# Radiocarbon Content in Japanese Cedar during the Maunder Minimum

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## Abstract

It is well known that sunspots almost disappeared in the Maunder Minimum (1645-1715 AD). Accordingly, solar activity in this period has drawn much attention. Investigating the variation of radiocarbon contents in tree rings will improve our understanding of the solar activity in a time when the sunspots were absent. In prior studies, Kocharov et al. and Stuiver and Braziunas examined independently the variation of the radiocarbon content in annual tree rings during the Maunder Minimum. However, their data differ in several points, notably the amplitude of the variation, the periodicities and the absolute peak value of the radiocarbon content. In this paper, we present new results on the variation of radiocarbon content during the Maunder Minimum in order to clarify which features are regional effects and which are the effect of solar activity. Some radiocarbon data from a Japanese cedar tree is presented and compared with the data obtained by Kocharov et al. and Stuiver and Braziunas.

## 1. Introduction

At present solar activity reveals a typical periodic behavior, comprising the 11-year variation of sunspot number or magnetic field strength and the 22-year polarity change of the magnetic field. However, this periodic activity has not been constant in the past. The Maunder Minimum (1645-1715 AD) is known as a period when solar activity was weak. This period seems to coincide with the so-called Little Ice Age, that is, a period of cold climate in 17th century and around. The duration of the Maunder Minimum is defined as the years when the sunspot number was almost nil [1]. The rare appearance of aurora and higher production of cosmogenic nuclides such as $^{14}C$ and $^{10}Be$ confirm the reality of this event.

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Solar activity affects the interplanetary magnetic field and solar wind causes a variation of the galactic cosmic ray intensity in the heliosphere. Since radiocarbon, $^{14}$C, is produced by galactic cosmic rays in the atmosphere of the earth, the production yield is anti-correlated with the solar activity. The radiocarbon produced forms carbon dioxide which exchanges between the various reservoirs of the global carbon cycle. Some of the carbon dioxide in the lower atmosphere is built into plants. Thus tree rings are considered to be a good archive of radiocarbon and give annual information concerning solar activity in the past.

Kocharov et al. [2] and Stuiver and Braziunas [3] measured the $^{14}$C content in annual tree rings during the Maunder Minimum. Although both data sets indicate an increase of $^{14}$C content, corresponding to a solar activity minimum, they differ in several points. In order to clarify the cause of the disagreement and to what extent the variation is due to solar activity, we have made measurements of the radiocarbon content in annual tree rings using a Japanese cedar tree. Here we report some results of our measurements.

## 2. Experimental Procedure

*Samples* The wood samples were taken from a block of the trunk of a Japanese cedar (Cryptomeria japonica) tree. This wood was obtained from the Murou-ji temple area in Nara, Japan (geographical location $34^o32'$ N, $136^o02'$ E and 400m a.s.l.). The tree fell in a typhoon in September 1998, prior to this the tree had been alive. The block we obtained is a trunk section of 1.1m in diameter and 30 cm thick. The calender year corresponding to each tree ring was determined by counting the number of annual rings from the outermost, which corresponds to 1998. The estimated age of the tree is 392 years. Annual samples of tree rings, corresponding to the period of the Maunder Minimum and around (1629-1739), were separated. As a first step, we measured the $^{14}$C content for every-other-year samples for a part of this period (1693-1731).

*Sample treatment* The cellulose component was extracted from the wood sample by dissolving resins in a benzene - ethyl alcohol mixture and by bleaching in a $NaClO_2$/HCl solution to remove lignin. Then the cellulose was combusted with CuO in vacuum and converted to $CO_2$, which was successively purified with cold traps (-90$^o$C and -130$^o$C). The $CO_2$ samples sealed in Pyrex glass tubes were sent to the AMS $^{14}$C Laboratory of the ETH and converted to graphite as targets for the ion source of accelerator mass spectrometers (AMS). Standard reference samples (NIST SRM4990C, oxalic acid) and blank samples for determination of the background (commercial oxalic acid from Wako Pure Chemical Industries) were also converted to graphite in the same way.

*Measurement and data analysis* The $^{14}$C content in terms of the ratio of

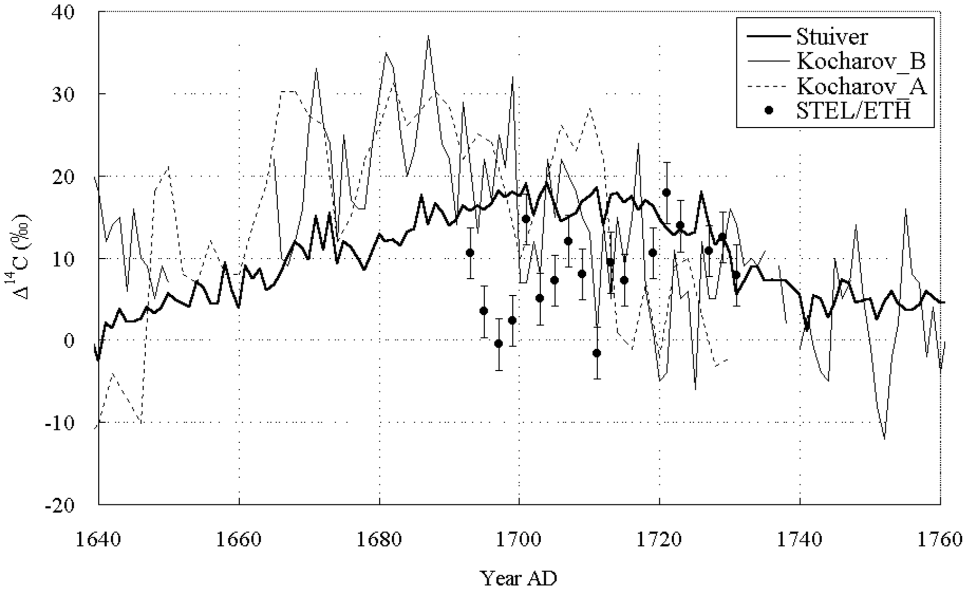


**Fig. 1.** Preliminary results of the measurement of radiocarbon contents in tree rings for the Maunder Minimum. Present data are compared with others.

$^{14}C/^{12}C$ was measured in the single-year samples using the AMS of ETH/PSI, Switzerland [4]. The measurement scheme followed the normal procedure of the AMS facility. The accuracy achieved was about 0.31 % for most samples. The isotope ratio $^{13}C/^{12}C$ was measured simultaneously and used to correct the $^{14}C$ content for isotope fractionation.

## 3. Results and Discussion

The measured $^{14}C$ content expressed as $\Delta^{14}C$ are plotted versus the calender year of the tree rings in Fig. 1, together with the data by Kocharov et al. [2] and Stuiver and Braziunas [3]. The present $^{14}C$ contents are in agreement with the data of Stuiver and Braziunas in the latter part of the measured period (1719-1731) but lower before 1715. On the other hand, the present data coincide well with the data of Kocharov et al. except for the early part of the measured period (1693-1699). It is difficult to say anything about periodicities in the present data because the number of data points is too small. The variation of $Delta^{14}C$ over short periods may be several permil, which is larger than that of Stuiver and Braziunas but smaller than that of Kocharov et al.

Kocharov et al. published two series of $\Delta^{14}C$ data for the Maunder Minimum, which are shown in the figure as Kocharov-A and Kocharov-B [2]. The measurement was done by the liquid scintillation method and the measurement error was claimed to be 0.3 %. The sample in Series A comprised bi-annual rings of pine trees from the South Urals and in Series B annual rings of pine trees from the West Ukraine. They reveal a similar tendency in that the $^{14}C$ content increased during 1670-1710, which corresponds to the main period of the Maunder Minimum (1645-1715). Series A shows a periodicity of 22-year during the peak while Series B seems to show the 11-year periodicity through the entire time span examined. The amplitude of the variation is 10-20 permil for these periodic changes and the mean variation is about 5 permil.

Stuiver and Braziunas reported a variation of $^{14}C$ content in annual tree rings from Washington (Pacific northwest coast), USA, for the time span 1510-1945 [3]. Some are shown in the figure. The measurement was carried out using gas proportional counters and the measurement error is about 0.2 %. The data of Stuiver and Braziunas shows a broad peak in the $^{14}C$ content around 1710, which is a few decades later than that of Kocharov et al. The amplitude variation is a few permil and the mean variation is 1.5 permil. Peristykh and Damon [5] analyzed the data and concluded that the 11-year cycle was present before and after the Maunder Minimum but was totally suspended during the Maunder Minimum, while the 22-year periodicity existed throughout. The maximum $^{14}C$ content in the peak of the Maunder Minimum in the data of Kocharov et al. is much larger than that of Stuiver and Braziunas.

As shown above, the $^{14}C$ data sets for the Maunder Minimum are not in agreement with each other. One possibility for the difference might be regional effects on $^{14}C$ circulation. Since our present data record is too short to draw final conclusions, it is necessary to perform additional measurements of tree ring samples from adjacent periods. Also annual data for the $^{14}C$ content are desirable to investigate the problems in detail. At the time of the conference we hope to be able to report more detailed features based on additional measurements, which are planned for the near future.

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