Variation of the Radiocarbon Content of Tree Rings during the Spoerer Minimum

Hiroko Miyahara[1,2], Kimiaki Masuda[1], Hideki Furuzawa[1], Yasushi Muraki[1], Toshio Nakamura[3], Hiroyuki Kitagawa[4] and Khikmatulla Arslanov[5]
(1) Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Aichi 464-8601, Japan. e-mail:miyahara@stelab.nagoya-u.ac.jp
(2) Research Fellow of the Japan Society for the Promotion of Science.
(3) Center for Chronological Research, Nagoya University, Japan.
(4) Graduate School of Earth and Environmental Sciences, Nagoya University, Japan.
(5) Geographical Research Institute, St. Petersburg University, Russia.

Abstract

The radiocarbon content of tree rings offers important information on the level of the solar activity in the past. We have focused on the variation of solar activity during the grand minima, when solar activity was extremely low. In order to clarify the characteristics of solar activity during the grand minima, we measured the radiocarbon content of tree rings from the Spoerer Minimum (1415-1534 AD) annually. The time series was analyzed and periodicities of 7, 11 and 22 years were derived. The 11-year periodicity was dominant, however it was weakened during 1460-1500 AD.

1. Introduction

Radiocarbon is produced mainly by the secondary neutrons of cosmic rays in the upper atmosphere. Hence, the production rate of the radiocarbon is determined by the flux of incoming cosmic rays, and is controlled by solar activity.

The radiocarbon (^{14}C) produced forms carbon dioxide ($^{14}CO_2$) immediately, and circulates within the global carbon cycle together with $^{12}CO_2$ and $^{13}CO_2$. Some is absorbed into trees to form tree rings. Thus, a record of the variation of the radiocarbon abundance caused by changes of solar activity is stored in the tree rings. Accordingly we may trace the history of solar activity by measuring the detailed radiocarbon content of long-lived trees.

Fig.1 is an example of ^{14}C data which reveals the variation of solar activity in the last millennium [1]. The three large peaks show the times of the grand minima, called Wolf, Spoerer and Maunder Minimum respectively. The Maunder Minimum (1645-1715 AD), one of the grand minima in the last millennium, is well known to have had almost no sunspots. In previous studies, a weakened 11-year

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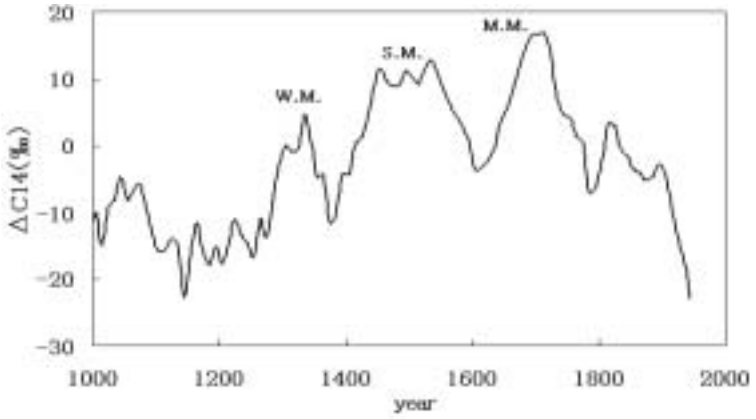

Fig. 1. Radiocarbon content in tree rings in the last millennium (decadal)[1]

period and the existence of a 22-year period during the Maunder Minimum has been suggested [2,3]. To determine if this characteristic is common among the grand minima, we survey the radiocarbon contents of tree rings from the Spoerer Minimum.

2. Methods

For this study, a 704-year-old Japanese cedar tree, obtained from Yaku Island (30.18° N, 130.30° E), was used. The ^{14}C content of each tree ring was measured using the accelerator mass spectrometer (AMS) at Nagoya University. For the measurement, cellulose is extracted from each tree ring and converted to graphite as the target material of the ion source of the machine. The preliminary procedure was as follows:

The tree rings were separated annually, and milled into small pieces. Each of the samples was then washed with a benzene - ethyl alcohol mixture to remove resins etc. The extracts were subsequently bleached by a $NaClO_2$/HCl solution at 80 to remove lignin. They were then boiled and rinsed in distilled water. The resultant celluloses were combusted with CuO to obtain CO_2 gas. After purification, the CO_2 gas was de-oxidized to graphite using H_2 gas [4]. Standard targets were also made in the same way from NIST SRM4990C oxalic acid.

3. Results

Fig.2 shows the radiocarbon content of tree rings from 1410 to 1550 AD. The solid curve is the same decadal data as in Fig.1 [1]. It is consistent with the curve in Fig.1 but our result reveals short term variations, which are not seen in the decadal data. First, the time series was analyzed by Fourier Analysis (Fig.3). The power spectrum shows peaks in the periodicity at 7, 11 and 22

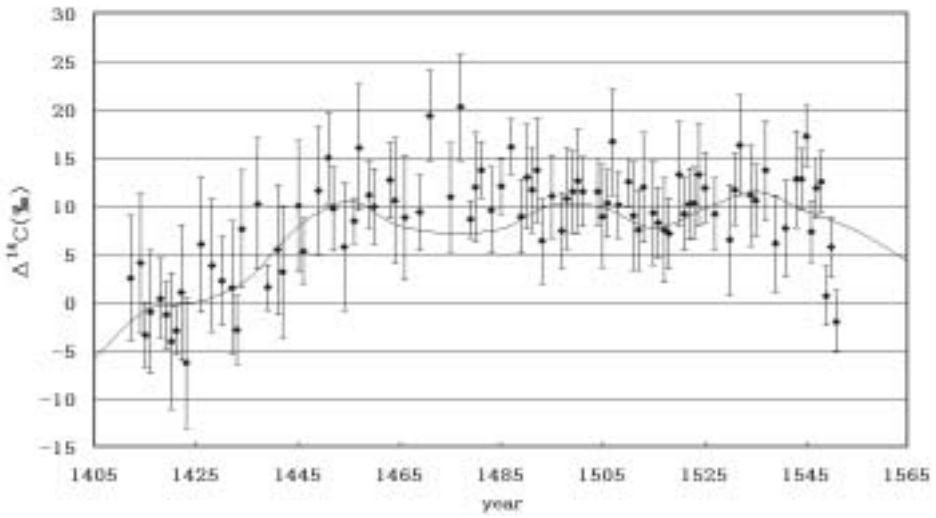

Fig. 2. Radiocarbon content in tree rings during the Spoerer Minimum

years. The confidence levels of the 11-year and 22-year periodicities, which can be assumed to be manifestations of solar activity, were 95% and 70%, respectively. Next, we surveyed the variation of strength of these two cycles during the Spoerer Minimum. By using a band-pass filter, two cycles were extracted from the time series of the data (Fig.4). There is an obvious difference between the two. The 11-year cycle is weaker during 1460-1500 AD, while the 22-year cycle maintains a steady amplitude.

4. Discussion

It can be said that solar activity was weakened most around 1460-1500 AD. As to the 11-year cycle, there are two possible interpretations of the results. One is that the 11-year cycle itself was weakened, and the other is that it was stretched by several years as the solar activity became weaker. It is well known that the period of the solar cycle is stretched when the sun is relatively quiet. It was pointed out by Peristykh and Damon [3] that the 11-year cycle was suppressed during the Maunder Minimum compared to before and after, while the 22-year cycle remained constant. These characteristics agree with those of the Spoerer Minimum obtained in this study. However, the data statistics have to be improved and a more detailed analysis of the 11-year cycle is needed.

5. Conclusions

The variation of solar activity during the Spoerer Minimum was surveyed by measuring the radiocarbon content of tree rings. As a result, it was found that solar activity was weakened most around 1460-1500 AD. In this period, the ampli-

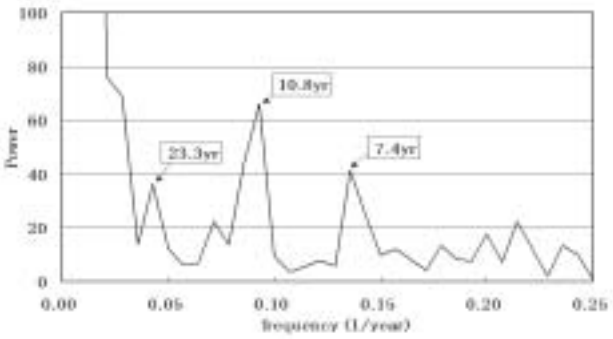

Fig. 3. Fourier Analysis

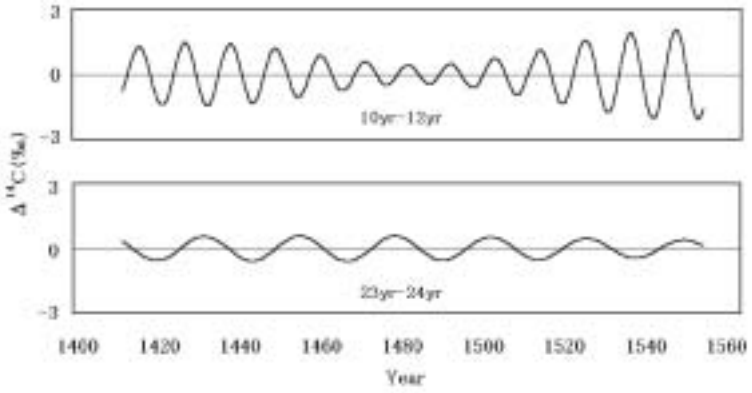

Fig. 4. Variation of the amplitude of 11-year and 22-year periods

tude of the 11-year cycle was suppressed, while that of the 22-year cycle remained constant. These characteristics agree with those of the Maunder Minimum, as revealed by Peristykh and Damon [3]. However, the statistical significance of the data can be still improved, so the measurements will be continued.

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