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Variation of Solar "11-year cycle" during the grand solar minimum in the 4th century BC by measurement of ^{14}C content in tree rings

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Abstract: Sunspot numbers, which reflect solar activity, have presented around 11-year periodicity since the early 18th century. However, in the period of 1645 to 1715 AD sunspots were almost absent, and this period is called the Maunder Minimum, one of grand solar minima implying weak solar activity. Variation of solar activity in grand solar minima can be investigated by determining the concentration of cosmogenic isotope ^{14}C in annual tree rings. We obtained the ^{14}C records of 1413 to 1745 AD including the Spörer Minimum (1416-1534 AD) and the Maunder Minimum with annual time resolution. As a result of frequency analysis of these ^{14}C records, we found that the cycle length of the "11-year cycle" during the Maunder Minimum was around 14 years while that during the Spörer Minimum was modulated from 11 years slightly. This suggests that a pattern of the "11-year" cycle length variation depends on a type of minima classified by their duration of estimated sunspot absence. In order to verify this hypothesis, we have measured ^{14}C contents in Japanese camphor tree rings during a possible grand solar minimum in the 4th century B.C. Preliminary result shows the solar cycle length was several years longer than 11 years, as in the Maunder Minimum.

Introduction

Solar activity alternates between active phase and quiet phase with a period of 11 years. The sun reverses its magnetic polarity when the activity reaches maximum every 11 years, so that after 22 years, the polarity returns to the original state. The sunspot number, which is one of the most obvious indices of solar activity, has presented an 11-year periodicity since the early 18th century. This 11-year periodicity of solar activity is called the Schwabe cycle, and the 22-year periodicity of magnetic polarity reversal is called the Hale cycle. However sunspots were almost absent between the middle of the 17th century and the early 18th century and did not seem to have noticeable periodicity. This period is called the Maunder Minimum, which is one of grand solar minima implying an extremely weak solar activity. Thus, solar activity has long-term variation whose timescale is several decades or more than a hundred of years other than the Schwabe/Hale cycles. A mechanism of this long-term variation has not been understood yet.

We investigate a variation of solar activity in grand solar minima by measuring the concentration of ^{14}C in annual tree rings. ^{14}C is produced in upper atmosphere by galactic cosmic rays (GCR), whose intensity on the earth is affected by solar magnetic field. Therefore, the atmospheric ^{14}C concentration has inverse correlation with solar activity. Atmospheric carbon is absorbed by trees in the form of CO_2 and forms annual rings of trees. Thus we can examine the solar activity in the past by determining the concentration of ^{14}C in tree rings. Decadal ^{14}C records of the last 3,000 years [1] shows the existence of several peaks of ^{14}C concentration with the duration of tens to a hundred years, suggesting grand solar minima (fig.1). We concentrate our investigation to the property of the Schwabe cycle in grand solar minima by determining annual ^{14}C records, and would like to shed some light on understanding of the long-term variation of solar activity.

We obtained the ^{14}C records of 1413 to 1745 AD including the Spörer Minimum and the Maunder Minimum with annual time resolution. As a result of frequency analysis of these ^{14}C records, we found that the length of the Schwabe cycle during the Maunder Minimum was around 14 years [2] while that during the Spörer Minimum was modulated from 11-years slightly [3]. The cycle length between the end of the Spörer Minimum and the beginning of the Maunder Minimum was also around 11 years [4]. Stuiver classified grand solar minima into two types, estimated (or real) sunspot absence in the Maunder-type minima persists around 80 years and that in the Spörer-type minima persists around 120 years [5]. Our results suggest that a cycle length variation of the Schwabe cycle might be dependent on the type of minima.

In order to examine this hypothesis, we started measurements of ^{14}C contents in Japanese camphor tree rings from a possible grand solar minimum in the 4th century B.C., which is considered to be one of the Maunder-type minima [5]. This ^{14}C peak starts at the end of the 5th century B.C. and lasts about 150 years (estimated sunspot absence lasted about 80 years). In this paper, we present a preliminary results on the dating of the sample tree and frequency analysis for our data of ^{14}C contents.

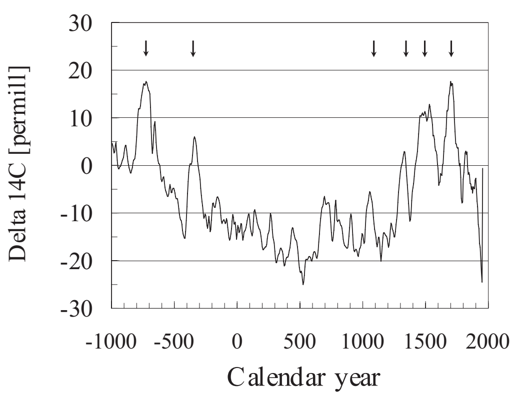

Figure 1: The INTCAL04 data set [1] of the last 3000 years. The ordinate is the concentrations of ^{14}C, and the abscissa is the calendar year. The arrows indicate the ^{14}C concentration peaks suggesting the grand solar minimum.

Method

The sample is a Japanese camphor tree (fig.2) excavated from the bottom of Fukushima River, Miyazaki in southern Japan (31° 28′ N and 131° 14′ E). The number of the tree rings of this sample is about 300.

We chemically extracted carbon from each tree ring, and measured contents of cabon isotopes using an accelerator mass spectrometer (AMS) at Nagoya University.

To estimate the sample age, we compared our measured data set with those of INTCAL04 [1] using chi-square test. The chi-square is defined as;

$$\chi^2(t) = \frac{1}{N} \sum_{n=1}^{N} \left(\frac{A_{int}(t-1+y_n) - A_{ste}(n)}{\sqrt{\sigma_{int}^2(t-1+y_n) + \sigma_{ste}^2(n)}} \right)^2$$

where t is the assumed age of the innermost ring, n is our sample number counted from the innermost ring, N is the number of data, $A_{ste}(n)$ is the ^{14}C age measured for the nth sample, $A_{int}(y)$ is the ^{14}C age by INTCAL04 for the calendar year y and was calculated by linear interpolation of existing INTCAL04 data [1], y_n is number of year for nth sample counted from the innermost ring, σ_{int} and σ_{ste} are the standard errors of A_{int} and A_{ste}, respectively.

Figure 2: A picture of the smple tree disc.

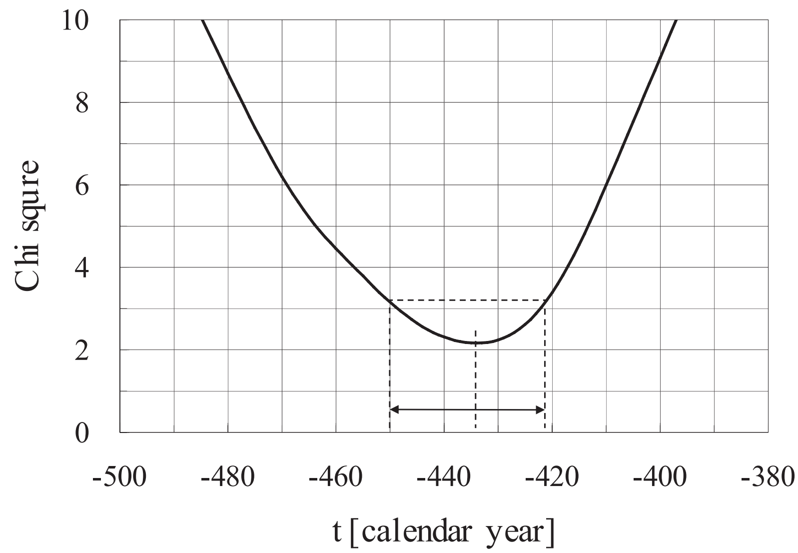

Figure 3: Variation of chi-square value for the age of the innermost tree ring. Negative year means B.C.

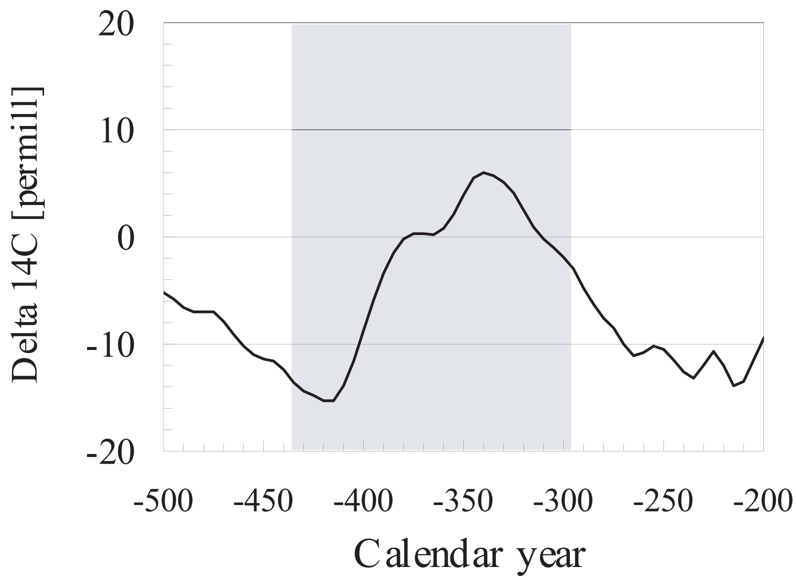

Figure 4: The region, our data set covers (= gray area). Solid line is INTCAL04.

Resuslts

At first, to obtain a rough estimate of sample age, we measured the ^{14}C contents in 4 rings (y_n= 1, 109, 202, 273). Using chi-square test, the age of the innermost tree-ring was estimated to be 451(+16,-51) B.C. that is around the begining of the peak of ^{14}C increase. The error of the age was obtained as a region of t for $\chi^2(t) - \chi^2_{min} \leq 1$.
Then we measured ^{14}C contents of 69 rings covering 138 years biennially. Measurement was done from the innermost (the oldest) ring to outer (newer). More accurate dating of the tree was obtained by the chi-square test using these data. Thus estimated age of the innermost tree-ring was 434(+16,-12) B.C. as shown in fig.3. This result confirms that our data set covers the period from the beginning of the ^{14}C increase to its top as shown in fig.4. On the whole, our results agrees with the INTCAL04 data. However, in more detail, ^{14}C contents fluctuate from INTCAL04 possibly due to the solar cycle. Wavelet analysis shows about 29-years periodicity in whole of the measured period, and about 15-years periodicity is seen around the top of the peak. These cycle lengths are nearly diploid number so that 15-years and 29-years periodicity is considered to be the Schwabe cycle and the Hale cycle. The length of the Schwabe cycle seems to be several years longer than 11-years and its amplitude is lower at the beginning of the peak. This property seems to be the same as that of the Maunder Minimum.

Conclusion

We have measured the ^{14}C contents of tree rings of 138 years biennially using the Japanese camphor-tree. As a result of dating, using chi-square test, our data set covers around the beginning of the ^{14}C increase to its top. Preliminary result of frequency analysis shows that the length of the Schwabe cycle was several years longer than 11-years as in the Maunder minimum. This suggests that the length of the Schwabe cycle in the Maunder-type minima is several years longer than 11-years.
We will carry out more measurements to clarify the property of the Schwabe cycle in the peak of the 4th century B.C. In addition, we will measure more precisely the property of the Schwabe cycle in the Spörer Minimum and compare the periodicity with that in the Maunder-type minima.

References

[1] Reimer, P.J., et al., Radiocarbon, 46 : 1029-1058, 2004.

[2] Miyahara, H., et al., *Sol. Phys.*, 224, 317-322, 2004.

[3] Miyahara, H., et al., *JGR*, *111*, A03103, 2006.

[4] Miyahara, H., et al., *J. Adv. Space Res*, doi:10.1016/j.asr.2006.12.044 (in press).

[5] Stuiver, M. and Braziunas, T.F., *Nature*, 338 : 405-408, 1989.