Measurements of C-14 concentration for 22 single-year tree rings of an old cedar ca. 2500 years ago

Hirohisa Sakurai[1], Wataru Kato[1], Tosiyuki Gandou[1], Tosiya Aoki[1], Yousuke Takahashi[1], Shuichi Gunji[1], Fuyuki Tokanai[1], Hiroyuki Matsuzaki[2]
(1) Department of Physics, Yamagata University, 1-4-12 Kojirakawa, Yamagata 990-8560, Japan
(2) Research Center for Nuclear Science and Technology, The University of Tokyo, Tokyo, Japan

Abstract

The ^{14}C concentrations of 22 tree rings of ca. 2500 years ago have been measured at single-year intervals with a highly accurate liquid scintillation counting system Quantulus (≤0.2%). The calendar age of the wood sample was 477B.C.±20 by ^{14}C dating and the variation of ^{14}C during the era is similar to that of Maunder or Spörer era when sunspots were absent. The least squares fit of a sine function for the Δ^{14}C of 22 single-year tree rings indicated the amplitude of 0.39% and the period of 11.5-year. It indicate that the tree rings of ca. 2500 years ago record 11-year solar variations for the ^{14}C concentrations.

1. Introduction

^{14}C concentrations in tree rings are proxy data of past terrestrial and extraterrestrial environments. Since tree rings record ^{14}C concentrations in chronological order with a time resolution of one year, ^{14}C measurements for single-year tree rings provide ^{14}C concentrations in the atmosphere in the period of one year. As the flux of cosmic rays reaching the earth are, modulated by time variations of geomagnetic and heliomagnetic fields, the ^{14}C concentrations in tree rings are affected by the modulation of cosmic rays [1,2,3,4]. In particular, ^{14}C measurements of the single-year tree rings of old wood samples are essential for investigating the 11-year periodicity of solar activity in the past, because we have no available observed data of sunspot number, which is the indicator of the 11-year cycle, for years earlier than A.D. 1700.

Moreover, since the record of the long-term modulation of galactic cosmic rays is at most for 50 years beginning at 1951 by neutron monitors, the precise observation of the 11-year modulation pattern due to ^{14}C measurement of single-year tree rings is necessary for the investigation of the stability of the cosmic-ray intensity and the state of the heliosphere over the past1000 and/or 10000 years. For instance, it is because two 11-year modulation patterns of cosmic rays over 22

pp. 4135–4138

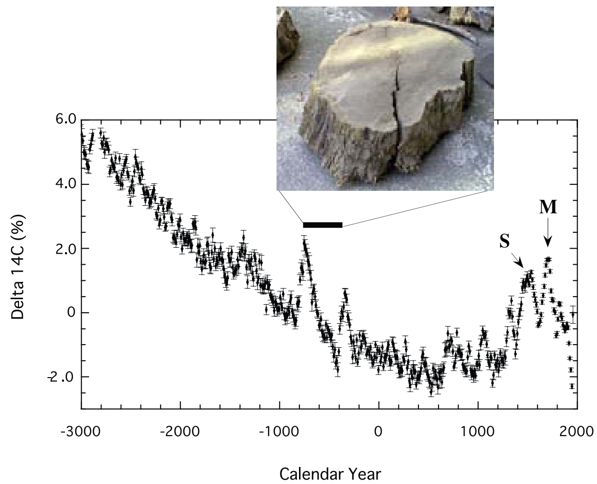

Fig. 1. The cedar tree rings of 2500 years ago and the time variation of decadal ^{14}C concentration by Stuiver. M and S indicate Maunder and Spörer era, respectively.

years indicate effects of the right and reverse solar magnetic polarity[5]. We have been measuring ^{14}C concentrations in single-year tree rings of an old cedar that date ca. 2500 years ago, constructing a ^{14}C measuring system with high accuracy (0.2%) that is composed of a benzene synthesizer (10 g) and a Quantulus liquid scintillation counting system (LSC) [6].

2. Experiment

An old wood sample of a cedar tree that was buried by the eruption of Mt. Choukai in Japan ca. 2500 years ago has been used in this study as shown a photograph in Fig. 1. It had about 300 tree rings, each 0.5 to 3.0 mm wide. The tree rings were separated with single-year intervals to measure the concentration of ^{14}C. -cellulose in the cell walls of the tree rings is the most reliable chemical component of the wood for measuring the annual concentration of ^{14}C, and it was chemically extracted [7].

From the extracted-cellulose, benzene was synthesized, because benzene has many carbon atoms in its molecule and is a suitable solvent for liquid scintillation. The amount of synthesized benzene was typically 10 g and it was produced from the single-year wood sample of 130 g. Measurements of ^{14}C in the synthesized benzene were carried out with a statistical accuracy of 0.2% using liquid scintillation counting system the Quantulus with an ultra-low background level. The counting rate of the old tree ring sample is approximately 80 cpm for 10.5 g of benzene and the background rate is typically 0.1 cpm for 1 g dead benzene sample without ^{14}C. The systematic error was less than 0.1% in total.

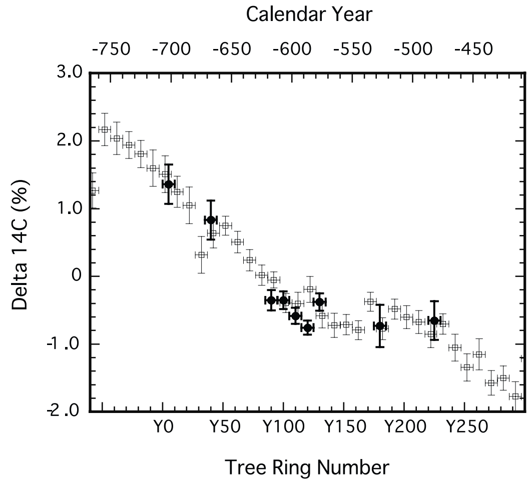

Fig. 2. Comparison between Δ^{14}C of the tree rings and of the Stuiver data.

3. Results and Discussion

The calendar age of the wood sample was 477B.C.±20 at an outer part of the tree rings by ^{14}C dating employing a calibration curve that is a relationship between radiocarbon ages and calendar ages [8]. As shown in fig. 1, this wood sample is located at a very interesting era because their Δ^{14}C, which indicates a variation of ^{14}C concentration referring the ^{14}C concentration at A.D.1950, show a peak area as well as Maunder or Spörer era when sunspots were absent. Moreover, this era shows a clear peak in the duration of past 5000 years. Note that the data of Δ^{14}C is for decadal tree rings measured by Stuiver. Fig. 2 shows a comparison between the Δ^{14}C of our tree rings and the stuiver data by decade. Although the calendar years of our samples have an uncertainty of ±20 years by the ^{14}C dating, they show good consistency because the average difference between Δ^{14}C of the samples and the Stuiver data is 0.18% for the 9 points.

We have measured the ^{14}C concentrations of 22 single-year tree rings from Y100 to Y121 with the accuracy of 0.2%. As shown in Fig. 3, their Δ^{14}C are plotted as a function of the tree ring number. In the figure the light curve is calculated by a least-squares fit of a sine function with four free parameters such as amplitude, period, initial phase, and DC component. The amplitude and the period were 0.39% and 11.5-year, respectively. The amplitude is between them of 0.14% and 0.48% for the 11-year cycle during the 18th‘19th centuries for Pacific trees and Russian trees. These indicate that the tree rings of ca. 2500 years ago record 11-year solar variations for the ^{14}C concentrations.

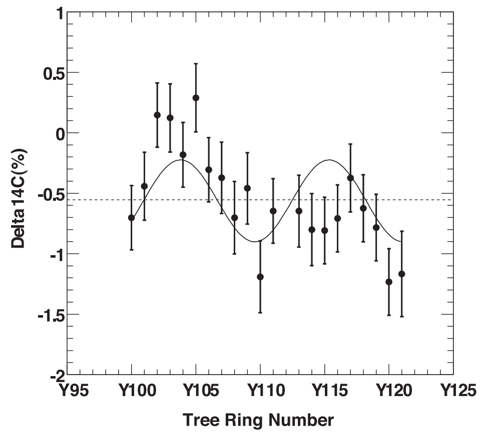

Fig. 3. The measured ^{14}C concentrations of 22 single-year tree rings and a least squares fitting curve.

4. Conclusion

The ^{14}C concentrations of old tree rings of ca. 2500 years ago have been measured at single-year intervals with a highly accurate LSC (0.2%) to investigate the 11-year periodicity of solar activity. The calendar age of the wood sample was 477B.C.±20 by ^{14}C dating. The sample locates at the era showing the variation of the ^{14}C concentrations as well as Maunder or Spörer era when sunspots were absent. The average difference between $\Delta^{14}C$ of the samples and the Stuiver's decadal data was 0.18% indicating good consistency.

$\Delta^{14}C$ of 22 single-year tree rings from Y100 to Y121 were measured with the accuracy of 0.2%. The least squares fit of a sine function indicated the amplitude of 0.39% and the period of 11.5-year. These indicate that the tree rings of ca. 2500 years ago record 11-year solar variations for the ^{14}C concentrations.

5. References

1. Belov A. 2000, Space Science Reviews 93, 79
2. Kocharov G.E. et al. 1995, Solar Physics 159, 381
3. Stuiver M., Braziunas T.F. 1998, Geophys. Res. Letters 25, 329
4. Beer J. et al. 1990, Nature 347,164
5. Potgieter M.S. 1998, Space Science Reviews 83, 147
6. Endo K., Sakurai H. et al. 2000, IEEE Trans. Nucl. Sci. 47, 1933
7. Matsumoto T., Sakurai H. et al. 2000, 27th Int. Cosmic Ray Conf. 10, 4133
8. Stuiver M. 1998, Radiocarbon 40