Be concentration is good in view of the fact that the 10Be signal contains also information about the transport and deposition processes taking place after its production in the atmosphere. It is also striking that the long-term trends of ^{10}Be and temperature are similar indicating that part of the observed temperature anomalies could be due to changes of the solar irradiance.

An important feature which shows up just at the end of the observa-

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tional period is the Maunder minimum, a period when almost no sunspots could be observed (Eddy, 1976). There are indications of earlier minima: Spoerer (1415-1535 AD) and Wolf (1260-1340 AD). All of them are clearly visible in Fig. 2 displaying two $\Delta^{14}C$ curves. One reflects the atmospheric ^{14}C variations in permil as measured in tree rings (Stuiver and Quay, 1980). The other is based on two measured ^{10}Be ice core records from Milcent (Greenland) and South Pole which were combined to remove some of the transport signal (Beer, et al., 1991). Due to the different geochemical behavior of ^{10}Be and ^{14}C these two isotopes cannot be compared directly. Therefore we used a carbon cycle model to calculate the $\Delta^{14}C$ variations which correspond to the measured ^{10}Be concentration changes. The good agreement strongly supports the explanation that for this period ^{10}Be and ^{14}C reflect mainly the solar modulation, and that the amplitude of variation over these longer time scales was larger than the one observed during the last few decades. It is also interesting to note that these minima coincide with the Little Ice Age, a climatic period which is characterized by a general advance of the glaciers (Denton and Karlen, 1973).

References

Baliunas, S., and Jastrow, R. (1990). Evidence for Long-Term Brightness Changes of Solar-Type Stars, *Nature*, **348** pp. 520–523.

Beer, J., Baumgartner, S., Hannen-Dittrich, B., Hauenstein, J., Kubik, P., Lukasczyk, C., Mende, W., Stellmacher, R., and Suter, M. (1994). Solar Variability Traced by Cosmogenic Isotopes in "The Sun as a Variable Star: Solar and Stellar Irradiance Variations", (eds. J.M. Pap, C. Fröhlich, H.S. Hudson, and S.K. Solanki) pp. 291–300.

Beer, J., Blinov, A., Bonani, G., Finkel, R.C., Hofmann, H.J., Lehmann, B., Oeschger, H., Sigg, A., Schwander, J., Staffelbach, T., Stauffer, B., Suter, M., and Wölfli, W. (1990). Use of ^{10}Be in polar ice to trace the 11-year cycle of solar activity, *Nature*, **347** pp. 164–166.

Beer, J., Raisbeck, G.M., and Yiou, F. (1991). Time Variations of ^{10}Be and Solar Activity in "The Sun in Time", (eds. C.P. Sonett, M.S. Giampapa, and M.S. Matthews) pp. 343–359.

Denton, G.H., and Karlen, W. (1973). Holocene climatic variations pattern and possible cause, *Quaternary Research*, **3** pp. 155–205.

Eddy, J.A. (1976). The Maunder Minimum, *Science*, **192** pp. 1189–1201.

Groveman, B.S., and Landsberg, H.E. (1979). *Reconstruction of northern hemisphere temperature: 1579-1880.* University of Maryland, College Park, MD. pp. 79–181.

Jones, P.D., Raper, S.C.B., Bradley, R.S., Diaz, H.F., Kelly, P.M., and Wigley, T.M.L. (1986). Northern Hemisphere surface air temperature variations, 1851-1984. *J. Clim. Appl. Met.*, **25** pp. 249–257.

Sofia, S., and Fox, P. (1994). Solar variability and climate, *Climate Change*, **27** pp. 249–257.

Stuiver, M., and Quay, P.D. (1980). Changes in Atmospheric Carbon-14 Attributed to a Variable Sun, *Science*, **207** pp. 11–19.

Willson, R.C., Hudson, H.S., Fröhlich, C., amd Brusa, R.W. (1986). Long-Term Downward Trend in Total Solar Irradiance, *Science*, **234** pp. 1114–1117.